PRACTICAL
MECHANICAL DRAWING
AND MACHINE DESIGN
SELF TAUGHT

Drafting Tools—Geometrical Definition of Plane Figures—Properties of the Circle—Polygons—Geometrical Definitions of Solids—Geometrical Drawing—Geometrical Problems—Mensuration of Plane Surfaces—Mensuration of Volume and Surface of Solids—The Development of Curves—The Development of Surfaces—The Intersection of Surfaces—Machine Drawing—Technical Definitions—Materials Used in Machine Construction—Shafting—Machine Design—Transmission of Motion by Belts—Horsepower Transmitted by Ropes—Horsepower of Gears—Transmission of Motion by Gears—Diametral Pitch System of Gears—Worm Gearing—Steam Boilers—Steam Engines—Tables

BY

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WITH OVER TWO HUNDRED ILLUSTRATIONS

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PREFACE

If mechanical drawing is to be of any practical use to a person, he must be able to thoroughly understand the form and arrangement of the various parts of a machine from an inspection of the drawings of the machine without reference to the machine itself. He ought also to be able to make drawings of a machine or the parts of a machine from the machine itself. As mechanical drawing is simply the application of the principles of geometry to the representation of machines, a person who wishes to become thoroughly conversant with mechanical drawing and machine design should commence by studying the geometrical problems given in this work. The student in following up the problems given, should not content himself by merely copying the drawings, but should do each example over and over, until he is thoroughly familiar with the principles involved in their construction, and also understands why each line is drawn.

In working over these examples several times the student is not only committing them to memory, but is at the same time becoming proficient in the handling of the various drawing tools.

THE AUTHOR.

PRACTICAL MECHANICAL DRAWING

DRAFTING TOOLS

Compasses. These, as well as all other instruments, should be chosen with great care on account of their variety in shape and quality. Drafting instruments are as a rule made of German silver and steel. The steel should be of the best grade and carefully tempered. The material used in the manufacture of some instruments is of so poor a quality that it neither holds its shape nor wears well. It is better therefore when buying, to select instruments of high grade, and which are made of the best German silver and a good quality of steel, as the joints are always carefully fitted and they will withstand the constant usage of many years. A compass set of convenient form is shown in Fig. 1. It has three removable parts: the pencil-point, the pen-point, and the lengthening-bar. There is a hinged joint in each leg of the compass and the socket for the removable legs is provided with a clamping screw. The shanks of the removable legs should be a nice fit in the socket and require scarcely any effort to remove. They should, however, stay in the socket without being held by the clamping screw. The lengthening-bar is used to extend the pen or pencil-legs when drawing large circles.

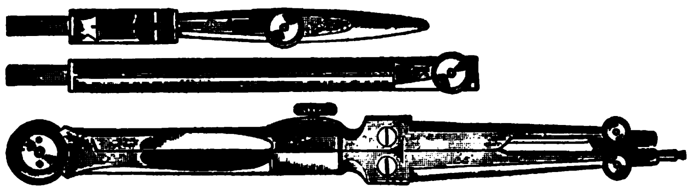


Fig. 1—Compass Set.

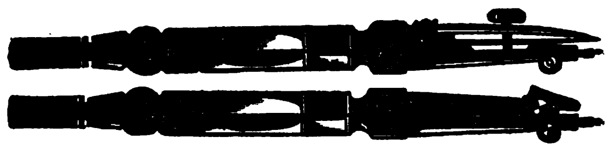


Fig. 2—Pen and Pencil Compasses.

A pen and pencil compass set of smaller size, without detachable legs are shown in Fig. 2, these instruments will be found useful in many cases as a medium between the large compasses and the spring-bow set.

The most important part of a pair of compasses is the head, which forms the hinged joint. There are two forms of joints: the **tongue-joint**, as shown in the left-hand view in Fig. 3, in which the head of one shank has a tongue, generally made of steel, which moves between two lugs on the other shank, and the **pivot** joint, as shown in the right-hand view in Fig. 3, in which each shank is reduced to half its thickness at the head. These shanks are

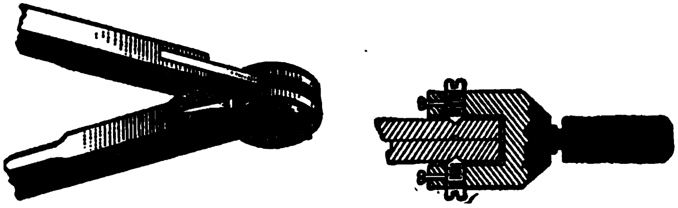


Fig. 3—Compass Joints.

surrounded by a clamp or yoke, which carries two cone-pointed set-screws, one in each side, the points of these screws working in countersunks in the yoke. The yoke is provided with a milled or knurled handle to manipulate the compass. The head joint of the compass should move freely and evenly throughout its entire movement, and not stiff at one point and loose at another. It should also be tight enough in the joint to hold its adjustment when once set. Figure 4 shows the method of holding a compass, and the correct position of the fingers before and after describing a circle. The non-removable leg of the compass should carry a needle-point, that may be easily replaced if lost or damaged, and it should have a shoulder to prevent the point from sinking into the paper beyond a certain depth. The needle-point should also be capable of being adjusted in or out, and fastened securely at any desired point, thus mak-

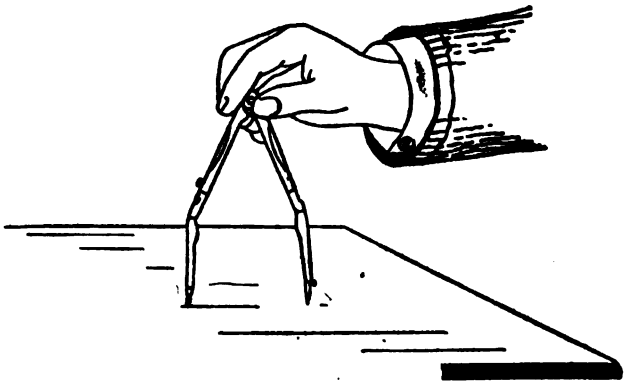


Fig. 4—Correct Manner of Holding a Compass.

ing the leg of the compass a little longer or shorter as may be desired.

The socket for the lead in the pencil-point should hold the lead firmly without the necessity of wedging it in the socket by means of paper or small pieces of wood.

When first adjusting the compass for use, place the pen-point in the instrument and securely clamp it in place, firmly against the shoulder of the socket, then adjust the needle-point so that its point is even with that of the pen. When once properly adjusted the needle-point should not be changed. The needle-point is usually made with a cone-point at one end and a fine shouldered-point at the other. The cone-point should never be used, as it makes too large a hole in the drawing paper.

Hair Spring Dividers. Dividers such as are shown in Fig. 5 are used for laying off equal distances and for transferring measurements from one part of a drawing to another, or from one drawing to another. They consist of steel points

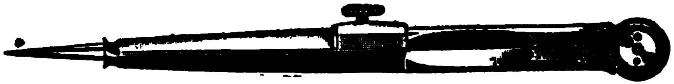


Fig. 5—Hair Spring Dividers.

set in German silver shanks which are hinged together. The joints of the dividers should work smoothly, the legs come close together, and the steel points should be sharp and of the same length. One of the legs of the dividers has a spring controlled by an adjustable thumb-nut. By means of this device, from which the instrument gets its name, the adjustable leg may be moved a trifle after the rough or approximate adjustment of the dividers has been made.

Spring-bow Instruments. The spring-bow dividers, pencil and pen, as shown in Fig. 6, are for the purpose of describing small circles and laying off distances of very small dimensions and are very convenient for these purposes. Any form of spring-bow instruments with interchangeable or removable legs will be found very unsatisfactory. The legs should be made of one piece of steel, to which the handle is attached. Any instrument in which the legs are separate pieces fastened to the

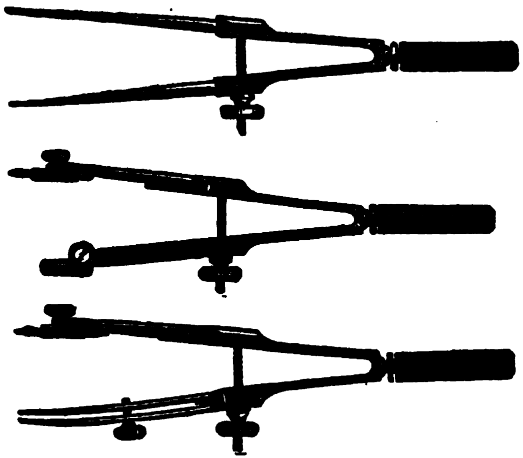


Fig. 6—Spring-bow Instruments.

shank are undesirable, because the parts are liable to become loose. The spring-bow dividers are used like the hair-spring dividers, for the spacing of distances, they have the advantage of being fixed in any position so that there is no liability of a change of measurement by the handling of the instrument. When spacing distances the divider is rotated alternately right and left, with the forefinger on top of the handle.

Ruling Pens. Ruling pens are of two different kinds, one kind with a hinge joint to allow the blades to be opened for cleaning and the other

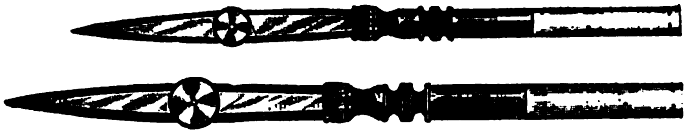


Fig. 7—Ruling Pens with Hinged Blade.

kind without a joint and made from a solid piece of steel. Two sizes of ruling pens with hinged joints are shown in Fig. 7. The joint in this style of pen should be very carefully made, otherwise the hinged blade will very soon become loose and render the pen useless. The best kind of pen for general use is the kind shown in Fig. 8, in which

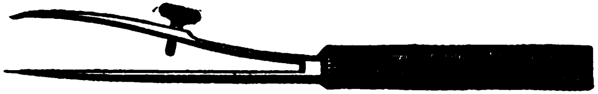


Fig. 8—Ruling Pen with Spring Blade.

the upper blade springs open when the adjusting screw is removed from the lower blade. A pen such as the one just described is to be preferred to one with a joint, no matter how well made it may be. Ruling pens with broad nibs and flat handles, as shown in Fig. 9, are preferred by many draftsmen, they hold a large quantity of ink and make a very uniform line.

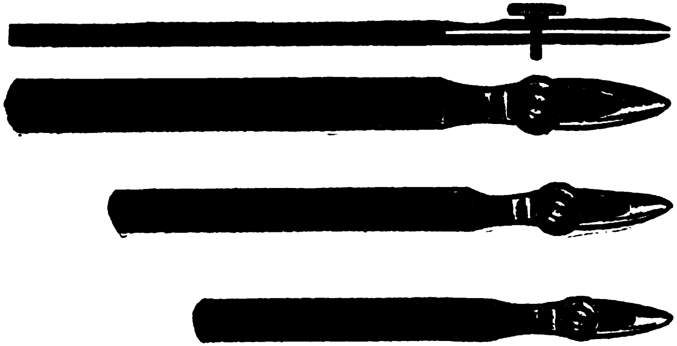


Fig. 9—Ruling Pens with Wide Blades.

The position in which a ruling pen should be held when drawing lines perpendicular to the T-square is shown in Fig. 10. The drawing board

Fig. 10—Correct Manner of Holding a Ruling Pen.

should be placed so as to permit the light to come from the upper left-hand corner, this position of the T-square and triangle will avoid any possibility of the shadows of the T-square blade or triangle being cast on the lines to be drawn.

Sharpening a Ruling Pen. The blades of the pen should be curved at the points, and elliptical in shape. To sharpen the pen, screw the blades together and then move the pen back and forth upon a fine oil-stone, holding it in the position it should have when in use, but moving it so that the points are ground to the same length, and to an

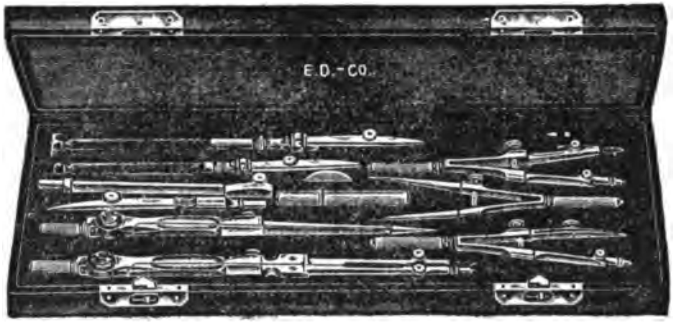


Fig. 11—Complete Set of Instruments in Case.

elliptical form. When this form has been secured, draw a folded piece of the finest emery paper two or three times between the blades, which are pressed together by the screw. This will remove any roughness from the inner surfaces of the blades, these surfaces should not be ground upon the oil-stone.

When the blades are ground to the proper shape, they must be placed flat upon the stone and ground as thin as possible without giving them a cutting edge. To do this, the pen should be moved back and forth and slightly revolved at the same time. Both blades must be made of equal thickness. If either blade is ground too thin, it will cut the paper as would a knife, and the process must be repeated from the beginning. In order to see the condition of the blades, they should be slightly separated while being brought to the proper thickness.

Drafting Instruments. A leather-covered case

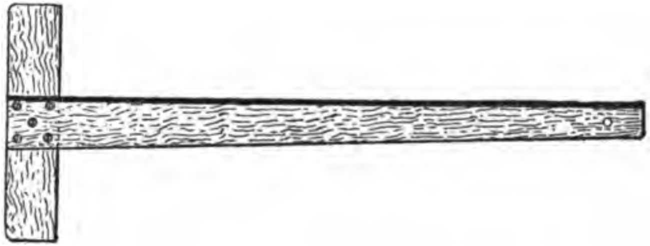


Fig. 12—Slanting Blade T-Square.

with a complete set of instruments in a velvet lined tray is shown in Fig. 11. This outfit is sufficient to fulfill the requirements of any ordinary draftsman in the way of instruments.

T-Square. The length of a T-square is always measured by the length of the blade outside of the head. The T-square should always be as long as the drawing board, and if possible a little longer. For the general run of work the head of the T-square should be of a single and fixed piece, that is, fastened permanently to the blade. The head should have its upper inside corner rabbeted, so that the guiding edge of the head may be trued up when occasion demands it. A very convenient

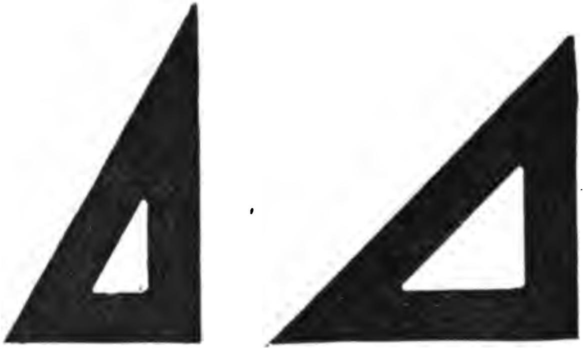


Fig. 13—60 and 45 Degree Triangles.

form of T-square is shown in Fig. 12, which has a slanting blade, the working edge of which is lined with ebony.

Fig. 14—15 Degree Triangle.

More elaborate forms of T-squares are sometimes used, in which the head is double and one side swivels in order to draw parallel lines other than horizontal. The adjustable or swivel head is clamped in any desired position by means of a thumb-screw.

Triangles or Set-Squares. Triangles are made of wood, hard rubber or transparent celluloid. The principal forms of triangles are shown in

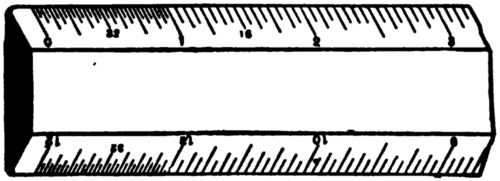


Fig. 15—Flat Beveled-edge Scale.

Figs. 13 and 14, which are 60°, 45° and 15° respectively. The two triangles generally used by draftsmen are the 60° and 45°. The former has angles of 30°, 60° and 90°. The latter two 45° and a 90° angle.

Testing Triangles. Place the triangle on the T-square with the vertical edge at the right, draw a

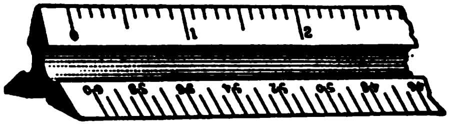


Fig. 16—Triangular Scale.

fine line in contact with this edge, then reverse the triangle and move the vertical edge towards the line. If the vertical edge of the triangle and the line coincide the angle is 90°. If they do not coincide, and the vertex of the angle formed by the line and the vertical edge of the triangle is at the top, the angle is greater than 90° by half the angle indicated. If the vertex of the angle is below, the angle is less than 90° by half the amount indicated.

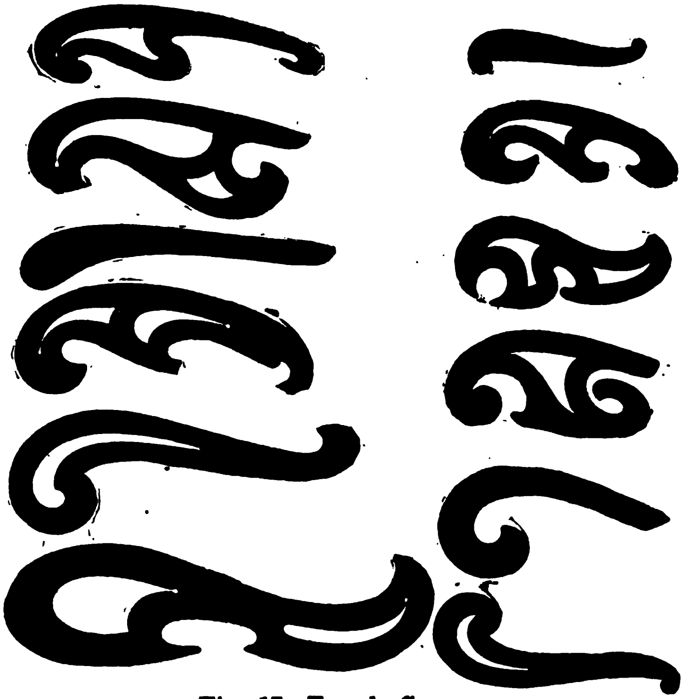


Fig. 17—French Curves.

Scales. The best and most convenient form of scale for general use is that shown in Fig. 15. Another form of scale which is very commonly used is shown in Fig. 16. The ordinary length of a scale is 12 inches, not counting the small portion at each end, which is undivided, and whose use is to protect the end graduations from injury. A scale should be used for dimensioning drawings only, and not used as a ruler or straight-edge. The measurements should be taken directly from the scale by laying it on the drawing, and not by transferring the distances from the scale to the drawing by means of a pair of dividers.

Curves. For inking in lines which are neither straight lines nor arcs of circles, it is necessary to

Fig. 18—Useful Form of Curve.

use curves. They are made in a great variety of forms as illustrated in Fig. 17, but the form similar to that illustrated in Fig. 18 will be found the most useful. They are made of wood, hard rubber and celluloid. Many curved lines can be inked in by means of a compass, but when the radius is too great, a curve should be used.

Paper. The paper must be tough and should have a surface which is not easily roughened by erasing lines drawn upon it. This is important when drawings are to be inked. For all mechanical work, the paper should be hard and strong.

For pencil drawings a paper which is not smoothly calendered is best, because the pencil marks more readily upon an unpolished paper, and because its surface will not show erasures as quickly as that of a smooth paper. For sketching, several kinds of paper, which are good enough for the work, may be obtained both in sheets, in block form, and also made up in blank books.

Whatman's paper is the best for drawings which are to be inked. There are two grades, hot and cold pressed, suitable for this use, the cold-pressed having the rougher surface. If the paper is not to be stretched, the cold-pressed is preferable, as its surface shows erasures less than that of the hot-pressed. The side from which the water-marked name is read is the right side, but there is little difference between the two sides of hot and cold pressed papers. Stretching the paper is unnecessary except when colors are to be applied by the brush, or when the most perfect inked drawing is desired.

Pencils. Lead pencils for drafting use are made of different degrees of hardness and each kind of pencil has its grade indicated by letters stamped on it at one end. The grade of pencil mostly used by draftsmen is 4 H; a 6 H pencil is too hard and unless used with great care will indent the paper so that the pencil marks cannot be erased. A 4 H pencil requires greater care and more frequent sharpening, but the draftsman will in this manner acquire a lighter touch, which is of much value. Drafting pencils should always be sharpened to a chisel or wedge-shaped point, as shown in Fig. 19, the finishing of the point should always be completed with a fine file or a sand paper pencil sharpener, but never with a knife. In drawing the pencil should be held vertical, or nearly so, the arm free from the body, and the flat side of the chisel-point lightly touching the edge of the blade of the T-square. Always draw from left to right, or from the bottom to the top of the board.

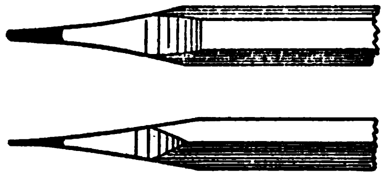


Fig. 19—Correct Manner of Sharpening a Pencil.

Pencil Sharpeners. Pencil sharpeners or pointers are of many different kinds, from a piece of fine sand paper or a file to quite complicated machines. For ordinary use a sand paper block from which the sheets can be removed as soon as worn out will be found the most convenient, as shown in Fig. 20. In sharpening a drafting pencil remove the wood from the end by means of a sharp knife, exposing about one-fourth to three-eighths of an inch of the lead. The end of the lead should then be sharpened to a chisel or wedge-shaped point on the sand paper block.

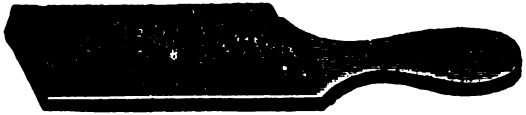


Fig. 20—Sand Paper Pencil Sharpener.

Pencil Erasers. A pencil eraser or rubber should be of soft, fine-grained rubber, free from sand or grit and having no tendency to glaze or smear the surface of the drawing paper. A pencil eraser of the kind shown in Fig. 21 will be found very satisfactory for general use.

Fig. 21—Pencil Rubber or Eraser.

Fig. 22—Ink Rubber or Eraser.

Ink Erasers. Inked lines should always be removed from the drawing by means of a sand-rubber, which is known as an ink eraser, but never by scratching the surface of the paper with a knife. As all drawing inks dry rapidly, and should not penetrate the surface of the paper, the object in erasing is to remove the ink from the surface of the paper without injury to it. An ink eraser, such as shown in Fig. 22, will leave the surface of the drawing in good condition to again receive ink.

Eraser Guard. An eraser guard or shield, which is used to protect other lines when remov-

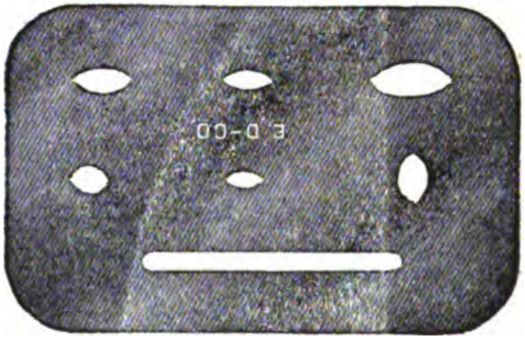


Fig. 23—Erasing Guard or Shield.

ing an inked line from the surface of the drawing paper, consists of a thin sheet of flexible metal, usually brass, provided with slots and holes of various shapes and sizes. The shield or guard permits erasures to be made of limited size without damage to the rest of the drawing.

Drawing Ink. Black drawing ink, preferably some make of waterproof ink, is to be had in liquid form, as shown in Fig. 24. The liquid ink is preferable to the Indian or Chinese stick inks, as shown in Fig. 25, which take considerable time

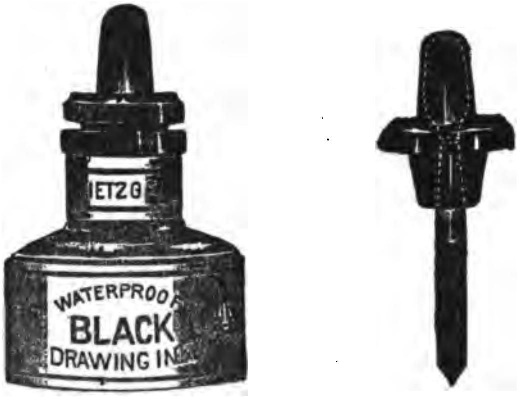


Fig. 24—Waterproof Black Drawing Ink.

to prepare, besides necessitating fresh mixing each time the ink is used.

Protractor. A protractor is a circular scale

Fig. 25—Chinese Stick Black Drawing Ink.

and is divided into degrees and fractions of a degree. Protractors are made both circular and semi-circular in shape, the latter being the ordinary and most commonly used form, as shown in Fig. 26. Protractors are made of paper, horn, brass, German silver and steel. Protractors usually have their edges bevelled so as to bring the divisions on the scale close to the drawing paper. A semi-circular protractor is to be preferred for all ordinary work. A semi-circular protractor has a straight edge upon which the center of the circle is marked, so that the protractor may

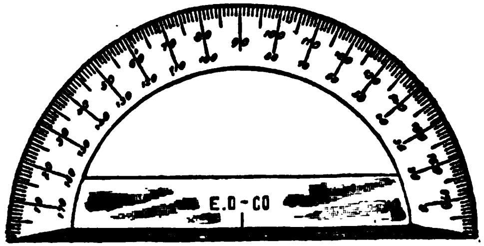


Fig. 26—German Silver Protractor.

be readily applied to the point at which it is desired to read or lay off an angle.

Drawing Boards. A drawing board for ordinary use should be about 20 by 27 inches in size. The material should be of first quality clear soft pine, free from pitch and thoroughly kiln dried. The board should be made of five or six strips about 4 by 27 inches, well glued together and held from warping by two cleats on the back, as shown in Fig. 27.

The working edge of the drawing board should be tested from time to time, as any unevenness in this edge will impair the accuracy of the drawing. Some draftsmen use the lower edge of the board when drawing long lines parallel to the working edge. This necessitates making this edge true, and the angle between this and the working edge exactly 90°.

Thumb-Tacks. Thumb-tacks are made of German silver or brass disks with pointed steel pins in their centers. The heads or disks should have

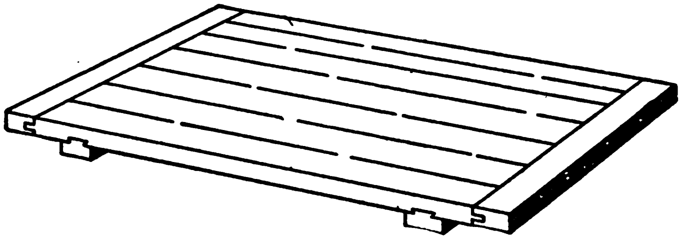


Fig. 27—Drawing Board with Cleats on Back.

very thin edges in order that the T-square may readily slide over them.

Lettering Triangle. A triangle or set-square for laying out lettering is shown in Fig. 28. The use of this triangle is plainly indicated by its name.

Section Liners. A section liner is a device for drawing a series of parallel lines equi-distant from each other. One form of section liner is shown in Fig. 29. Its operation is as follows: Place the instrument in the position shown in the drawing, and rule a line along its vertical edge. Hold the straight-edge firmly in place, and slide the triangle along it until the other side of the tapered edge of the tongue comes in contact with the other stud and holds it in this position, then allow the straight-edge to be drawn forward by the spring. Then draw a second line which will

Fig. 28—Lettering Triangle.

evidently be parallel to the first. The distance between the lines is regulated by moving the tongue in or out between the studs, as far as desired.

Another form of section liner is shown in Fig. 30, having a horizontal instead of a vertical adjustment to regulate the width of the spacing.

Beam Compasses. A beam compass is not, as a rule, included in a draftsman's outfit, but every well equipped drafting room should have one. A beam compass is shown in Fig. 31, with removable

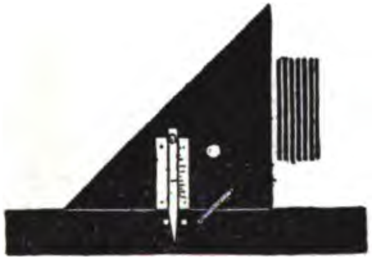


Fig. 29—Section Liner with Vertical Adjustment.

legs and pen, pencil and needle-points. The right-hand leg in the illustration has a horizontal ad-

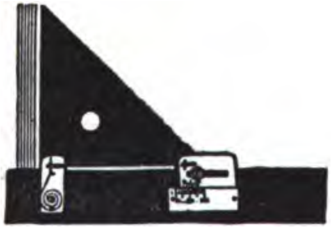


Fig. 30—Section Liner with Horizontal Adjustment.

justment of about one-half an inch, operated by the milled thumb-nut shown.

Water Colors. These may be obtained in the form of a thick paste in small porcelain pans, or in thin paste or semi-liquid form in collapsible tubes. The colors in tubes are liable to get hard, in which case they cannot be expelled from the tubes by pressure. The caps to the tubes also get stuck in place by the colors and are often removed

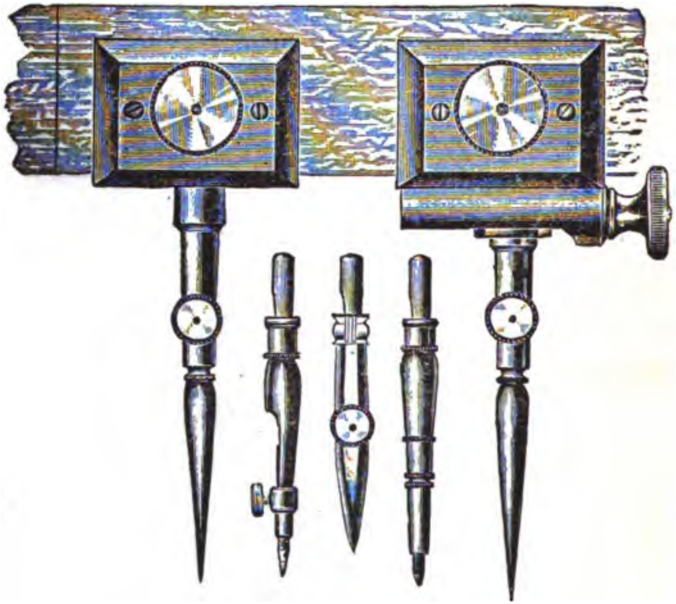


Fig. 31—Beam Compass with Pen, Pencil and Needle-Points.

with much difficulty. For the draftsman's purposes the moist colors in pans will be found the most satisfactory.

A box of moist water colors is illustrated in Fig. 32. The colors should be kept in a box of this kind, which can also be used as a palette.

The box keeps all dust and dirt from the colors and prevents them from drying out rapidly.

Water Color Brushes. These are made from

Fig. 32—Moist Water Colors in Case.

black or red sable and camel's hair. Black sable brushes are too expensive for the draftsman's ordinary use.

The best grade of camel's hair brushes such as are shown in Fig. 33, will be found quite satisfactory for ordinary use.

To ascertain whether a brush is of good quality or not, dip it in water until thoroughly wet,

Fig. 33—Water Color Brushes.

and then remove the water from it by a quick motion. The brush if of good quality should assume a convex shape, come to a fine point and also preserve its elasticity.

GEOMETRICAL DEFINITIONS OF PLANE FIGURES.

A line is the boundary or limit of a surface.

A line has only one dimension, that of length.

A point is considered as the extremity or limit of a line. The place where two lines intersect is also a point. A point has position but no dimensions.

In practical work a point is represented by a fine dot.

Lines may be either straight, broken or curved.

A straight line is one which has the same direction throughout its length.

A straight line is also called a **right line.**

A straight line is usually called a line simply, and when the word line occurs it is to be understood as meaning straight line unless otherwise specified. A straight line is the shortest distance between two points. If any other path between the points were chosen, the line would become curved or broken. Therefore two points determine the position of the straight line joining them.

A broken line is one which changes direction at one or more points.

A curved line is one which changes direction constantly throughout its length. The word curve is used to denote a curved line.

Lines may be represented as full, dotted, dashed, or dot-and-dashed.

A full line is one which is continuous throughout its length.

A dotted line is one which is composed of alternate dots and spaces.

A dash line is one which is composed of alternate dashes and spaces.

A dot-and-dash line is one which is composed of dots, spaces and dashes. These may be arranged in several ways according to the character of the line, that is, the meaning it is to convey.

Surfaces may be either plane or curved. A plane surface is usually called a plane.

A plane is such a surface that if a straight line be applied to it in any direction, the line and the surface will touch each other throughout their length.

A curved surface is one no part of which is a plane.

Any combination of points, lines, surfaces or solids is termed a **figure.**

A plane figure is one which has all of its points in the same plane.

Plane geometry treats of figures whose points all lie in the same plane.

Lines may be so situated as to be parallel or inclined to each other.

Parallel lines are those which have the same or opposite directions. Parallel lines are everywhere equally distant. Parallel lines will not meet, however far produced.

Inclined lines are those other than parallel. In-

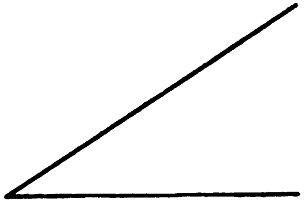


Fig. 34.

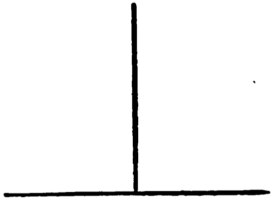


Fig. 35.

clined lines will always meet if produced far enough. Their mutual inclination forms an angle.

The **extremities of a surface** are lines.

A **plane rectilineal angle** is the inclination of two straight lines to one another in a plane which meet together, but are not in the same straight line as in Fig. 34.

When a straight line, standing on another straight line, makes the adjacent angles equal to one another, each of the angles is called a **right angle** and the straight line which stands on the other is called a **perpendicular** to it as in Fig. 35.

An **obtuse angle** is that which is greater than a right angle as in Fig. 36.

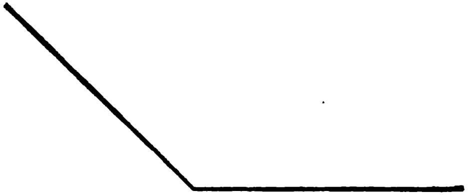


Fig. 36.

An **acute angle** is that which is less than a right angle as in Fig. 34.

A **term or boundary** is the extremity of anything.

An **equilateral triangle** is that which has three equal sides as in Fig. 37.

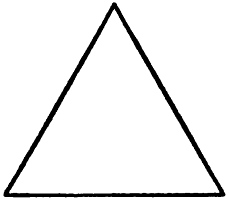


Fig. 37.

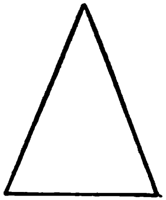


Fig. 38.

An **isosceles triangle** is that which has two sides equal as in Fig. 38.

A **scalene triangle** is that which has three unequal sides as in Fig. 39.

A **right angled triangle** is that which has a right angle as in Fig. 40.

An **obtuse-angled triangle** is that which has an obtuse angle as in Fig. 39.

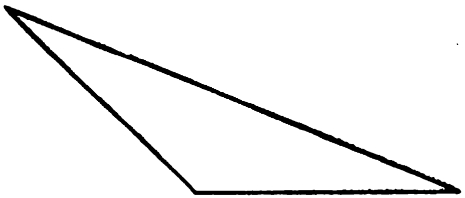


Fig. 39.

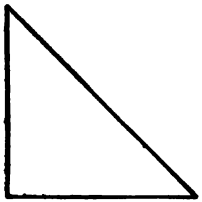


Fig. 40.

The **hypothenuse** in a right angled triangle is the side opposite the right angle as in Fig. 40.

A **square** is that which has all its sides equal and all its angles right-angled as in Fig. 41.

A **rectangle** is that which has all its angles

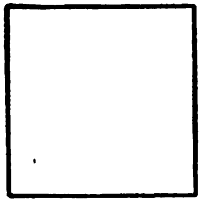


Fig. 41.

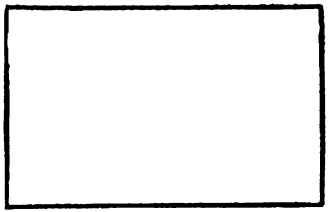


Fig. 42.

right angles, but only its opposite sides equal as in Fig. 42.

A **rhombus** is that which has all its sides equal, but its angles are not right angles as in Fig. 43.

A **quadrilateral** figure which has its opposite sides parallel is called a parallelogram as in Figs. 41, 42 and 43.

A line joining two opposite angles of a quadrilateral is called a **diagonal.**

An **ellipse** is a plane figure bounded by one continuous curve described about two points, so that the sum of the distances from every point in the curve to the two foci may be always the same—Fig. 44.

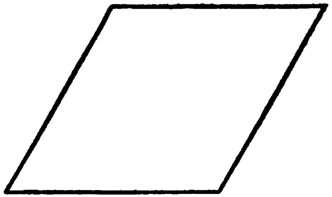


Fig. 43.

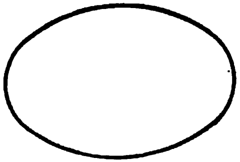


Fig. 44.

PROPERTIES OF THE CIRCLE.

A **circle** contains a greater area than any other plane figure bounded by the same length of circumference or outline.

A **circle** is a plane figure contained by one line and is such that all straight lines drawn from a point within the figure to the circumference are equal, and this point is called the center of the circle.

A **diameter** of a circle is a straight line drawn through the center and terminated both ways by the circumference, as AC in Fig. 45.

A **radius** is a straight line drawn from the center to the circumference, as LH in Fig. 45.

A **semicircle** is the figure contained by a diameter and that part of circumference cut off by a diameter as AHC in Fig. 45.

A **segment** of a circle is the figure contained by a straight line and the circumference which it cuts off, as DHE in Fig. 45.

A **sector** of a circle is the figure contained by two straight lines drawn from the center and the

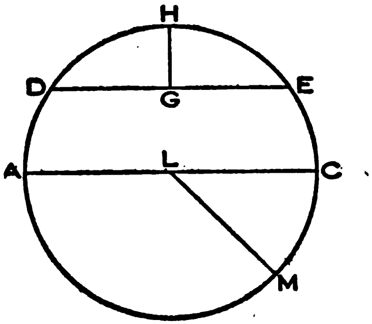


Fig. 45.

circumference between them, as LMC in Fig. 45.

A **chord** is a straight line, shorter than the diameter, lying within the circle, and terminated at both ends by the circumference as DE in Fig. 45.

An **arc** of a circle is any part of the circumference as DHE in Fig. 45.

The **versed sine** is a perpendicular joining the middle of the chord and circumference, as GH in Fig. 45.

Circumference. Multiply the diameter by 3.1416, the product is the circumference.

Diameter. Multiply the circumference by .31831, the product is the diameter, or multiply the square root of the area by 1.12837, the produce is the diameter.

Area. Multiply the square of the diameter by .7854, the product is the area.

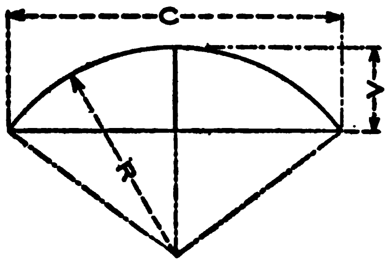


Fig. 46.

Side of the square. Multiply the diameter by .8862, the product is the side of a square of equal area.

Diameter of circle. Multiply the side of a square by 1.128, the product is the diameter of a circle of equal area.

To find the versed sine, chord of an arc or the radius when any two of the three factors are given—Fig. 46.

$$R=\frac{C^2+4V^2}{8V} \qquad C=2\sqrt{V(2R-V)}$$

$$V=R-\sqrt{\frac{4R^2-C^2}{4}}$$

To find the length of any line perpendicular to the chord of an arc, when the distance of the line from the center of the chord, the radius of the arc and the length of the versed sine are given—Fig. 47.

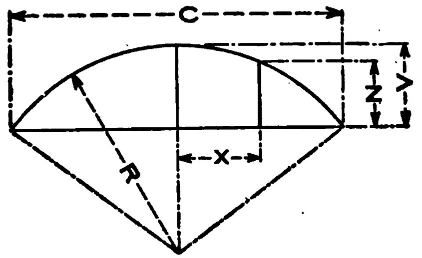


Fig 47.

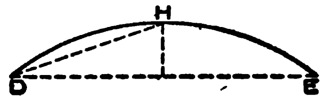
$$N=\sqrt{(R^2-X^2)}-(R-H \qquad R=\frac{C^2+4V^2}{8V}$$

$$C=2\sqrt{V(2R-V)} \qquad V=R-\sqrt{\frac{4R^2-C^2}{4}}$$

To find the diameter of a circle when the chord and versed sine of the arc are given.

$$AC=\frac{DG^2+GH^2}{GH}$$

To find the length of any arc of a circle, when the chord of the whole arc and the chord of half the arc are given—Fig. 48.



$$\text{Arc DHE}=\frac{8DH-DE}{8}$$

Fig. 48.

A **Tangent** is a straight line which touches the circumference but does not intersect it. The point where the tangent touches the circle is called the **Point of Tangency.**

Two **Circumferences** are tangent to each other when they are tangent to a straight line at the same point.

A **Secant** is a straight line which intersects the circumference in two points.

A Polygon is **inscribed** in a circle when all of its sides are chords of the circle.

A Polygon is **circumscribed** about a circle when all of its sides are tangent to the circle, and a circle is circumscribed about a polygon when the circumference passes through all the vertices of the polygon.

DEFINITION OF POLYGONS.

A **polygon**, if its sides are equal, is called a regular polygon, if unequal, an irregular polygon.

A **pentagon** is a five-sided figure.

A **hexagon** is a six-sided figure—Fig. 49.

A **heptagon** is a seven-sided figure.

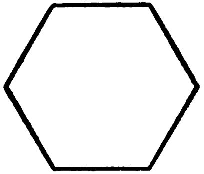


Fig. 49—Hexagon.

An **octagon** is an eight-sided figure.

A **nonagon** is a nine-sided figure.

A **decagon** is a ten-sided figure.

A **unadecagon** is an eleven-sided figure.

A **duodecagon** is a twelve-sided figure.

GEOMETRICAL DEFINITION OF SOLIDS.

A **solid** has length, breadth and thickness. The boundaries of a solid are surfaces.

A **solid angle** is that which is made by two or more plane angles, which are not in the same plane, meeting at one point.

A **cube** is a solid figure contained by six equal squares—Fig. 50.

A **prism** is a solid figure contained by plane figures of which two that are opposite are equal, similar, and parallel to one another, the other sides are parallelograms—Fig. 51.

A **pyramid** is a solid figure contained by planes, one of which is the base, and the remainder are triangles, whose vertices meet a point about the base, called the vertex or apex of the pyramid—Fig. 52.

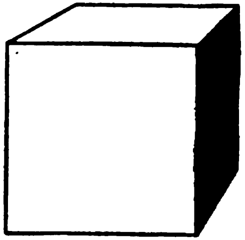


Fig. 50—Cube.

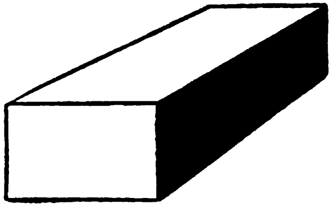


Fig. 51—Prism.

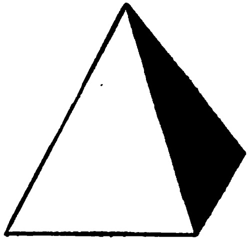


Fig. 52—Pyramid.

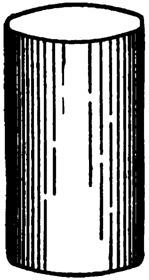


Fig. 53—Cylinder.

A **cylinder** is a solid figure described by the revolution of a rectangular or parallelogram about one of its sides—Fig. 53.

The **axis** of a cylinder is the fixed straight line about which the parallelogram revolves.

The **ends** of a cylinder are the circles described by the two revolving sides of the parallelogram.

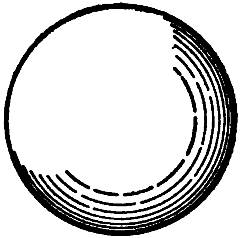


Fig. 54—Sphere.

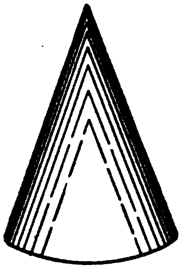


Fig. 55—Cone.

A **sphere** is a solid figure described by the revolution of a semicircle about its diameter, which remains fixed—Fig. 54.

The **axis** of a sphere is the fixed straight line about which the semicircle revolves.

The **center** of a sphere is the same as that of the semicircle.

The **diameter** of a sphere is any straight line which passes through the center and is terminated both ways by the surface of the sphere.

A **cone** is a solid figure described by the revolution of a right-angled triangle about one of its sides containing the right angle, which side remains fixed—Fig. 55.

The **axis** of a cone is the circle described by that side of the triangle containing the right angle which revolves.

The **base** of the cone is the circle described by that side of the triangle containing the right angle which revolves.

If a cone be cut obliquely so as to preserve the base entirely, the section is an **ellipse.**

When a cone is cut by a plane parallel to one of sloping sides, the section is a **parabola,** if cut at right angles to its base, an **hyperbola.**

MECHANICAL DRAWING

While many draftsmen are familiar with all of the problems given in this section of the work, it is not to be expected that all draftsmen or students are thoroughly conversant with all of them, and it is intended that this section of the work shall be used not only as reference data but for practical examples of elementary mechanical drawing. If the different problems given in this section are drawn with great accuracy, the technical skill acquired in drawing and proper handling of the different instruments will be found to be of great value. It will not be necessary to ink in these simple geometrical problems, as it is better to acquire precision or accuracy in pencil work before going further. These problems are believed to be an essential part of a work on mechanical drawing. To understand geometry certain qualities of mind are absolutely necessary, and many persons find it impossible to grasp even the simple problems of this study. The draftsman or student who is without practical knowledge of geometry is very poorly equipped for his duties.

THE CONSTRUCTION OF ANGLES.

To bisect a given angle. Let DAC be the given angle. With center A and any radius AE describe an arc cutting AC and AD at E and G. With the same radius and centers E and G, describe arcs intersecting at H, and join AH. The angle DAC is bisected—Fig. 56.

To construct an angle of 30°. With radius AE

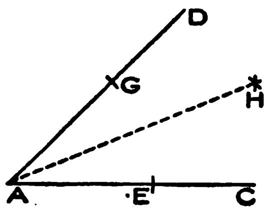


Fig. 56.

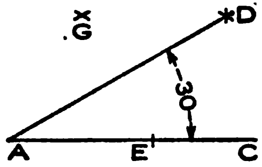


Fig. 57.

and with center A and E, describe arcs intersecting at G. With the same radius and with centers E and G, describe arcs intersecting at D, and join AD. The angle DAC contains 30°—Fig. 57.

To construct an angle of 60°. With radius AE, and with centers A and E, describe arcs intersecting at G, draw AD through G. The angle DAG contains 60°—Fig. 58.

To construct an angle of 45°. With radius AE and centers A and E, describe arcs intersecting at F, draw EG through F, and make FG equal to FE. Join GR, and with center R and radius AE make AH equal to AE, with the same radius and with centers E and H describe arcs intersecting at

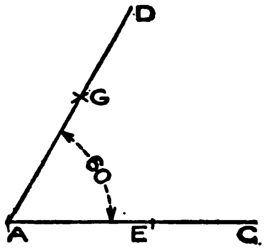


Fig. 58.

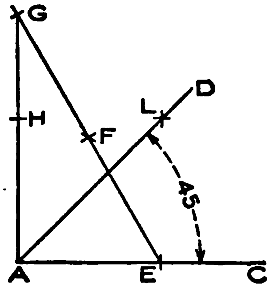


Fig. 59.

L, draw AD through L. The angle DAC is 45°—Fig. 59.

To construct an angle of 90°. With radius AE and centers A and E, describe arcs intersecting at F, with the same radius and center F describe the arc AGD, with radius AE, lay off AG and GD and join DA. The angle DAG is 90°—Fig. 60.

To bisect a straight line—Fig. 61. Let BC be the straight line to be bisected. With any convenient radius greater than AB or AC describe

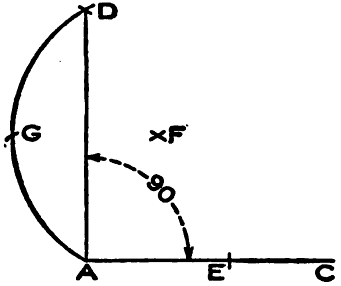


Fig. 60.

arcs cutting each other at D and E. A line drawn through D and E will bisect or divide the line BC into two equal parts.

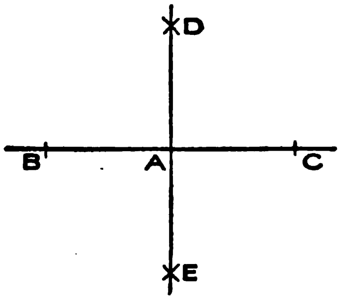


Fig. 61.

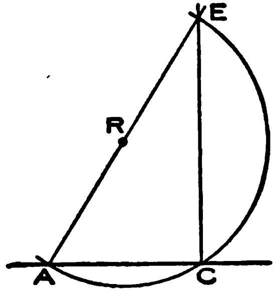


Fig. 62.

To erect a perpendicular line at or near the end of a straight line—Fig. 62. With any convenient radius and at any distance from the line AC, describe an arc of a circle as ACE, cutting the line at A and C. Through the center R of the circle draw the line ARE, cutting the arc at point E. A line drawn from C to E will be the required perpendicular.

To divide a straight line into any number of equal parts—Fig. 63. Let AB be the straight line to be divided into a certain number of equal parts: From the points A and B, draw two parallel lines AD and BC, at any convenient angle with the line AB. Upon AD and BC set off one less than the

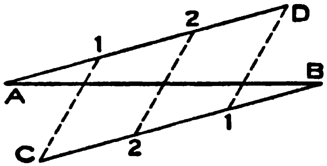


Fig. 63.

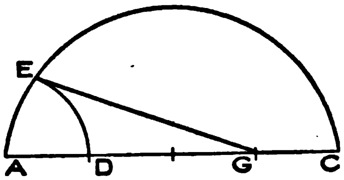


Fig. 64.

number of equal parts required, as A-1, 1-2, 2-D, etc. Join C-1, 2-2, 1-D, the line AB will then be divided into the required number of equal parts.

To find the length of an arc of a circle—Fig. 64. Divide the chord AC of the arc into four equal parts as shown. With the radius AD equal to one-fourth of the chord of the arc and with A as the center describe the arc DE. Draw the line EG and twice its length will be the length of the arc AEC.

To draw radial lines from the circumference of

a circle when the center is inaccessible—Fig. 65. Divide the circumference into any desired number of parts as AB, BC, CD, DE. Then with a radius

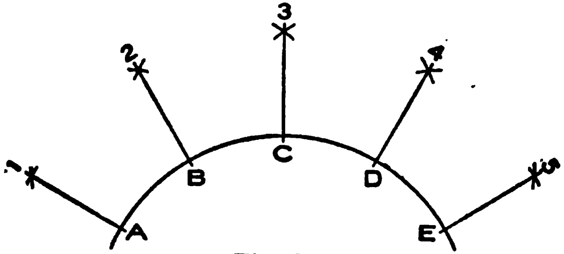


Fig. 65.

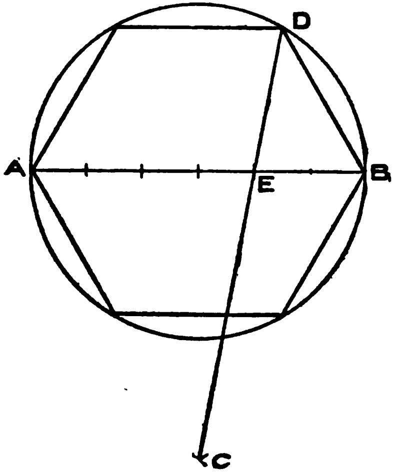


Fig. 66.

greater than the length of one part, describe arcs cutting each other as A-2, C-2, B-3, D-3, etc., also B-1, D-5. Describe the end arcs A-1, E-5 with a radius equal to B-2. Lines joining A-1, B-2, C-3, D-4 and E-5 will all be radial.

To inscribe any regular polygon in a circle—Fig. 66. Divide the diameter AB of the circle into as many equal parts as the polygon is to have sides. With the points A and B as centers and radius AB, describe arcs cutting each other at C. Draw the line CE through the second point of division of the diameter of AB, intersecting the circumference of the circle D. A line drawn from B to D is one of the sides of the polygon.

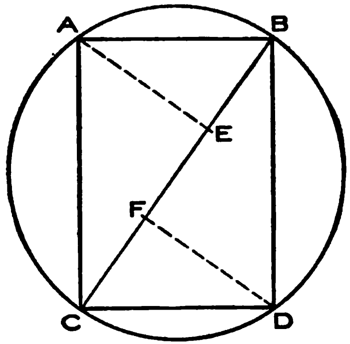


Fig. 67.

To cut a beam of the strongest shape from a circular section—Fig. 67. Divide any diameter CB of the circle into three equal parts as CF, FE and EB. At E and F erect perpendiculars EA and FD on opposite sides of the diameter CB. Join AB, BD, DC and CF. The erect angle ABCD will be the required shape of the beam.

To divide any triangle into two parts of equal area—Fig. 68. Let ABC be the given triangle: Bisect one of its sides AB at D and describe the semicircle AEB. At D erect the perpendicular DE and with center B and radius BE describe the arc EF which intersects the line AB at F. At F draw the line AG parallel at AC, this divides the triangle into two parts of equal area.

To inscribe a circle of the greatest possible di-

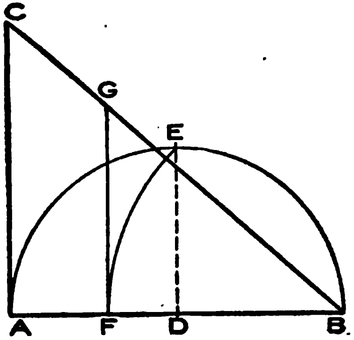


Fig. 68.

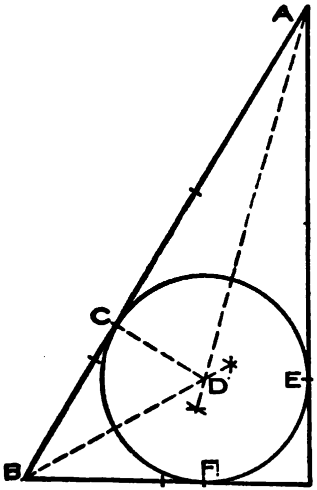


Fig. 69.

ameter in a given triangle—Fig. 69. Bisect the angles A and B, and draw the lines, AD, BD which intersect each other at D. From D draw the line CD perpendicular to AB. Then CB will be the radius of the required circle CEF.

To construct a square equal in area to a given circle—Fig. 70. Let ACBD be the given circle: Draw the diameters AB and CD at right angles to each other, then bisect the half diameter or radius DB at E and draw the line FL, parallel to BA. At the points C and F erect the perpendiculars CH and FG, equal in length to CF. Join HG, then CFGH is the required square. The

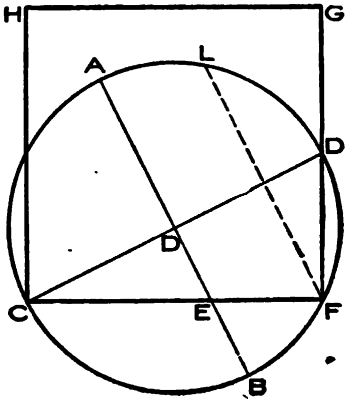


Fig. 70.

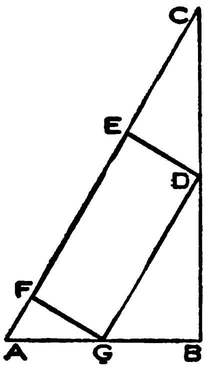


Fig. 71.

dotted line FL is equal to one-fourth the circle ACBD.

To construct a rectangle of the greatest possible area in a given triangle—Fig. 71. Let ABC be the given triangle: Bisect the sides AB and BC at G and F. Draw the line GD and from the points G and D, draw the lines GF and DE perpendicular to GD, then EFGD is the required rectangle.

To construct a rectangle equal in area to a given triangle—Fig. 72. Let ABC be the given triangle: Bisect the base AB of the triangle at D and erect the perpendiculars DE and BF at D and B. Through C draw the line ECF intersecting the

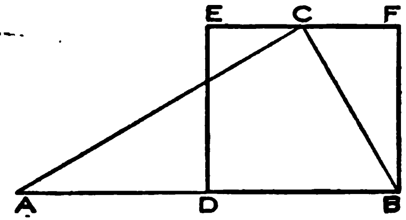


Fig. 72.

perpendiculars DE and B at E and F. Then BDEF is the required rectangle.

To construct a triangle equal in area to a given parallelogram—Fig. 73. Let ABCD be the given parallelogram: Produce the line AB at B and

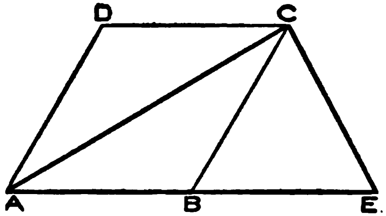


Fig. 73.

make BE equal to AB. Join the points A and C and ACE will be the triangle required.

To inscribe a square within a given circle—Fig. 74. Let ADBC be the given circle: Draw the diameters AB and CD at right angles to each other. Join AD, DB and CA, then ACBD is the inscribed square.

To describe a square without a given circle—Fig. 75. Draw the diameters AB and CD at right angles to each other. Through A and B draw the lines EF and GH, parallel to CD, also draw the lines EG and FH through the points C and D and

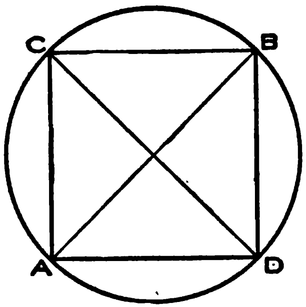


Fig. 74.

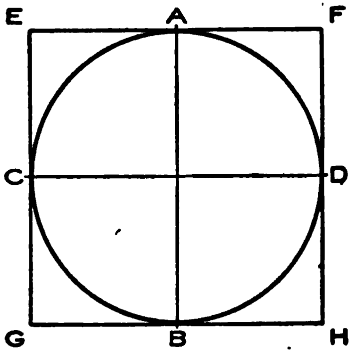


Fig. 75.

parallel to AB, this completes the required square EFGH.

To construct an octagon in a given square—Fig. 76. Let ABCD be the given square: Draw the diagonal lines AC and BD, which intersect each other at the point O. With a radius equal to AO or OC, describe the arcs EF, GH, IK and LM. Connect the points EK, LG, FI and HM, then GFIHMKEL is the required octagon.

To construct a circle equal in area to two given circles—Fig. 77. Let AB and AC equal the diameters of the given circles: Erect AC at A and at right angles to AB. Connect B and C, then bisect the line BC at D and describe the circle ACB which is the circle required and is equal in area to the two given circles.

To describe an octagon about a given circle—Fig. 78. Let ACBD be the given circle: Draw

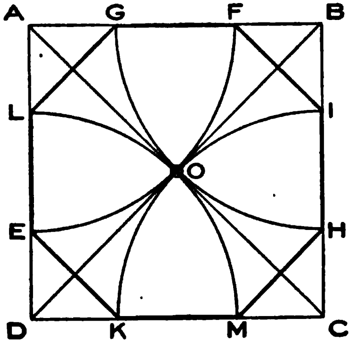


Fig. 76.

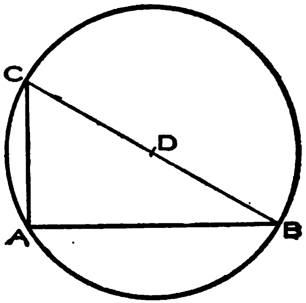


Fig. 77.

the diameters AB and CD at right angles to each other. With any convenient radius and centers A, C, B and D describe arcs intersecting each other at E, H, F and G. Join EF and GH which form two additional diameters. At the points AB and CD draw the lines KL, PR, MN and ST parallel with the diameters CD and AB respectively. At the points of intersection of the circumference of the circle by the lines EF and GH, draw the lines KP, RM, NT and SL parallel with the lines EF and HG respectively, then PRMNTSLK is the required octagon.

To draw a straight line equal in length to a given portion of the circumference of a circle—Fig. 79. Let ACBD be the given circle: Draw the diameters AB and CD at right angles with each other. Divide the radius RB into four equal parts. Produce the diameter AB and B and make BE

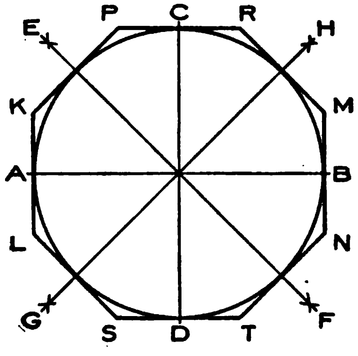


Fig. 78.

equal to three of the four parts of RB. At A draw the line AF parallel to CD and then draw the line ECF which is equal to one-fourth of the circumference of the circle ACBD. If lines be drawn from E through points in the circumference of the circle as 1 and 2, meeting the line AF and G and H, then C-1, 1-2 and 2-A will equal FG, GH and HA respectively.

To construct a square equal in area to two given

squares—Fig. 80. Let AC and AD be the length of the sides of the given squares: Make AD perpendicular to AC and connect DC, then DC is one of the sides of the square DCEG which is equal to the two given squares.

To inscribe a hexagon in a given circle—Fig. 81. Draw a diameter of the circle as AB: With centers A and B and radius AC or BG, describe arcs

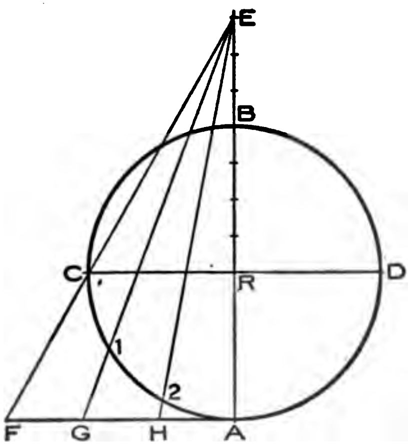


Fig. 79.

cutting the circumference of the circle at D, E, F and G. Join EF, FB, BG, GD, DA and AE, this gives the required hexagon.

To describe a cycloid, the diameter of the generating circle being given—Fig. 82. Let BD be the generating circle: Draw the line ABC equal in length to the circumference of the generating circle. Divide the circumference of the generating circle into 12 parts as shown. Draw lines from the points of division 1, 2, 3, etc., of the circum-

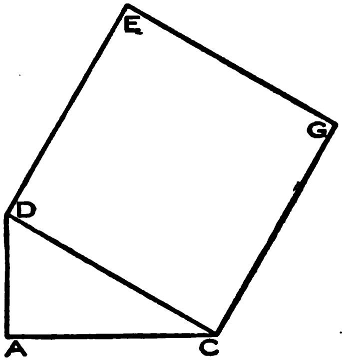


Fig. 80.

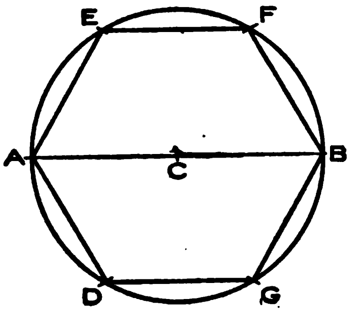


Fig. 81.

ference of the generating circle parallel to the line ABC and on both sides of the circle. Lay off one division of the generating circle on the lines

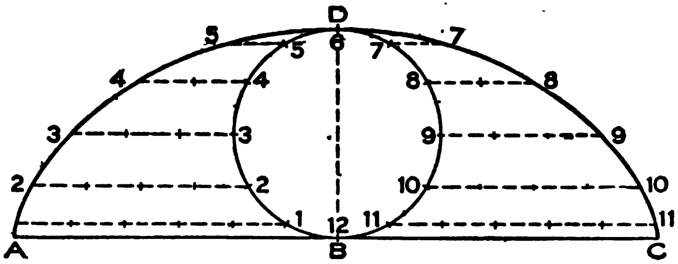


Fig. 82.

5 and 7, two divisions on the lines 4 and 8, three divisions on the lines 3 and 9, four divisions on the lines 2 and 10, and five divisions on the lines

1 and 11. A line traced through the points thus obtained will be the cycloid curve required.

To develop a spiral with uniform spacing—Fig. 83. Divide the line BE into as many equal parts as there are required turns in the spiral. Then subdivide one of these spaces into four equal parts. Produce the line BE to 4, making the extension E-4 equal to two of the subdivisions. At 1 draw the line 1-D, lay off 1-2 equal to one of the subdivisions. At 2 draw 2-A perpendicular to 1-D and at 3 in 2-A draw 3-C, etc. With center 1 and radius 1-B describe the arc BD, with center 2 and radius 2-D describe the arc DA, with center 3 and radius 3-A, etc., until the spiral is completed. If carefully laid out the spiral should terminate at E as shown in the drawing.

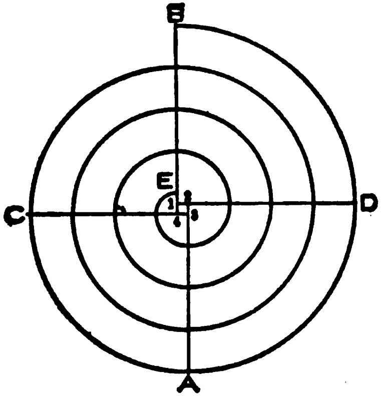


Fig. 83.

MENSURATION

Mensuration is that branch of arithmetic which is used in ascertaining the extension and solidity or capacity of bodies capable of being measured.

DEFINITIONS OF ARITHMETICAL SIGNS.

$=$Sign of Equality, as $4+8=12$.

$+$Sign of Addition, as $6+6=12$, the Sum.

$-$Sign of Subtraction, as $6-3=3$, the Remainder.

$\times$Sign of Multiplication, as $8\times4=32$, the Product.

$\div$Sign of Division, as $24\div6=4$ $\frac{24}{6}=4$.

$\surd$ Sign of Square Root, signifies Evolution or Extraction of Square Root.

^{2} Sign of to be Squared, thus $8^2=8\times8=64$.

^{3} Sign of to be Cubed, thus $3^3=3\times3\times3=27$.

MENSURATION OF PLANE SURFACES.

To find the area of a circle—Fig. 84. Multiply the square of the diameter by .7854.

To find the circumference of a circle. Multiply the diameter by 3.1416.

Circle: Area$=.7854D^2$
Circ.$=3.1416D$

To find the area of a semi-circle —Fig 85. Multiply the square of the diameter by .3927.

To find the circumference of a semi-circle. Multiply the diameter by 2.5708.

Semi-Circle: Area$=.3927D^2$
Circ.$=2.5708D$

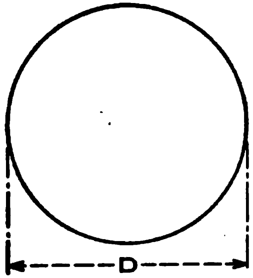


Fig. 84—Circle.

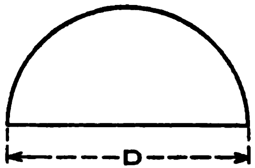


Fig. 85—Semi-circle.

To find the area of an annular ring—Fig. 86. From the area of the outer circle subtract the area of the inner circle, the result will be the area of the annular ring.

To find the outer circumference of an annular ring. Multiply the outer diameter by 3.1416.

To find the inner circumference of an annular ring. Multiply the inner diameter by 3.1416.

Annular ring: Area= $.7854 (D^2—H^2)$
Out. circ.=3.1416 D
Inn. circ.=3.1416 H

To find the area of a flat-oval—Fig. 87. Multiply the length by the width and subtract .214 times the square of the width from the result.

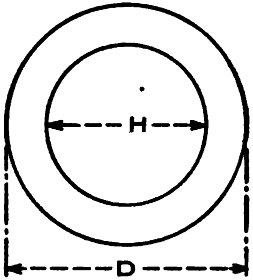


Fig. 86—Annular Ring.

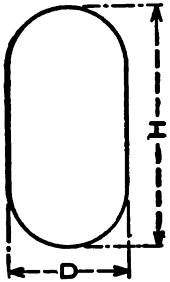


Fig. 87—Flat Oval.

To find the circumference of a flat-oval. The circumference of a flat-oval is equal to twice its length plus 1.142 times its width.

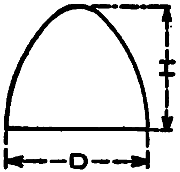


Fig. 88—Parabola.

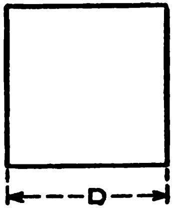


Fig. 89—Square.

Flat-oval: Area=D (H—0.214D)
Circ.=2 (H×0.571D)

To find the area of a parabola—Fig. 88. Multiply the base by the height and by .667.

Parabola: Area=.667(D×H)

To find the area of a square—Fig. 89. Multiply the length by the width, or, in other words, the area is equal to square of the diameter.

To find the circumference of a square. The circumference of a square is equal to the sum of the lengths of the sides.

Square: Area=D^2
Circ.=4D

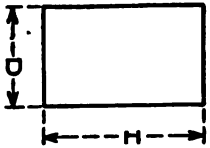


Fig. 90—Rectangle.

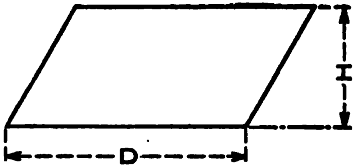


Fig. 91—Parallelogram.

To find the area of a rectangle—Fig. 90. Multiply the length by the width, the result is the area of the rectangle.

To find the circumference of a rectangle. The circumference of a rectangle is equal to twice the sum of the length and width.

Rectangle: Area=D×H
Circ.=2(D×H)

To find the area of a parallelogram—Fig. 91. Multiply the base by the perpendicular height.

Parallelogram: Area=D×H

To find the area of a trapezoid—Fig. 92. Multiply half the sum of the two parallel sides by the perpendicular distance between the sides.

Trapezoid: Area= $\frac{(HE+D)}{2}$

To find the area of an equilateral triangle—Fig. 93. The area of an equilateral triangle is equal to the square of one side multiplied by .433.

To find the circumference of an equilateral triangle. The circumference of an equilateral triangle is equal to the sum of the length of the sides.

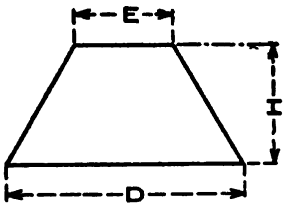


Fig. 92—Trapezoid.

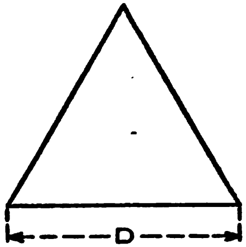


Fig. 93—Equilateral Triangle.

Equilateral triangle: Area=.433D²

Circ.=3D

To find the area of a right-angle or an isosceles triangle—Fig. 94. Multiply the base by half the perpendicular height.

To find the circumference of any regular polygon—Fig. 95. The circumference of any polygon is equal to the sum of the length of the sides.

Polygon: Area= $\frac{\text{No. of sides} \times D \times P}{2}$

Circ.=No. of sides×D

D=Length of one side.

P=Perpendicular distance from the center to one side.

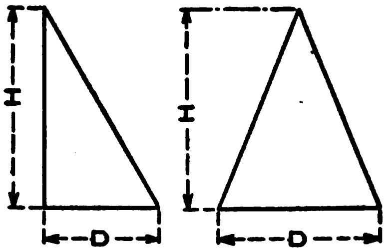


Fig. 94—Right-angle and Isosceles Triangles.

To find the area of an ellipse—Fig. 96. Multiply the long diameter by the short diameter and by .7854.

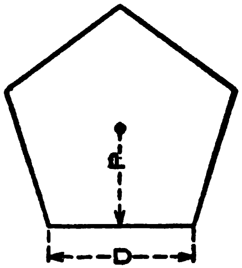


Fig. 95—Regular Polygon.

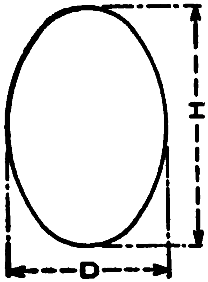


Fig. 96—Ellipse.

To find the circumference of an ellipse. Multiply half the sum of the long and short diameters by 3.1416.

Ellipse: Area= .7854 (D×H)
Circ.=1.5708 (D+H)

To find the area of a hexagon—Fig. 97. Multiply the square of one side by 2.598.

To find the circumference of a hexagon. The circumference of a hexagon is equal to the length of the sides.

Hexagon: Area=2.598 S^2
Circ.=6 S
D=1.732 S

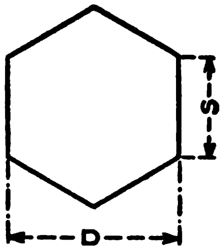


Fig. 97—Hexagon.

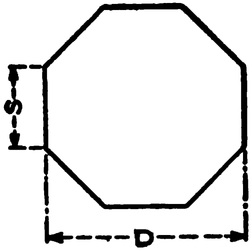


Fig. 98—Octagon.

To find the area of an octagon—Fig. 98. Multiply the square of the short diameter by .828.

To find the circumference of an octagon. The circumference of an octagon is equal to the sum of the length of the sides.

Octagon: Area=.828 D^2
Circ.=8 S
S=.414 D

MENSURATION OF VOLUME AND SURFACE OF SOLIDS.

To find the cubic contents of a sphere—Fig. 99. Multiply the cubic of the diameter by .5236.

To find the superficial area of a sphere. Multiply the square of the diameter by 3.1416.

Sphere: Cubic contents=.5236D^3
Superficial area=3.1416D^2

The area of the surface of a sphere is equal to the area of the surface of a cylinder, the diameter

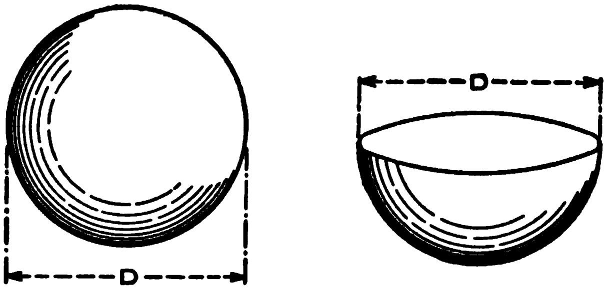


Fig. 99.

and the height of which are each equal to the diameter of the sphere. Also, the area of the surface of a sphere is equal to four times the area of its diameter.

The latter definition is easily remembered, and is useful in calculating the areas of the hemispheres, because the area of the sheet or disc of metal required for raising a hemisphere must be equal in area to the combined areas of two discs, each equal to the diameter of the hemisphere.

To find the cubic contents of a hemisphere—Fig. 99. Multiply the cube of the diameter by .2618.

To find the superficial area of a hemisphere.

Hemisphere: Cubic contents $= .2618D^2$
Superficial area $= 2.3562D^2$

To find the cubic contents of a cylindrical ring—Fig. 100. To the cross-sectional diameter of the

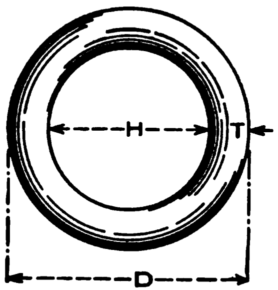


Fig. 100.

ring add the inner diameter of the ring, multiply the sum by the square of the cross-sectional diameter of the ring and by 2.4674, the product is the cubic contents.

To find the superficial area of a cylindrical ring. To the cross-sectional diameter of the ring add the inner diameter of the ring. Multiply the sum by the cross-sectional diameter of the ring and by 9.8696, the product is the superficial area.

Cylindrical ring: Cubic contents $= 2.4674T^2\ (T+H)$
Superficial area $= 9.8696T\ (T+H)$
$D = (H+2T)$

To find the cubic contents of a cylinder—Fig. 101. Multiply the area of one end by the length of the cylinder, the product will be the cubic contents of the cylinder.

To find the superficial area of a cylinder. Multiply the circumference of one end by the length of the cylinder and add to the product the area of both ends.

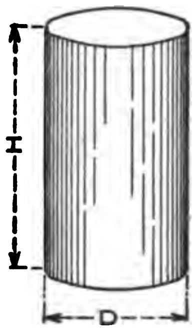


Fig. 101.

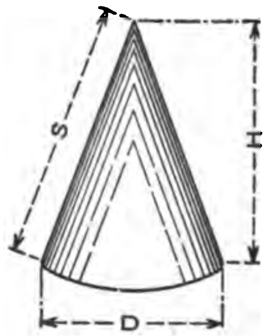


Fig. 102.

Cylinder: Cubic contents $= .7854\ (D+H)$
Superficial area $= 1.5708D\ (2H+D)$

To find the cubic contents of a cone—Fig. 102. Multiply the square of the base by the perpendicular height and by .2618.

To find the superficial area of a cone. Multiply the circumference of the base by one-half the slant height and add to the product the area of the base.

Cone: Cubic contents=.2618 $(D^2 \times H)$
Superficial area=.7854 $(2S+D)$

To find the cubic contents of the frustum of a cone—Fig. 103. To the sum of the areas of the two ends of the frustum, add the square root of the product of the diameters of the two ends, this result multiplied by one-third of the perpendicular height of the frustum will give the cubic contents.

To find the superficial area of the surface of the frustum of a cone. Multiply the sum of the diameters of the ends by 3.1416 and by half the slant height. Add to the result the area of both ends and the sum of the two will be superficial area.

Frustum of cone:

$$\text{Cubic Contents} = \frac{H(.2618\,(E^2+D^2)\sqrt{E \times D})}{3}$$

$$\text{Superficial area} = 3.1416S\left(\frac{D+E}{2}\right) + .7854(E^2+D^2)$$

$$S = \sqrt{\left(\frac{D-E}{2}\right)^2 + H^2}$$

To find the contents of a cube—Fig. 104. The contents of equal to the cube of its diameter.

To find the superficial area of a cube. The superficial area of a cube is equal to six times the square of its diameter.

Cube: Cubic contents=D^3
Superficial area=$6D^2$

To find the cubic contents of a rectangular solid

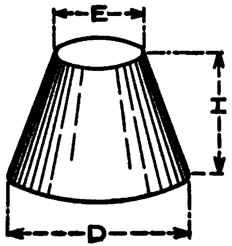


Fig. 103.

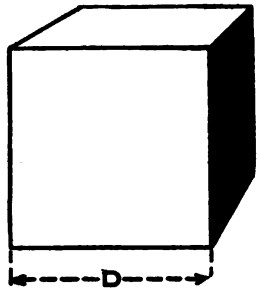


Fig. 104.

—Fig. 105. Multiplying together the length, width and height will give the cubic contents of the rectangular solid.

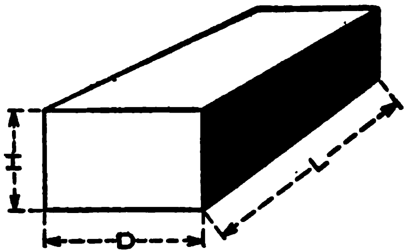


Fig. 105.

To find the superficial area of a rectangular solid. Multiply the width by the sum of the height and length and add to it the product of the height multiplied by the length, twice this sum is the superficial area of the rectangular solid.

Rectangular solid:

$$\text{Cubic contents} = D \times H \times L$$

$$\text{Superficial area} = 2\ (D\ (H+L) + HL)$$

To find the cubic contents of a pyramid—Fig. 106. Multiply the area of the base by one-third the perpendicular height and the product will be the cubic contents of the pyramid.

To find the superficial area of a pyramid. Multiply the circumference of the base by half the slant height and to this add the area of the base. the sum will be the superficial area.

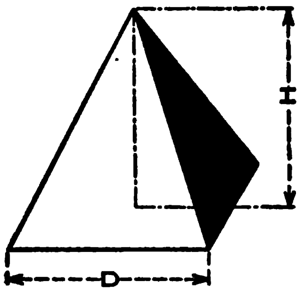


Fig. 106.

$$\textbf{Pyramid: Cubic contents} = \frac{D^2 \times H}{3}$$

$$\textbf{Superficial area} = \left(\frac{4D+S}{2} + 4D\right)$$

$$S = \sqrt{\frac{D^2}{4} + H^2}$$

MENSURATION OF TRIANGLES.

To find the base of a right-angle triangle when the perpendicular and the hypothenuse are given —Fig. 107. Subtract the square of the perpendicular from the square of the hypothenuse, the square root of the difference is equal to the length of the base.

$$\text{Base} = \sqrt{\text{Hypothenuse}^2 - \text{Perpendicular}^2} \quad \text{or} \quad B = \sqrt{C^2 - H^2}$$

To find the perpendicular of a right-angle triangle when the base and hypothenuse are given. Subtract the square of the base from the square of the hypothenuse, the square root of the difference is equal to the length of the perpendicular.

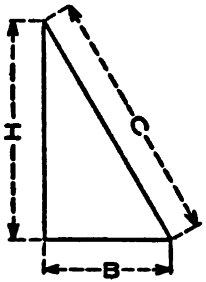


Fig. 107.

$$\text{Perpendicular} = \sqrt{\text{Hypothenuse}^2 - \text{Base}^2} \quad \text{or} \quad H = \sqrt{C^2 - B^2}$$

To find the hypothenuse of a right-angle triangle when the base and the perpendicular are given. The square root of the sum of the squares of the base and the perpendicular is equal to the length of the hypothenuse.

$$\text{Hypothenuse}=\sqrt{\text{Base}^2+\text{Perpendicular}^2}$$

$$C=\sqrt{B^2+H^2}$$

To find the perpendicular height of any oblique angled triangle—Fig. 108. From half the sum of the three sides of the triangle, subtract each side severally. Multiply the half sum and the three remainders together and twice the square root of the result divided by the base of the triangle will be the height of the perpendicular.

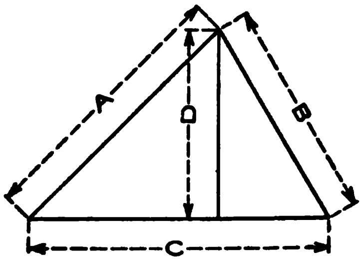


Fig. 108.

$$D=\frac{2\sqrt{S(S-A)\,(S-B)\,(S-C)}}{C}$$

$$S=\frac{\text{Sum of sides}}{2}$$

To find the area of any oblique angled triangle when only the three sides are given. From half the sum of the three sides, subtract each side severally. Multiply the half sum and the three remainders together and the square root of the products is equal to the area required.

$$\text{Area}=\sqrt{S(S-A)\,(S-B)\,(S-C)}$$

To find the height of the perpendicular and the two sides of any triangle inscribed in a semi-circle, when the base of the triangle and the location of the perpendicular are given—Fig. 109.

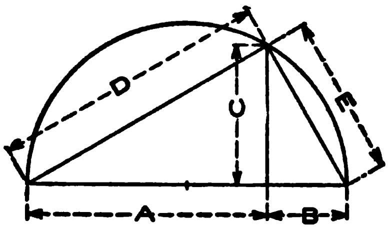


Fig. 109.

$$A=\frac{C^2}{B} \qquad B=\frac{C^2}{A} \qquad C=\sqrt{A\times B}$$

$$D=\sqrt{A(A+B)} \qquad E=\sqrt{B(A+B)}$$

THE MECHANICAL POWERS

Mechanical Powers consist of simple mechanical devices whereby weights may be raised or resistances overcome with the exertion of less power than would be necessary without them.

They are six in number: The **lever**, the **wheel** and **pinion**, the **pulley**, the **inclined plane**, the **wedge**, and the **screw**. Properly two of these comprise the whole, namely, the **lever** and the **inclined plane**,—the wheel and pinion being only a lever of the first kind, and the pulley a lever of the second, the wedge and screw being also similarly allied to that of the inclined plane. Although such seems to be the case, yet they each require, on account of their various modifications, a different rule of calculation adapted expressly to the different circumstances in which they are required to act.

The primary elements of machinery are therefore two only in number, the **lever and the inclined plane.**

The Lever.

Levers, according to the method of application, are of the first, second, or third kind. Although levers of equal lengths produce different effects, the general principles of estimation in all are the same, namely, the power is to the weight, as the distance of one end of the fulcrum is to the distance of the other end to the same point.

In a lever of the first kind the fulcrum is between the power and the weight, as in Fig. 110. A pair of pliers or scissors are double levers of the first kind.

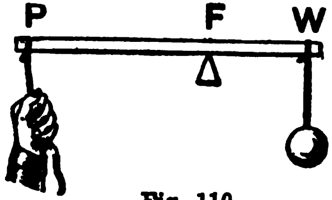


Fig. 110.

In a lever of the second kind, the weight is between the power and the fulcrum, as in Fig. 111. A wheel-barrow, or the oars of a boat where the water is considered the fulcrum, and a door, represent levers of the second kind.

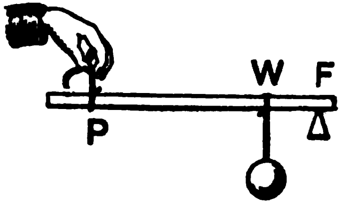


Fig. 111.

In a lever of the third kind, the power is between the fulcrum and the weight, as in

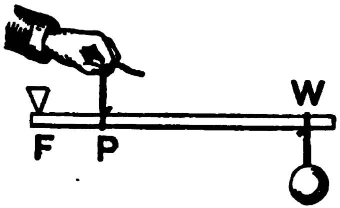


Fig. 112.

Fig. 112. Levers of the third kind are instruments such as tongs, shears, etc.

In the **first kind**, the power is to the weight, as the distance W F is to the distance F P.

In the **second**, the power is to the weight, as the distance F W is to that of F P; and,

In the **third**, the weight is to the power, as the distance F P is to that of F W.

To find the power. Multiply the weight by its distance from the fulcrum, and divide by the distance of the weight from the fulcrum.

To find the weight. Multiply the power by its distance from the fulcrum, and divide by the distance of the weight from the fulcrum.

To find the distance of the power from the fulcrum. Multiply the weight by its distance from the fulcrum, and divide by the power.

To find the distance of the weight from the fulcrum. Multiply the power by its distance from the fulcrum, and divide by the weight.

Let **P** be the power, **F** the fulcrum and **W** the weight, then for a lever of the **first kind.** (Fig. 110.)

$$P=W\frac{FW}{FP} \qquad W=P\frac{FP}{FW}$$

And for a lever of the **second kind.** (Fig. 111.)

$$P=W\frac{FW}{FP} \qquad W=P\frac{FP}{FW}$$

And for a lever of the **third kind.** (Fig. 112.)

$$P=W\frac{FW}{FP} \qquad W=P\frac{FP}{FW}$$

The Wheel and Pinion.

The mechanical advantage of the wheel and pinion system, Fig. 113, is as the velocity of the weight to the velocity of the power, and being only a modification of the **first kind** of lever, it of course partakes of the same principles.

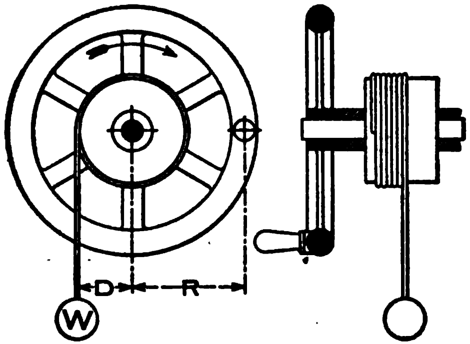


Fig. 113.

To find the power. Multiply the weight by the radius of the drum, and divide by the radius of the wheel.

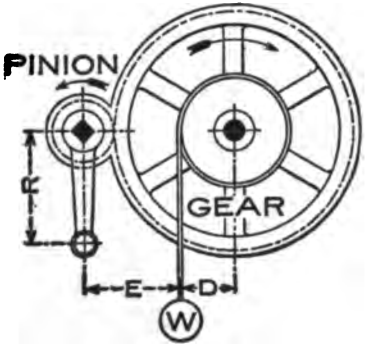
To find the radius of the wheel. Multiply the weight by the radius of the drum, and divide by the power.

To find the radius of the drum. Multiply the power by the radius of the wheel, and divide by the weight.

To find the weight. Multiply the power by the radius of the wheel, and divide by the radius of the drum.

Let **W** be the weight, **D** the radius of the drum, **R** the radius of the wheel and **P** the power required to lift the weight, then for a **Wheel and Drum system:** (Fig. 113.)

$$P=\frac{W\times D}{R} \qquad D=\frac{P\times R}{W} \qquad R=\frac{W\times D}{P} \qquad W=\frac{P\times R}{D}$$



$$P=\frac{W\times D\times P}{R\times G}$$

$$W=\frac{P\times R\times G}{D\times P}$$

Fig. 114.

For a Crank, Pinion and Gear and Drum system: (Fig. 114.)

To determine the amount of effective power produced from a given power by means of a crank, pinion and gear, and drum system. Multiply the diameter of the circle described by the crank or turning handle by the number of revolutions of the pinion to one of the wheel. Divide the product by the diameter of the drum and the quotient is the ratio of the effective power to the exertive force. Fig. 114.

Given any two parts of a crank, pinion and gear, and drum system, to find the third, that shall produce any required proportion of mechanical effect. Multiply the two given parts together, and divide the product by the required proportion of effect, the quotient is the dimensions of the other part.

$$D=\frac{P\times R\times G}{W\times P} \qquad R=\frac{W\times D\times P}{P\times G}$$

P=Either pitch diameter or number of teeth in the pinion.

G=Either pitch diameter or number of teeth in the gear.

Let E be the **ratio** of the **effective power** to the **effective force** produced, then

$$E=3.1416\frac{R\times G}{D\times P}$$

The Pulley or Sheave.

The pulley or sheave is a wheel over which a rope is passed to transmit the force applied to the cord in another direction. There are two kinds of pulleys, the one turning on fixed centers, the other turning on traversing centers.

The fixed or stationary pulley (Fig. 115). This acts like a lever of the first kind. It affords no mechanical advantage, and merely changes the direction of the force, and does not alter its intensity, but it affords great facilities in the application of force, as it is easier to pull downwards than upwards. In this class of pulley the power is equal to the weight to be raised.

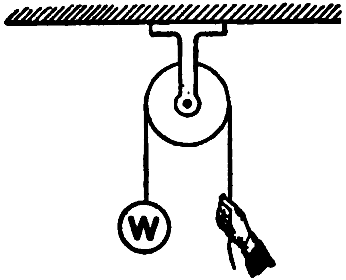


Fig. 115.

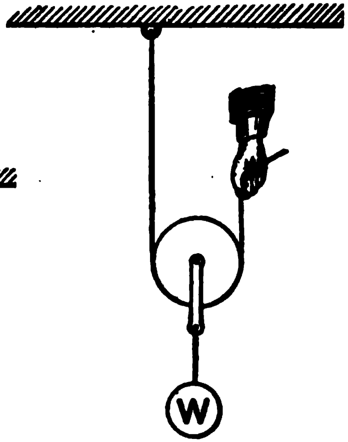


Fig. 116.

The movable pulley (Fig. 116). This acts like a lever of the second kind. One end of the rope is suspended to a fixed point, as a fulcrum, in a beam, and the weight is attached to the axis of the pulley. This kind of pulley doubles the power at the expense of the speed, and the product of the power by the diameter of the pulley, is equal to the product of the weight by the radius of the pulley.

A movable pulley acting as a lever of the third kind is shown at Fig. 117. One end of the cord is fixed to a floor, and the weight is attached to the other end, the power being applied to the axis. The power is equal to twice the weight, and the product of the power by the radius of the pul-

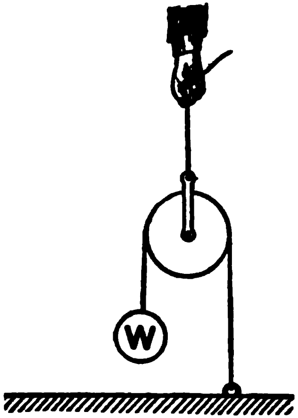


Fig. 117.

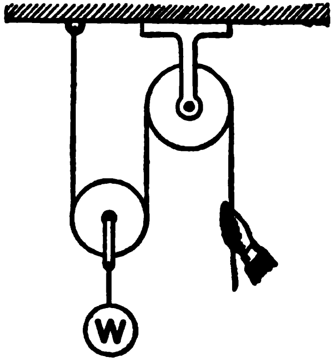


Fig. 118.

ley is equal to the product of the weight by the diameter of pulley. In the arrangement shown at Fig. 118 the power is equal to one-half the weight.

A combination of movable pulleys with separate and parallel cords is shown at Fig. 119. Each system reduces the resistance to the extent of one-half, hence the power may be found by dividing and subdividing the weight successively by

2, as many times as there are movable pulleys. The weight may be found by multiplying the power successively by 2, as many times as there are movable pulleys.

To find the power. Divide the weight to be raised by the number of cords leading **to, from,** or **attached,** to the power block. The quotient is the power required to produce an equilibrium, provided friction did not exist. When the fixed end of the rope is attached to the fixed block, the power may be found by dividing the weight by twice the number of movable pulleys. When the fixed end of the rope is attached to the movable block, the power may be found by dividing the weight by twice the number of movable pulleys plus 1.

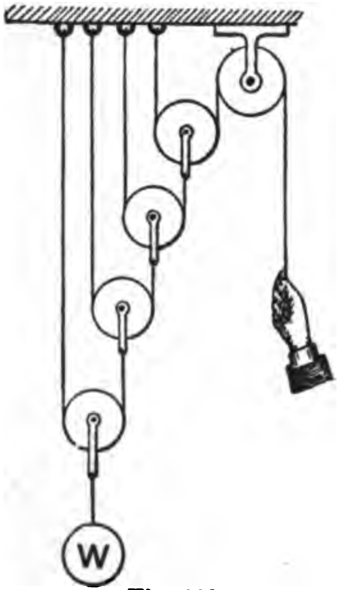


Fig. 119.

To find the number of sheaves or pulleys required. Divide the power to be raised by the power to be applied; the quotient is the number of sheaves in, or cords attached to the rising block.

To find the weight that will be balanced by a given power. When the rope is attached to the fixed block, multiply the power by twice the number of movable pulleys.

When the rope is attached to the movable block multiply the power by twice the number of movable pulleys plus 1.

The Inclined Plane.

The inclined plane (Fig. 120) is properly the second elementary power, and may be defined the lifting of a load by regular instalments. In principle it consists of any right line not coinciding with, but laying in a sloping direction to, that of the horizon, the standard of comparison of which commonly consists in referring the rise to so many parts in a certain length or distance, as 1 in 100, 1 in 200, etc., the first number representing the perpendicular height, and the latter the horizontal length in attaining such height, both numbers being of the same denomination, unless otherwise expressed.

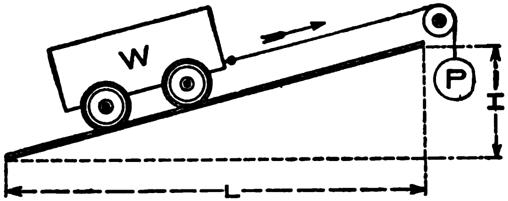


Fig. 120.

In using an inclined plane for the purpose of raising loads to a higher level, the power is applied parallel to the inclined plane, and the weight is raised in opposition to gravity, the work done on it is expressed by the product of the weight and the vertical height of the inclined plane.

The advantage gained by the inclined plane, when the power acts in a parallel direction to the plane, is as the length to the height.

To find the power. Multiply the weight by the height of the plane, and divide by the slant length. The quotient is the power.

To find the weight. Multiply the power by the slant length of the plane, and divide by the height.

To find the height of the inclined plane. Multiply the power by the slant length, and divide by the weight.

To find the slant length of the inclined plane. Multiply the weight by the height of the plane, and divide by the power.

Let **W** be the weight to be drawn up the inclined plane, **H** the height and **S** the slant length of the incline. If **P** be the power required to draw the weight **W** up the inclined plane, then

$$P=\frac{W\times H}{S} \qquad W=\frac{P\times S}{H} \qquad H=\frac{P\times S}{W}$$

$$S=\sqrt{L^2+H^2}$$

The Wedge.

The wedge is a double inclined plane, consequently its principles are the same. When two bodies are forced asunder by means of the wedge in a direction parallel to its head: Multiply the resisting power by half the thickness of the head or back of the wedge, and divide the product by

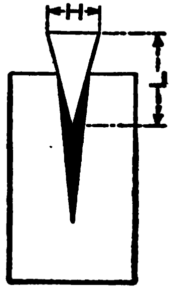


Fig. 121.

the length of one of its slant sides. The quotient is the force required equal to the resistance.

F=Force required. P=Resisting power.

$$F=\frac{P\times H}{25} \qquad P=\frac{F\times 25}{H} \qquad \text{(Fig. 121.)}$$

$$S=\text{Slant side of wedge}=\sqrt{\frac{H^2}{4}+L^2}$$

When only one of the bodies is movable, the whole breadth of the wedge is taken for the multiplier, and the following rules are for such wedges, acting under pressure only on the head of the wedge, or at the point of the wedge by drawing.

To find the transverse resistance to the wedge or weight. Multiply the power by the length of the slant side of the wedge, and divide by the breadth of the head.

To find the power. Multiply the weight or transverse resistance by the breadth of the head and divide by the length of the slant side of the wedge.

To find the length of the slant side of the wedge.

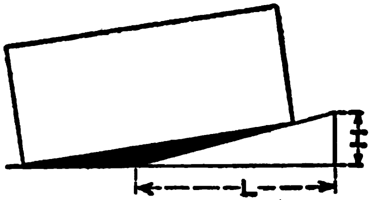


Fig. 122.

Multiply the weight by the breadth of the wedge and divide by the power.

To find the breadth of the wedge. Multiply the power by the length of the slant side of the wedge, and divide by the weight.

F=Force required. P=Resisting power.

$F=\frac{P\times H}{S}$ $P=\frac{F\times S}{H}$ (Fig. 122.)

S=Slant side of wedge $=\sqrt{H^2+L^2}$

Note.—For all practical purposes the length L may be used instead of the slant S of the side.

The Screw.

The screw, Fig. 123, in principle, is that of an inclined plane wound around a cylinder which generates a spiral of uniform inclination, each revolution producing a rise or traverse motion equal to the pitch of the screw, or distance between two consecutive threads. The pitch being the height or angle of inclination, and the circum-

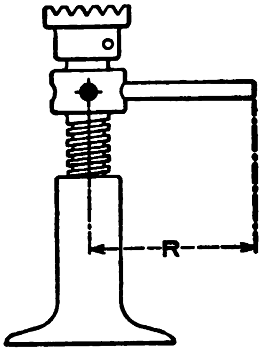


Fig. 123.

ference the length of the plane when a lever is not applied. The lever being a necessary qualification of the screw, the circle which it describes is taken, instead of the screw's circumference, as the length of the plane, the mechanical advantage is therefore as the circumference of the circle described by the lever where the power acts, is to the pitch of the screw, so is the force to the resistance.

As the circumference of a circle is equal to the radius multiplied by twice 3.1416, or 6.2832, hence the following rules for the screw.

To find the power. Multiply the weight by the pitch of the screw and divide by the product of the radius of the handle by 6.2832.

To find the weight. Multiply the power by the product of the radius of the handle by 6.2832 and divide by the pitch of the screw.

To find the pitch of the screw. Multiply the power by the product of the radius of the handle by 6.2832 and divide by the weight.

To find the length or radius of the handle. Multiply the weight by the pitch of the screw and divide by the product of the power by 6.2832.

P=Lifting power of jack. **R**=Length of lever.

F=Force required at end of lever.

N=Number of threads per inch of jack screw.

$$P = 6.283(N \times R \times F) \qquad F = \frac{P}{6.283(N \times R)}$$

$$N = \frac{P}{6.283(R \times F)} \qquad R = \frac{P}{6.283(N \times F)}$$

The Spiral is a curve generated by a point moving in a plane about a center from which its distance is continually increasing.

Imagine a right line, AB, Fig. 124, free to revolve in the plane of the paper about one of its

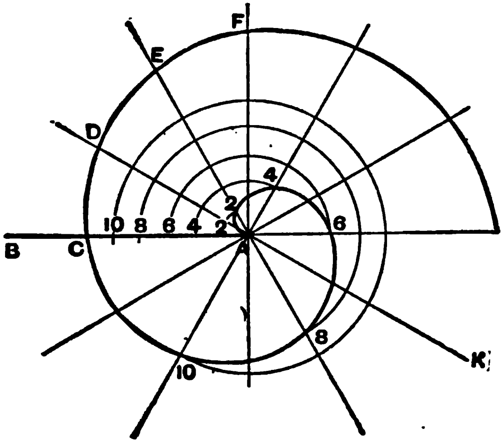


Fig. 124—The Spiral of Archimedes.

extremities, A, as an axis. Also, conceive a point free to move on this line. Three classes of lines may now be derived in the following manner: If the line be stationary and the point moves, a straight line will be generated. If the point be stationary and the line revolves, a circle will be generated. If both point and line move, a spiral will be generated. By varying the relative motion of point and line the character of the ourve will be changed and the various classes of spirals described.

The Spiral of Archimedes—Fig. 124. If the motion of the line and the point be uniform the equable spiral will be generated. The line AB is called the kadius vector, and the radial distance traversed by the point during one revolution of the radius vector is called the pitch. Twelve successive positions of the radius vector are shown by AC, AD, AE, etc. The distance of the point from the center being increased by one-twelfth of the pitch, AC, for each one-twelfth of a revolution of the radius vector. In practice, determine at least twenty-four points, and lightly sketch the curve freehand.

The Logarithmic Spiral. The construction of this curve is based on the principle that any radius vector, as AD, Fig. 125, which bisects the angle between two other radii, as AC and AB, is a mean proportional between them, that is, $(AD)^2 = AC \times AB$. This spiral is called equiangular because the angle between any radius vector and the tangent to the curve at its extremity is constant.

If B and C are points in the spiral and the ratio of AC and AB be given, the intermediate point D may be obtained by describing a semicircle on BC as a diameter and erecting a perpendicular at A.

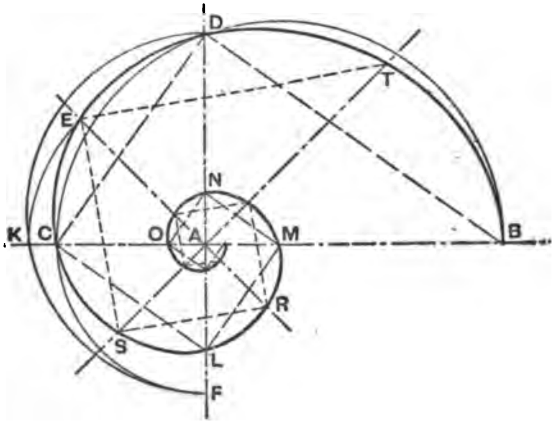


Fig. 125—The Logarithmic Spiral.

Its intersection with the semicircle at D will determine the required point, and AD will be a mean proportional between AC and AB. Other points on the curve lying on the diameters BC and DF may be obtained by intersecting these diameters with the perpendiculars CL, LM, MN, etc. Again, having points C and D, bisect DAC and determine a mean proportional between AC and AD. This may be done by laying off AF equal to AC and determining the mean proportional AK as before. Then lay off AE equal to AK. Other points on the diameters ER and T may be obtained by perpendiculars as indicated.

The Ellipse is a curve generated by a point moving in a plane so that the sum of the distances

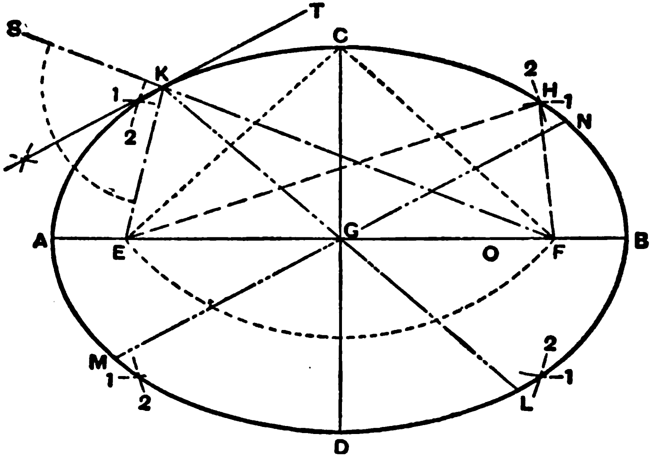


Fig. 126—The Ellipse—1.

from this point to two fixed points shall be constant. Fig. 126, if EKF be a cord fastened at its extremities, E and F, and held taut by a pencil-point at K, it may be seen that as motion is given to the point it will be constrained to move in a fixed path dependent on the length of the cord. When the pencil-point is at B, one segment of the cord will equal BE and the other BF, their sum being the same as KE plus KF, and also equal to AB. The fixed points E and F are called the foci. They lie on the longest line that can be drawn terminating in the curve of the ellipse. The line is known as the major axis, and the perpendicular to it at its middle point, also terminating in the ellipse, is the minor axis. Their intersection is called the center of the ellipse, and lines drawn through this point and terminating in the ellipse are known as diameters. When two such diameters are so related that a tangent to the ellipse at the extremity of one is parallel to the second, they are called conjugate diameters. KL and MN are two such diameters.

In order to construct an ellipse it is generally necessary that either of the following be given: The major and minor axes, either axis and the foci, two conjugate diameters, a chord and axis.

A series of points must be chosen that the sum of the distances from either of them to the foci must equal the major axis. Thus, HE+HF must equal CE+CF, or KF+KE, each being equal to AB. If the major axis and the foci be given to draw the curve, points may be determined as follows: From E, with any radius greater than AE and less than EB, describe an arc. From F, with a radius equal to the difference between the major axis and the first radius, describe a second arc cutting the first. The points of intersection of these arcs will be points, the sum of whose distances from the foci will equal the major axis, and therefore points of an ellipse. Similarly find as many points as may be necessary to enable the curve to be drawn free-hand.

Having given the major and minor axes, find the foci by describing, from C as a center, an arc with a radius equal to one-half the major axis. The points of intersection with the major axis will

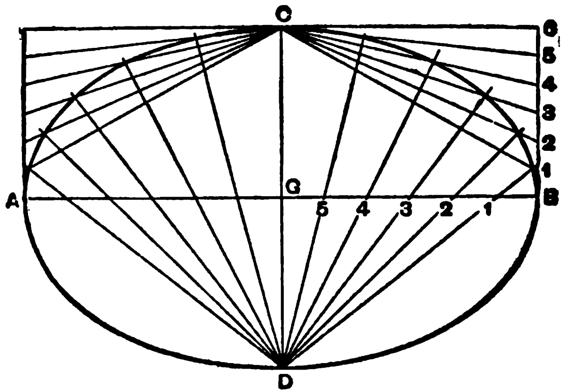


Fig. 127—The Ellipse—2.

be the foci, and this must be so since the sum of these distances is equal to the major axis, and the point C being midway between A and B the two lines CE and CF must be equal. Again, if the major axis and foci are given, with a radius equal to one-half this axis describe arcs from the foci cutting the perpendicular drawn at the middle point of the major axis and thus obtain the minor axis. Having the two axes proceed as before.

A tangent to an ellipse may be drawn at any point, K, by producing FK and dissecting the angle SKE, the bisecting line, KT, will be the required tangent.

Having given the major and minor axes in Fig. 127. From the extremity of the major axis, draw B6 parallel and equal to the minor axis, and divide it into any number of equal parts, in this case six. Divide BG into the same number of equal parts.

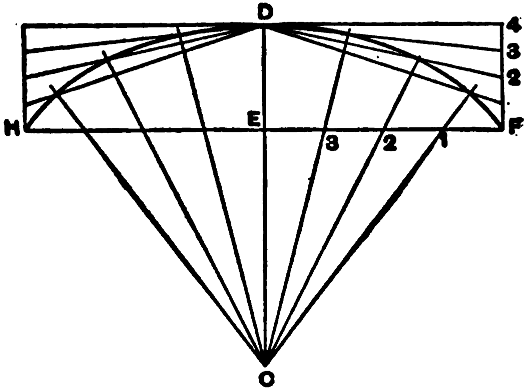


Fig. 128—The Ellipse—3.

Through points 1, 2, 3, etc., on B6, draw lines to extremity C of the minor axis. From D, the other extremity of the minor axis, draw lines through points 1, 2, 3, etc., on BG, intersecting the above lines in points which will lie in the required ellipse. Construct the remainder of the ellipse in the same manner.

Having given an axis CD and chord FH as in Fig. 128. From F draw F4 parallel to CD, divide it into any number of equal parts, in this case four. Divide the half chord FE into the same number of equal parts, through these points and extremities of given axis draw intersecting lines as before, thereby obtaining the elliptical arc FD. Construct opposite side in the same manner.

The **Parabola** is a curve generated by a point moving in a plane so that its distance from a

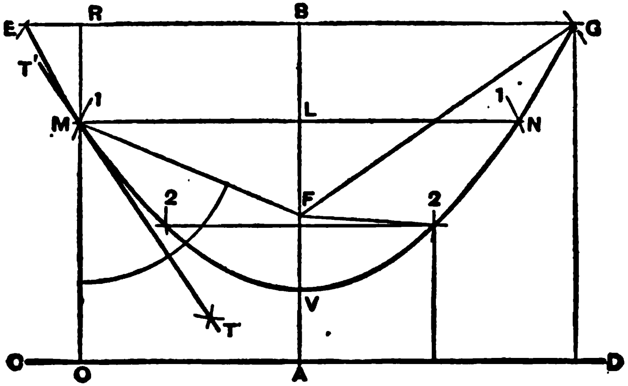


Fig. 129—The Parabola.

fixed point shall be constantly equal to its distance from a given straight line. Point F in Fig. 129 is the focus, CD is the given straight line called the directrix, and AB, a perpendicular to CD through F, is the Axis V, the intersection of the axis with the curve, is the vertex, and it must be equidistant from the focus and the directrix.

Having given the focus F and the directrix CD. Bisect FA to find the vertex V. Through any point on the axis, as L, draw MN parallel to the directrix and with radius LA describe arc 1 from focus F

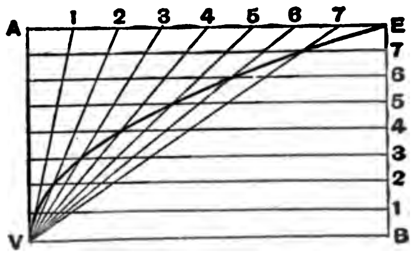


Fig. 130.

as center, intersecting line MN at points M and N. These are points in the parabola. Similarly obtain other points and draw the required curve. A tangent to the curve may be drawn at any point M by drawing MO parallel to the axis and bisecting the angle OMF. MT is the required tangent at the point M.

Since the angle TMR is equal to the angle TMF, it follows that MR would be the direction of a ray of light emitted from the focus F and reflected from the parabola at M.

Having given the abscissa VB, and the ordinate BE in Fig. 130. Draw AE parallel and equal to VB. Divide AE and BE into the same number of equal parts. From the divisions on BE draw parallels to the axis and from the divisions on AE draw lines converging to the vertex V. The intersection of these lines, 1 and 1, 2 and 2, etc., will determine points in the required curve. In like manner obtain the opposite side.

To develop a square tapering article. The plan and vertical height or elevation are shown in Fig. 131. Draw the diagonals and take the distance

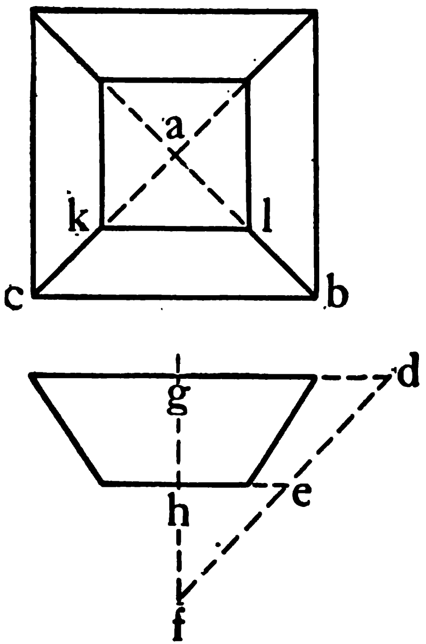


Fig. 131.

from the center **a** to **b**, and mark off the same from **g** to **d**. Take the distance from **a** to **l** or **k**, and mark off the same from **h** to **e**. Draw a line through the points **d**, **e**, to cut the perpendicular line at **f**. Then draw the perpendicular line **af**, Fig. 132, and take the radius **fd**, Fig. 131, and with it describe the arc of a circle **hdk**, Fig. 132. With the radius

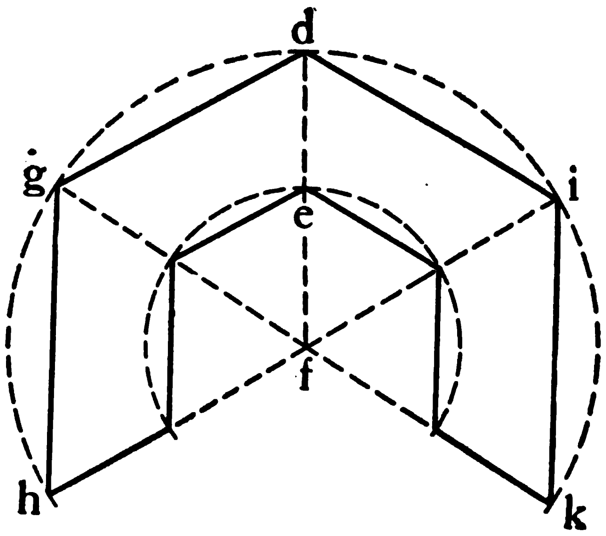
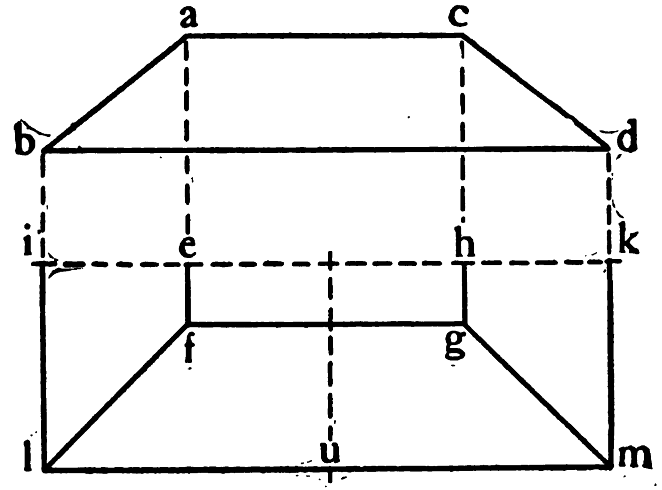


Fig. 132.

fe in Fig. 131, and with **f** in Fig. 132 as a center, draw the smaller arc **e**. Take the length of one side of the base from **c** to **b**, Fig. 131, and mark off the same four times on the circle **hdk** at **h, g, d, i, k**.

Draw through these points to the center **f**, join these points **hg**, **gd**, **di**, and **ik**. Also join the points on the smaller circle in the same manner, which will complete the development.

Fig. 133.



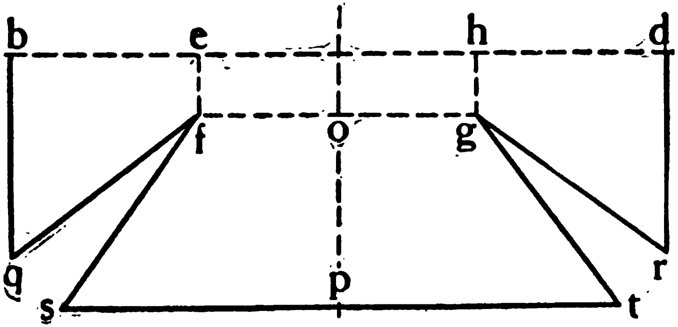


Fig. 134.

To develop a rectangular taper-sided tray. The vertical height and one-half the plan are shown in Fig. 133. Draw the horizontal line **bd** and the perpendicular line **op** as in Fig. 134. Draw the rectangle **efgh** the same size as **efgh** in Fig. 133. Take the length **ab** as in Fig. 133 and mark off a corresponding distance from **e** to **b**, **h** to **d**, and **o** to **p**, as in Fig. 134, and draw through the points **b**, **p**,

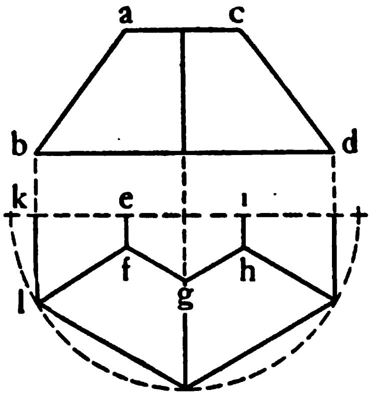


Fig. 135.

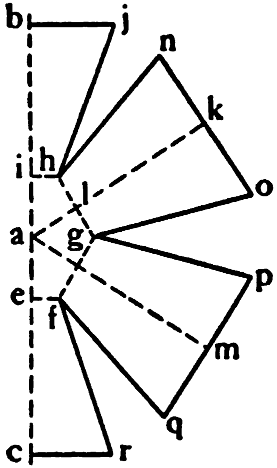


Fig. 136.

and **d** the lines at right angles as **bq**, **st**, and **dr**. Transfer the length **il** to **bq** and to **dr**, also the length **ul** from **p** to **s**, and from **p** to **t**. Then draw the lines **qf**, **sf**, **tg**, and **rg**, which will complete one-half of the development.

To develop a hexagon tray with tapering sides. The elevation and one-half the plan are shown in

Fig. 135. To develop the pattern draw the perpendicular **bc**, Fig. 136, and draw the half-hexagon **efghi**, of the same size as **efghi** in Fig. 135. Divide the lines **hg** and **gf** into two equal parts and draw the lines **ak** and **am** through the points of bisec-

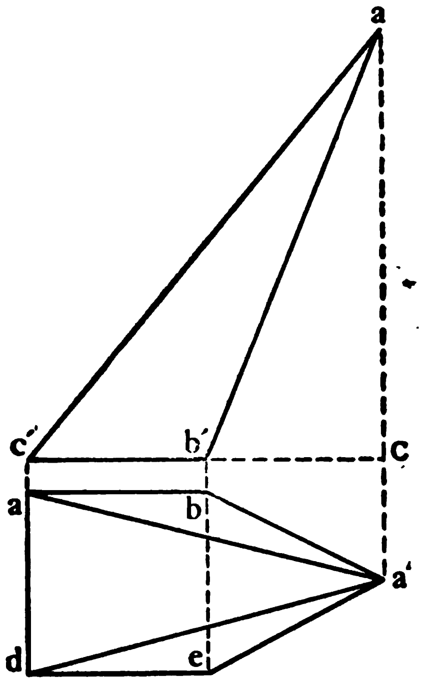


Fig. 137.

tion, then carry the length **ab**, Fig. 135, from **l** to **k** in Fig. 136. Draw through **k** the line **no** parallel to **hg**. Then take the **kl**, Fig. 135, and mark off the same from **k** to **n** and from **k** to **o**, and draw the lines **hn** and **go**. Proceed in the same manner to draw the remainder, which will complete one-half of the development.

To develop an oblique pyramid. The lengths of the sides are shown projected, **a′b** to **Cb′**, and **a′a** to **Cc′** giving for the true lengths **a′b′** and **a′c′**.

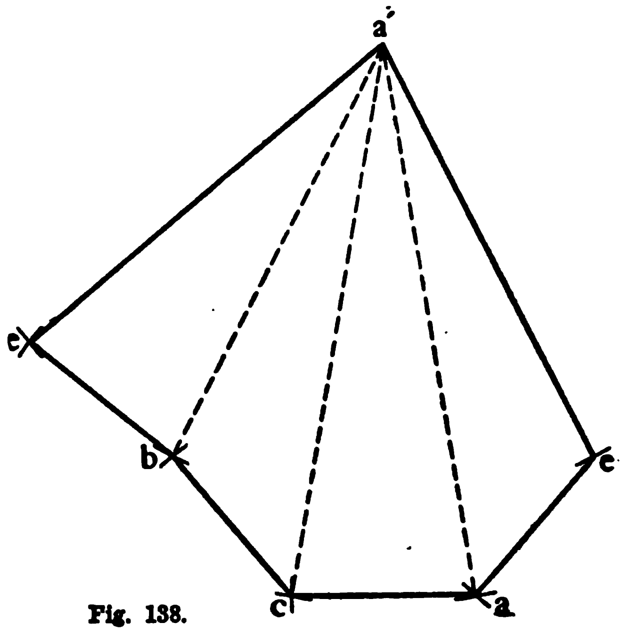


Fig. 138.

Take the length **a′c′** in Fig. 137, and with it strike the radius **a′c** in Fig. 138. With the length **a′b′** in Fig. 137, strike the radius **a′b** in Fig. 138. Take the length of one side as **ba** in Fig. 137, and set it off from **e** to **a**, and from **a** to **c**, from **c** to **b**, and from **b** to **e**. Connect the points of intersections of the arcs by means of straight lines as **ae, ac, cb,** and **be.** Also **a′** with **e** and **e**, and the outline will be described.

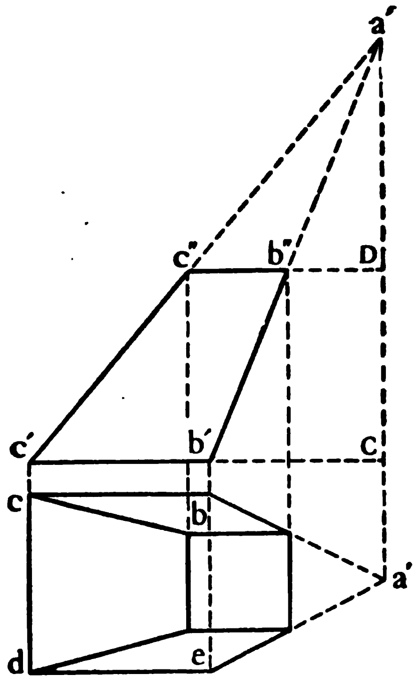


Fig. 139.

To develop an oblique truncated pyramid. The correct lengths of the sides are shown projected in Fig. 139 as in the previous figure. The lengths **ab″, ac″** on the plane **D,** are also the correct lengths for the sides of the small end of the pyramid. In Fig. 140 the outline of the base is developed precisely the same as in the previous example. To develop the top edge, the lengths **c′c″** in Fig. 139 are transferred to **ac″, cc″** in Fig. 140, and the lengths **b′b″** in Fig. 139 to **b′b″, eb″** in Fig. 140.

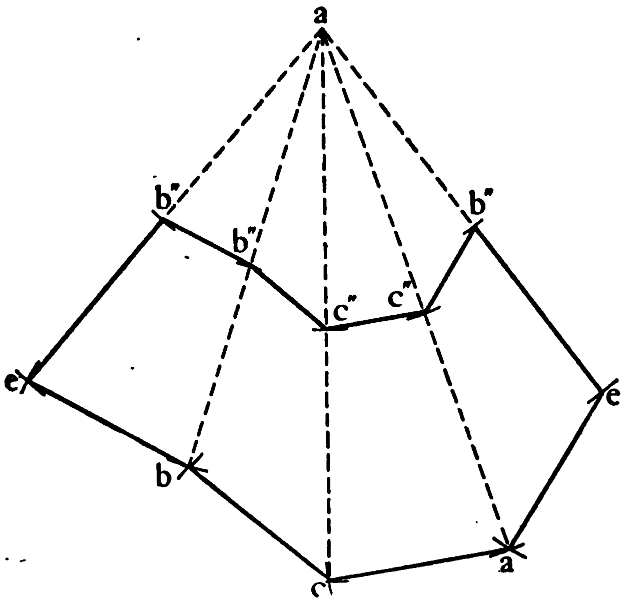


Fig. 140.

Connecting these points with straight lines gives the outline of the development.

To develop a cone cut in elliptical section. Fig. 141 shows the cone at **b-b,** the cut section forming or having the shape of an ellipse and Fig. 142 is the development of the lower part of the cone. Let

ABC, Fig. 141, represent the outline of the cone. Strike a semicircle **BGC**, equal in radius to half the length of the base **BC**, and divide it into any

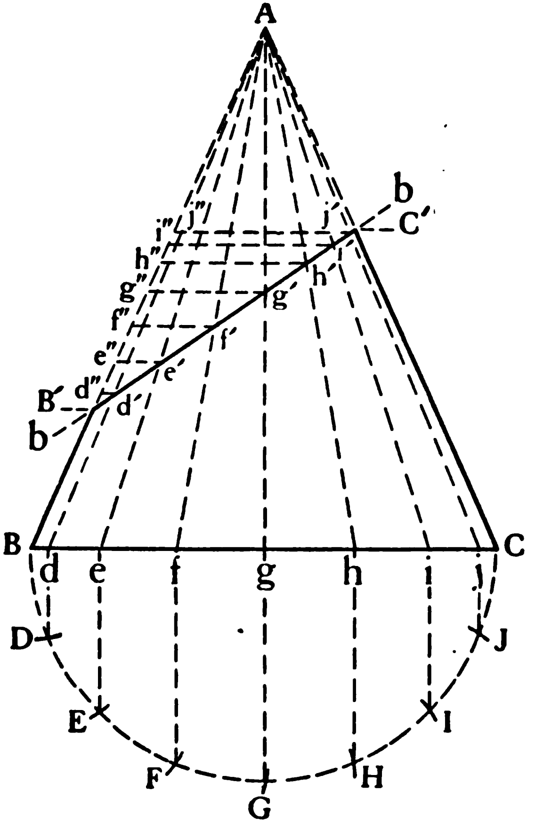


Fig. 141.

number of equal parts as **B, D, E, F, G, H, I, J, C.** Carry perpendicular lines up to cut the line **BC** in

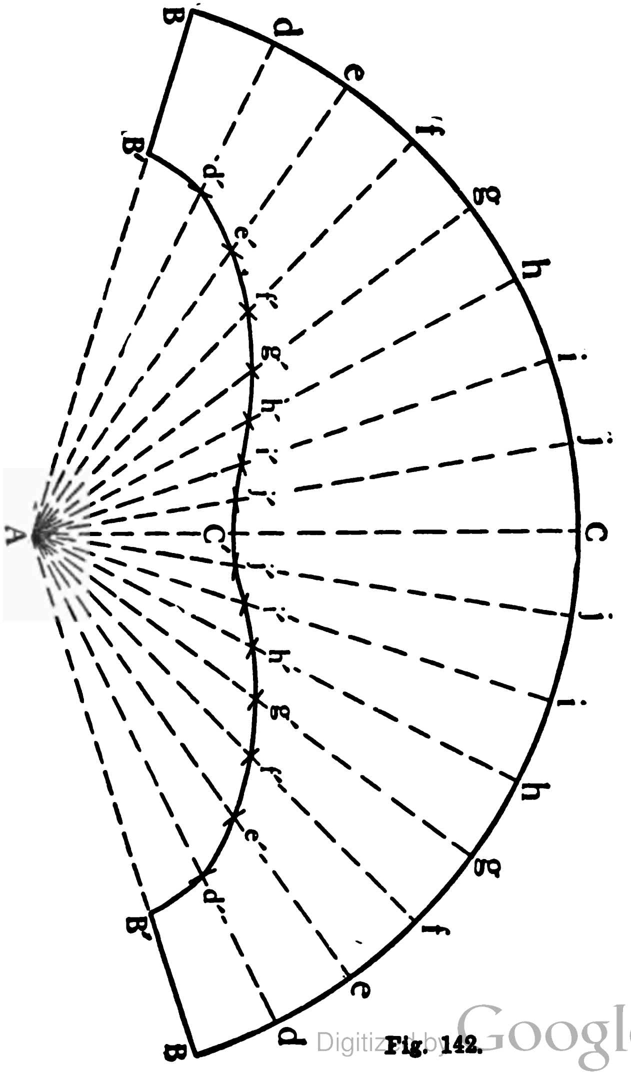


Fig. 142.

d, e, f, g, h, i, j, and draw lines from these points to the apex at **A.** They will cut the diagonal **b-b** at **d′e′f′g′h′i′j′**, then carry horizontal lines from these points to meet the slant edge **B′A** in **d″, e″, f″, g″, h″, i″, j″**. Then the lengths **Bd″, Be″, Bf″, Bg″, Bh″, Bi″, Bj″**, will be the actual lengths of the lines **dd′, ee′, ff′ gg′, hh′, ii″, jj″** in Fig. 142. To describe the pattern take the length **AB** as a radius and strike an arc of a circle as **ABCD.** From the point **C** set off to the right and left the points **J, I, H, G, F, E, D, B,** using the lengths of the points of division in Fig. 141. Draw lines from the points of division to **A.** On these lines set off the projected lengths from Fig. 141, thus: Take the length **CC′** and set off from **C to C′** in Fig. 142. Take the length from **B** to **j′** and set it off from **j** to **j′** in Fig. 142. Take the length **B** to **i″** and set it off from **i** to **i′**, and so on. A curve drawn through the points **c′, j′, i′, h′, g′, f′, e′,** and **d′** to right and left will give the shape of the development.

To develop the intersection of a round elbow at right angles. Draw **ABCFED**, which is the size of the elbow required. On the line **CF**, Fig. 143, strike a semicircle of the same diameter as the pipe. Divide the semicircle into any number of equal parts as **a, b, c, d, e**. Draw the line **FF** in Fig. 144, and make it equal to twice the length of the circumference of the semicircle in Fig. 143, by setting the parts **a, b, c, d, e** from **C** to **F** and **F** on each side, and draw the perpendicular line **Fn, em, dl, ck, bi, ah, Cg**. Extend the line **BC** to cut the perpendicular **Cg**, and draw lines from the points **a, b, c, d,** and **e** in the semicircle to cut the perpendiculars at **h, i, k, l,** and **m**. Draw a curve through all the points of intersection, as **n, m, l, k, i, h,** and **g**. This will form the curve for half of the development.

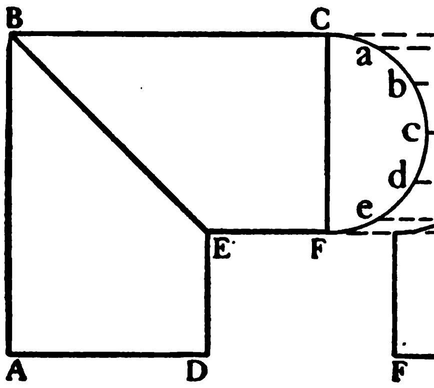


Fig. 143.

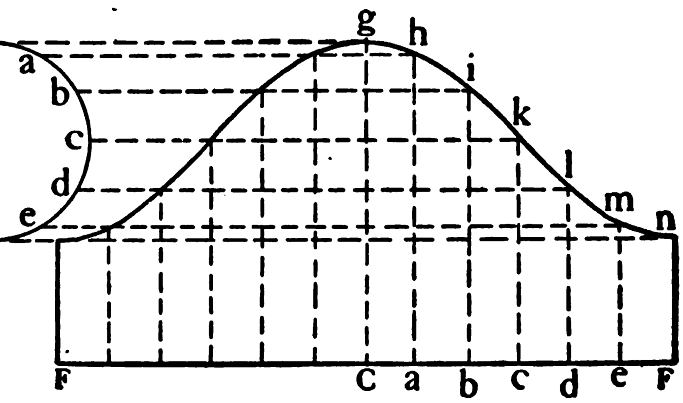


Fig. 144.

To develop the intersection of two pipes which

intersect at an angle. Let **DAEC** represent the larger pipe, and let **HFJG** be drawn to the required size of the pipe that is to be connected with it at any desired angle. Draw the line **FG**, Fig. 145, at right angles with **FH**, on **FG** describe a semicircle, and divide into any number of equal parts, as 1, 2, 3, 4, 5, draw lines through these points at right angles with **FH**. Then describe a semicircle **ABC** representing the diameter of the larger pipe, and extend the line **DA** to **M** and **CA** to **L**, take the radius **OF** of the smaller semicircle and from **A** mark off the same distance to **M**, then take the half length of the base of the smaller pipe as **K** to **H** or **H** to **J** and mark off a like distance from **A** to **L**. A quarter of an ellipse is required as shown from **L** to **M**, the radius of which may be obtained in the following manner: Draw a line from **M** to **N**, also one from **L** to **N** at right angles, and draw the diagonal line **LM**; draw a line from the point **N** to cut the diagonal **LM** at right angles, producing the points **c** and **b**. With **c** as a center and radius **cL** draw a curve from **L** to **a**. With **b** as a center and radius **ba**, draw the remainder of the curve from **a** to **M**. Divide the curve from **L** to **M** into three equal parts, and then draw perpendicular lines from these points to intersect the semicircle **ABC**, as **df**, **eg**, **Mh**. Draw lines parallel to **AD** from **f** to **i**, **g** to **k**, and **h** to **l**. The points where these lines are intersected by the lines drawn from the semicircle on the smaller cylinder will be the points through which to draw the curve **r**, **s**, **t**, **w**, **v**. Draw the line **GG**, Fig. 146, equal to the circumference of the smaller pipe, or to twice the number of divisions in the small semicircle. Divide one-half of **GG** into six equal parts, as **Fm**, **mn**, **no**, **op**, **pq**, and **qG**. Draw perpendicular lines from **F**, **m**, **n**, **o**, **p**, **q**, and **G**. Take the length of the lines in

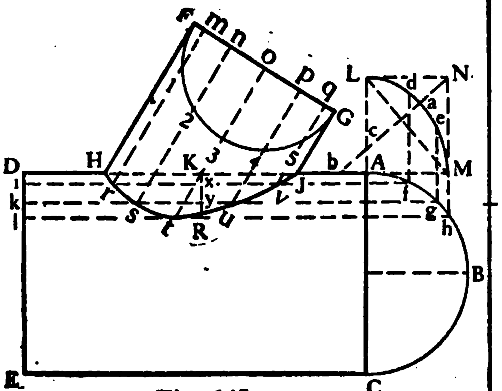


Fig. 145.

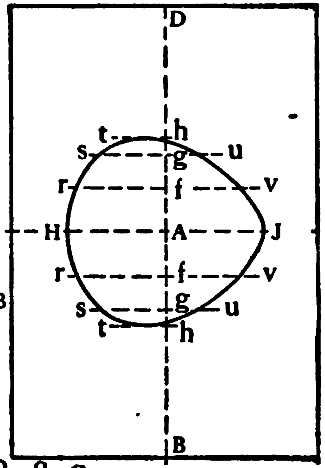


Fig. 147.

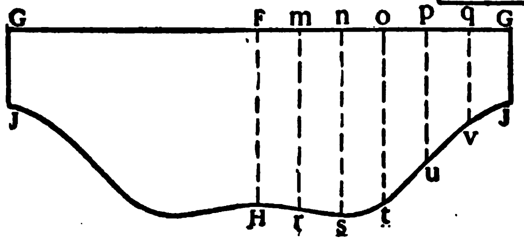


Fig. 146.

Fig. 145, as **FH**, **mr**, **ns**, **ot**, **pu**, **qv**, and **GJ**, and transfer their lengths to the perpendicular lines marked by corresponding letters. Draw a curve through the points thus obtained as **H**, **r**, **s**, **t**, **w**, **v**, and **J**. This will give the half-pattern for the

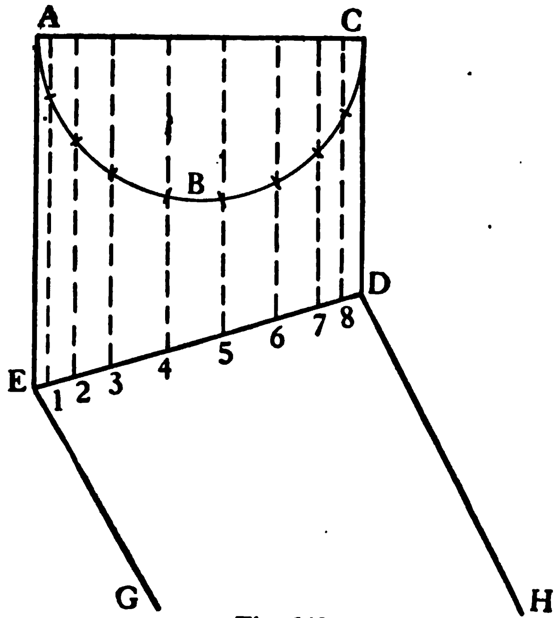


Fig. 148.

smaller pipe. To obtain the curve for the hole in the large pipe. Draw **DB** and **HJ**, Fig. 147, at right angles, take the distances in Fig. 145, from **A** to **f**, **g** and **h**, and mark off like distances on each side of **A** in Fig. 147 on the line **DB**, as **f**, **g**, and **h**, and draw lines from these points parallel to **HJ**. Draw a perpendicular line from the point **K** to **R** in Fig. 145, and transfer the lengths **KH** and **KJ**, from **A** to **H** and **A** to **J** in Fig. 147, also the distances **xr** and **xv** from **f** to **r** and **f** to **v** in Fig. 147, and the distances **y** to **s** and **y** to **u**, from **g** to **s**

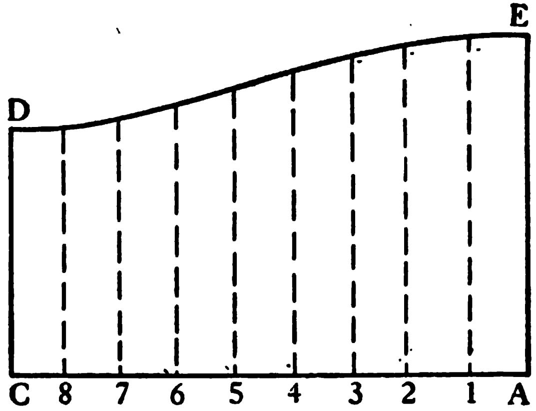


Fig. 149.

and **g** to **u**. Take the distance from **R** to **t** in Fig. 145 and mark off from **h** to **t** in Fig. 147. The curve drawn through these points will give the shape of the opening in the larger pipe.

To develop an intersection for a joint at any angle in a circular pipe. Let **ABC**, Fig. 148, be the half diameter of the pipe. Draw the line **AC** and the lines **EG** and **DH**, then draw the line **ED**, cutting the lines at the points **E** and **D**. Divide the circumference of the semicircle **ABC** into any number of equal parts, and from these points draw lines parallel to **AF**, as **1, 2, 3, 4, 5, 6, 7**, and **8**. Then lay off the line **AC**, Fig. 149, equal in length to the circumference of the semicircle **ABC**. Erect the lines **AE** and **CD** at right angles to **AC**, and then lay off on the line **AC** the same number of spaces as on the circumference of the semicircle **ABC**, and from these points draw lines parallel to **AE**, as **1, 2, 3, 4, 5, 6, 7**, and **8**. Make **AE** equal to **AE** in Fig. 148 and **CD** to **CD** in the same figure, also each of the parallel lines bearing the numbers **1, 2, 3, 4, 5, 6, 7**, and **8**. A curve drawn through these points will give the shape of the half intersection.

Line Shading. When it is necessary to suggest the character of a surface without a second view, line shading may be used. Fig. 150 illustrates a good method for the shading of a cylindrical surface. The lines may be equally spaced, although the appearance is somewhat improved by

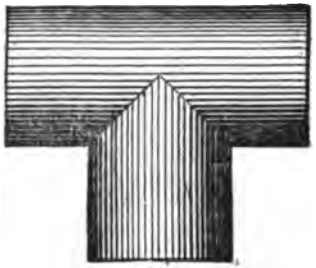


Fig. 150.

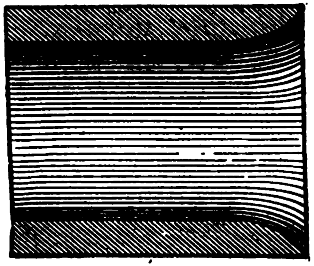


Fig. 151.

increasing the space as the center line is approached, and decreasing the space on the lower half, while increasing the width of the line. In shading a concave surface, as in Fig. 151, the operation is reversed. Spherical, and other classes of surfaces may be represented by this method as in Fig. 152, but the rendering of them requires considerable skill, and it is beyond the scope of this work to consider the various methods.

Sections. It is frequently necessary to make the representation of an object as it would appear if cut by a plane, and with the portion nearer the observer removed. This cut section is indicated by a series of parallel lines, usually drawn at an

Fig. 152.

angle of 45°. The width of the lines is the same as a fine line, and the distance between the lines is determined by the area and intricacy of the section. These lines are not to be drawn in pencil, but only in ink. An instrument known as a section liner is designed to insure accuracy in the spacing, but the draftsman should learn to judge this by the eye. In doing so, care must be used to avoid making too small a space, and it is desirable to try the spacing on a separate sheet before sectioning the drawing. A greater degree of uniformity may be obtained by looking back after drawing every three or four lines.

The different surfaces in the plane of the section are indicated by changing the direction of the

Section Lining or Brass Hatching Shown in Fig. 153.

A	B	C	D	E	F
Cast Iron.	W. Iron.	C. Steel.	W. Steel.	T. Steel.	Brass.
G	H	I	J	K	L
Copper.	Lead or Babbitt.	Aluminum.	Rubber or Vulcanite.	Leather.	Asbestos.
M	N	O	P	Q	R
Wood.	Brick.	Stone.	Glass.	Earth.	Liquid.

lines. Seven distinct surfaces may be shown by changing the direction and angle of the section lines.

Differences in the material are also indicated by the character of the lines, but there is no general agreement as to notation. Fig. 153 illustrates eighteen types of sectioning, together with the names of the materials which are indicated by

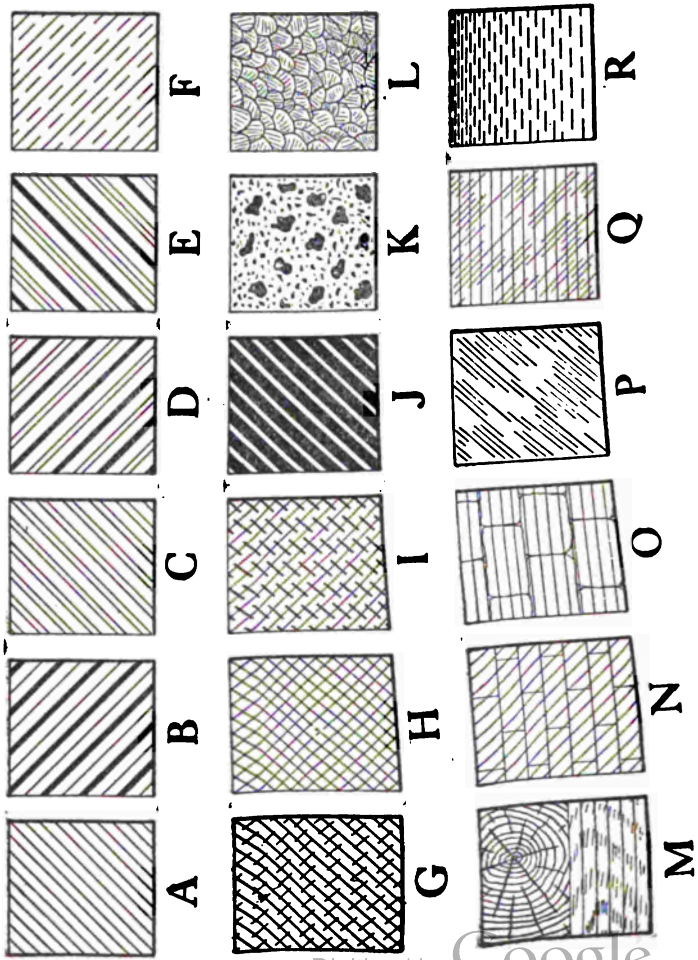


Fig. 153.

them. Whenever figures or notes occur in a section, the section lines should not be drawn across them.

Instructions for Inking. Never begin the inking of a drawing until the pencilling is completed. Always ink the circles and circular arcs first, beginning with the small arcs. If the drawing is to have shade lines, shade each arc as drawn. To omit the shading of circles until they have first been inked in fine lines will necessitate almost double the time otherwise required. It should be observed that the width of both fine and heavy lines is determined by the shading of the first circular arc. Next, ink all the full and dotted straight lines. Begin on the upper side of the sheet and ink all the fine horizontal lines, omitting those lines which are to be shaded. Next, ink the vertical lines, beginning with those at the left. Do not dwell too long at the end of a line, especially if it be a heavy one, as the pressure of the ink in the pen will tend to widen the line. If a series of lines radiate from a point, allow sufficient time for the drying of each line, otherwise a blot may be made. Ink all lines at other angles and those curved lines requiring the use of curves. The same order is to be followed in the inking of the shade lines, evenness being secured by ruling them at one time. Draw the section lines and ink the center and the dimension lines, and put on the figures and notes.

Tracings. When it is desired to reproduce a drawing, tracing cloth is placed above the original and the lines of the drawing traced on the new surface, as though one were inking a pencilled drawing. Tracing cloth is usually furnished with one surface glazed and the other dull. Either side may be used, but it is difficult to erase from the dull side. Pencilling must be done on the dull surface. Tracing cloth is used frequently in place of paper for original drawings, the pencilled drawing being traced on the cloth in ink.

As the cloth absorbs moisture quite rapidly, it shrinks and swells under varying atmospheric conditions. Because of this, large drawings which require considerable time to complete, should be inked in sections, as the cloth will require frequent adjustment in order that its surface may be smooth and in contact with the paper drawing. Only the best quality of cloth should be used, as the cheaper kinds are improperly sized and absorb ink, causing blots. If the ink fails to run freely on the cloth, dust on the surface a little finely powdered pumice stone or chalk, rubbing it lightly across the surface with a piece of chamois skin or cloth.

Inked lines may be removed from the cloth by means of a sharp knife and an ink eraser, or by dusting a little finely powdered pumice stone on the lines to be erased, and briskly rubbing them with the end of the finger or a piece of rubber. As the pumice becomes discolored replace it with

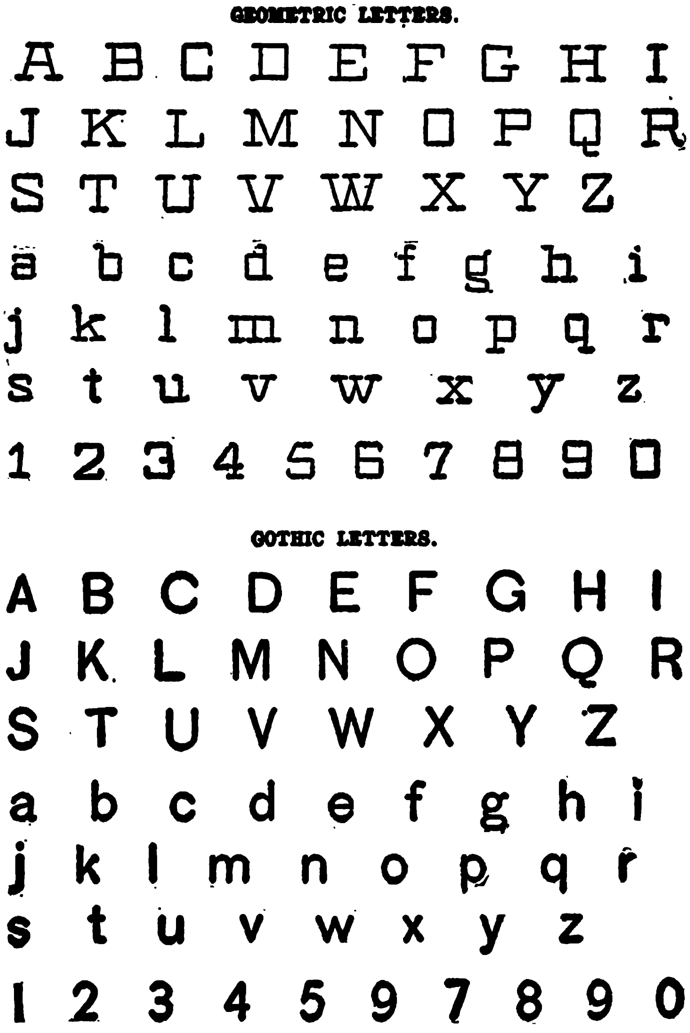


Fig. 154.

fresh powder. Pencilled lines may be removed by the ordinary pencil eraser, or by means of a cloth moistened with benzine.

Lettering. The subject of lettering is of such importance to the draftsman that he should adopt some clear type for general use, and acquire proficiency in the free-hand rendering of it. While at times it may be necessary to make use of instruments and mechanical aids for the construction of letters and figures, usually they may be written free-hand.

The accompanying alphabets shown in Fig. 154, will be acceptable in the regular practice of drafting. Their study will afford an excellent exercise, as well as skill in the figuring and lettering of drawings. Both types should be written with the aid of instruments. The first is known as the geometric, and the second as the Gothic. Large and small capitals may be used in the place of capitals and lower case, as illustrated. The small capitals and lower case may be made about two-thirds the height of the initial letters.

Round writing is also shown in Fig. 155, pens for executing this style of writing and lettering may be purchased at any drawing material dealer's store.

Instructions for Pencilling. Pencilling is a prerequisite to inking. Of first importance is the sharpening of a pencil, and as it wears away rapidly it must be sharpened frequently.

The pencil should be held vertical, or nearly so, the arm free from the body, and the flat edge of the chisel point lightly touching the straight-edge. Do not attempt to draw with the pencil point in the angle made by the paper and the edge of the blade or straight-edge. Draw from left to right or from bottom to top of board. In general, lines are drawn from the body, the draftsman facing the board when drawing horizontal lines, and having his right side to the board when drawing long vertical lines. For the drawing of other lines the position of the draftsman should be such as to enable him to draw at ease, having a free-arm movement, even though it be necessary to draw from the opposite side of the board.

Fig. 155.

Economize in the drawing of lines by omitting such portions as may be unnecessary. Lines, which should be dotted when inking, may frequently be pencilled in full.

Dimensioning. To dimension a drawing is to place upon it all measurements of the object represented, so that the workman may construct the object from the given measurements.

In order to be easily read the dimensions should be so placed as not to crowd or interfere with each other or with the lines of the drawing, and the figures must be neatly made, poor figures will spoil the appearance of the best drawing.

Dimensions should be placed upon dimension lines which, by means of arrow-heads at each end, indicate the position of the dimension. These lines should not be continuous, a space being left to receive the figures, which should be symmetrically placed upon the line. The line may be omitted when the space between the arrow-heads is short, and when there is not room for both arrow-heads and dimension, the arrow-heads may be turned in the direction of the measurement and placed outside the line.

When there is not room even for the dimension, arrow-heads may be used either outside or inside the dimension lines, and the dimension placed where there is room for it.

Arrow-heads and figures should be drawn free-hand, when the drawing is inked they should be drawn with a common writing pen and with black ink, while the dimension lines should be red. The line separating the figures indicating the fraction must be parallel to the dimension line.

Vertical dimensions should always be placed so as to read right-handed.

The dimensions may be placed upon the drawing when there is room, but when the space is small it is better to carry the dimension outside the drawing by means of dot and dash lines.

The space between the different views is often the best position for many of the dimensions.

When an object is divided into different parts and the lengths are given in detail, an over-all dimension should be given.

Dimensions should not be placed upon center lines.

Distances between centers of all parts, such as rods, bolts, or any evenly spaced parts, should be given, and when the parts are arranged in a circle, the diameter of the circle passing through their centers should be given.

The diameter of a circle and the radius of an arc should be given. The center of an arc, when not otherwise shown, should be marked by a small circle placed about it, and used instead of an arrow-head. The dimension line should begin at this small circle.

Dimensions should be clearly given in some one view, and not repeated in other views, they should seldom be placed between a full and a dotted line, or between dotted lines when they can be placed in a view where the part is represented by full lines.

Simple objects, circular in section, are often shown by only one view.

When several pieces are alike, only one is drawn, and the number to be made is expressed by lettering.

When parts are to be fitted together, it is customary to write whether the fit is to be tight or loose.

Working Drawings. A good working drawing should be prepared in the following manner: It must first be carefully outlined in pencil and then inked in. After this all parts cut by planes of section should be cross hatched, the cross hatching used indicating the materials of which the parts are made. The center lines are now inked in with red ink. The red ink may be prepared by rubbing down a cake of crimson lake. Next come the distance or dimension lines, which should be put in with red ink. The arrow-heads at the ends of the dimension lines are now put in with black ink, and so are the figures for the dimensions.

The arrow-heads and the figures should be made with a common writing pen. The dimensions should be put on neatly. Many a good drawing has its appearance spoiled through being slovenly dimensioned.

Here may be pointed out the importance of putting the dimensions on a working drawing. If the drawing is not dimensioned, the workman must get his sizes from the drawing by applying his rule or a suitable scale. Now this operation takes time, and is very liable to result in error. Time is therefore saved, and the chance of error reduced, by marking the sizes in figures.

Tinting. A drawing is colored or tinted for the purpose of making clear the divisions, as in map drawing, to indicate the character of the surface, whether plane or curved, and possibly its relation to other surfaces by the casting of shadows, or to designate the materials used.

The paper should be of proper quality, such as Whatman's cold pressed, and must be stretched by wetting the surface and glueing it to the board in the following manner: Having laid the paper on a flat surface, fold over about one-half inch of each edge. Thoroughly wet all the paper except folded edges, using a soft sponge for this purpose, but do not rub the surface of the paper. Next apply mucilage, strong paste, or a light glue, to the underside of the folded portion and press this to the board with a slight outward pressure so as to bring the surface of the paper close to the board. As the glue should set before the paper begins to dry and shrink, it is necessary to have the paper very wet, but no puddles must be allowed to remain on the surface after the edge is glued. The paper must be allowed to dry gradually in a perfectly horizontal position, as otherwise the water would tend to moisten the lower edge and prevent the drying of the glue. If the paper should dry too rapidly, not allowing sufficient time for the glue to set, the surface may be moistened again.

The color employed in making the wash may be a water color or ground India ink, but none of the prepared liquid inks are suitable for the purpose. The color should be very light, and when the desired shade is to be dark it should be obtained by applying several washes, allowing sufficient time for each to dry. The color must be free from sediment, but since some deposit is liable to take place, the brush should be dipped in the clear portion only, and not allowed to touch the bottom of the saucer.

The brush should be of good size, depending somewhat on the surface to be covered, and of such quality that when filled with the color or water, it will have a good point.

Two classes of tinting are employed, the flat tint of uniform shade, and the graded tint for the representation of inclined or curved surfaces.

Remove all pencilled lines which are not to be a part of the finished drawing, and do all the necessary cleaning of the surface, using the greatest care not to roughen the paper. Inking should be done after the tinting, but if for any reason it is necessary to ink the drawing first, a waterproof ink must be used.

In putting on the color, slightly incline the board to permit of the downward flow of the liquid, and, beginning at the upper portion of the drawing, pass lightly from left to right, using care just to touch the outline with the color, but not to overrun, and making a somewhat narrow horizontal band of color. Advance the color by successive bands, the brush just touching the lower edge of the pool of water made by the preceding wash. This lower edge should never be allowed to dry, as it would cause a streak to be made in the tinted surface. Having reached the lower edge, use less water in the brush so as to enable a better contact to be made with the outline. Finally dry the brush by squeezing it or touching it to a piece of blotting paper. It may then be used to absorb the small pool of color at the bottom edge or corner.

Avoid touching the tinted surface until it is dry, at which time any corrections that are necessary may be made by stippling. This consists in using a comparatively dry brush and cross hatching the surface to be corrected.

If the surface to be covered is large, it is desirable to apply a wash of clear water before applying the color. This dampened surface will prevent the quick drying of the color and insure a more even tint. When necessary to remove the tint from a surface, use a sponge with plenty of clean water, and by repeated wettings absorb the color, but do not rub the surface of the paper.

A graded tint may be applied by several methods, the simplest being to divide the surface into narrow bands and apply successive washes, each covering an additional band. If the tint is sufficiently light, and the bands narrow, the division line between the bands will not be very noticeable, but this may be lessened by the softening of the edges with a comparatively dry brush and clean water.

Another method, which requires considerable dexterity, is to put on a narrow band of the darkest tint that may be required, and, instead of removing the surplus water from the edge, touch the brush to some clean water and with this lighter tint continue the wash over the second band. Continue in this manner until the entire surface is covered.

Making Blue Prints. To make good blue prints, being guided only by the appearance of the exposed edge of sensitized paper, requires considerable experience. Very often, especially on a cloudy day, the edge looks just about right, but when taken out of the frame and given a rinsing, it is only to find that the print looks pale because it should have been allowed to remain exposed for a longer period.

Take a small test-piece of the same paper, about 4 inches square, and a piece of tracing cloth with several lines on its surface and lay these small pieces out at the same time the real print is being exposed, and cover these samples with a piece of glass about 4 inches square. As a general rule, a place can be found on top of the frame for the testing-piece, and by having a small dish of water at hand for testing the print by tearing off a small bit and washing same to note its appearance, the novice can get just as good results as the experienced hand and without much danger of failure.

When several prints are to be made the second one may be placed into the frame while the first one is soaking, when the print is properly soaked, say about ten minutes, lift it slowly out of the water by grasping two of its opposite corners; immerse again and pull out as before. This is to be continued until the paper does not change to a deeper blue color. Hang the paper on the rack by two of its corners to dry. In case any spots appear it is an indication that the prints were not properly washed.

When corrections or additions are to be made to a blue print a special chemical preparation must be used to make white lines. A solution of bicarbonate of soda and water is generally used for this purpose. When white lines or figures are to be obliterated a blue pencil may be used to cover same.

The solution used for ordinary blue printing is made according to the following receipt:

One ounce of red prussiate of potash dissolved in 5 ounces of water.

One ounce of citrate of iron and ammonia dissolved in 5 ounces of water.

Keep the solution separate in dark colored bottles in a dark place not exposed to the light. To prepare the paper, mix equal portions of the two solutions and be careful that the mixtures are not longer exposed to the light than is necessary to see by. It is, therefore, a necessity to perform this work in a dark room, provided with a trough of some kind to hold water, this should be larger than the blue print and from six to eight inches deep, a flat board should be provided to cover this trough, there should also be an arrangement like a towel rack to hang the paper on while drying. The sheets should be cut in such a manner as to be a little larger than the tracing, in order to leave an edge around it when the tracing is placed upon it. From ten to twelve sheets are placed upon a flat board, care must be taken to spread them flat one above another, so that the edges are all even. The sheets should be secured to the board by a small nail through the two upper corners, strong enough to hold the weight of the sheets when the board is placed vertically.

Place the board on the edges of the trough with one edge against the wall and the board somewhat inclined, only as much light as is absolutely required should be obtained from a lamp or gas jet, turned down very low. The solution referred to above should be applied evenly with a wide brush or a fine sponge over the top sheet of paper. When the top sheet is finished remove it from the board by pulling at the bottom of same and tearing it from the nail which holds it, place the sheet in a drawer where it can lie flat and where it cannot be reached by the light.

Treat the remaining sheets in the same way as the first one.

The draftsman should not as a rule be content with simply reproducing the views shown in the different examples given, to the dimensions marked on them, but should lay out other views and cross sections. The great importance of the value of being able to make intelligible free hand sketches of machine details cannot be overestimated, the draftsman should practice this art, not only from the illustrations given herewith, but from actual machine details. Fully dimensioned free hand sketches of actual machines or their details, form excellent examples for drawing practice. All such sketches should be made in a book kept for the purpose, always putting in the dimensions where possible. The description of the various applications of the mechanical powers hereinbefore given is more for reference than for the purpose of teaching these principles. As machine drawing is simply the application of the principles of geometry to the representation of machines, if the draftsman or student is not already familiar with the study of geometry, he should make himself acquainted with the problems given in this work, before going further.

U. S. Standard Hexagonal Bolt-head and Nut. Two types of head and nut are illustrated, the rounded or spherical, and the chamfered or conical, as shown in Fig. 156. Three dimensions are fixed by this standard: First, the distance across the flats or short diameter, commonly indicated by H, and equal to one and one-half times the diameter of the bolt plus one-eighth of an inch, second, the thickness of the head, which is equal to one-half its short diameter, third, the thickness of the nut, which is equal to the diameter of the bolt.

Example 1: Hexagonal head bolt and nut. Draw the views of the bolts and nuts as shown in Fig. 156, for bolts 4 inches long under head and 1 inch diameter. Scale—Full size.

Cast iron flange coupling. In the kind of coupling shown in Fig. 157 a cast iron center or boss provided with a flange is secured to the end of each shaft by a sunk key driven from the face of the flange. These flanges are then connected by bolts and nuts.

To ensure the shafts being in line the end of one projects into the flange of the other.

In order that the face of each flange may be exactly perpendicular to the axis of the shaft they should be faced in the lathe, after being keyed on to the shaft.

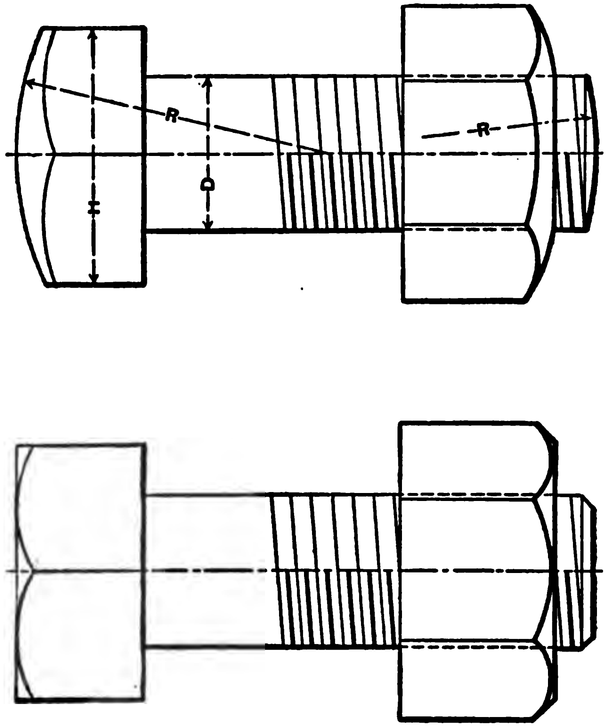


Fig. 156—Hexagonal-head Bolt and Nut.

If the coupling is in an exposed position, where the nuts and bolt-heads would be liable to catch the clothes of workmen or an idle driving band which might come in the way, the flanges should be made thicker, and be provided with recesses for the nuts and bolt-heads.

DIMENSIONS OF CAST-IRON FLANGE COUPLINGS.

Diameter of shaft D	Diameter of flange F	Thickness of flange T	Diameter of boss B	Depth at boss L	Number of bolts	Diameter of bolts d	Diameter of bolt circle C
1½	7¼	⅞	3½	2⅝	3	⅝	5½
2	8⅞	1 1/16	4⅜	3 3/16	4	¾	6¾
2½	10⅝	1¼	5 5/16	3¾	4	⅞	8⅛
3	12⅜	1 7/16	6¼	4 5/16	4	1	9½
3½	13⅛	1⅝	7⅛	4⅞	4	1	10 5/16
4	14	1¾	8	5 7/16	6	1	11¼
4½	15⅝	2	8⅞	6	6	1⅛	12½
5	17⅜	2⅛	9 13/16	6⅝	6	1¼	13 13/16
5½	18¼	2 5/16	10¾	7¼	6	1¼	14¾
6	19⅞	2½	11⅝	7¾	6	1⅜	16

The projection of the shaft p varies from ¼ inch in the small shafts to ½ inch in the large ones.

Example 2. Cast-iron Flange Coupling. Draw the views shown in Fig. 157 of a cast-iron flange coupling, for a shaft 5 inches in diameter, to the dimensions given in the above table. Scale—3 inches to 1 foot.

Proportions of Rivet Heads. The diameter of the snap head is about 1.7 times the diameter of the rivet, and its height about .6 of the diameter of the rivet. The conical head has a diameter twice and a height three quarters of the rivet diameter. The greatest diameter of the oval head is about

1.6, and its height .7 of the rivet diameter. The greatest diameter of the countersunk head may be

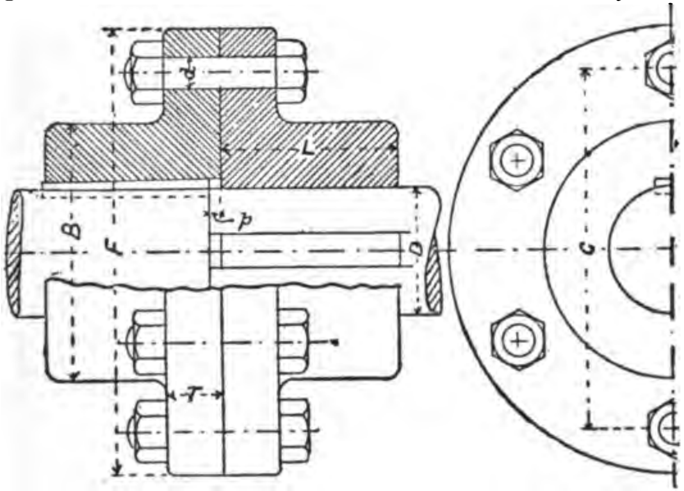


Fig. 157—Cast-iron Flange Coupling.

one and a half, and its depth a half of the diameter of the rivet.

TABLE SHOWING THE PROPORTIONS OF SINGLE RIVETED LAP JOINTS FOR VARIOUS THICKNESSES OF PLATES.

Thickness of plates.	5/16	3/8	7/16	1/2	5/16	5/8	11/16
Diam. of rivets	5/8	3/4	7/8	15/16	1	1 1/16	1 1/8
Pitch of rivets	1 7/16	1 11/16	2	2 1/16	2 1/8	2 1/4	2 3/8

Distance from center of rivets to edge of plate – 1½ times diameter of rivets.

Example 3. Single-riveted butt Joints. In Fig. 158 are shown two forms of single riveted butt joints. One of the sectional views shows a butt joint with one splice plate, the other sectional view shows a joint with two splice plates. The plan view shows both arrangements. Draw all these views full size.

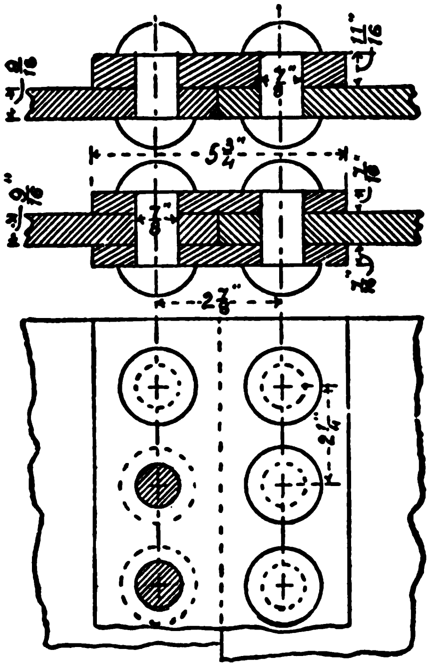


Fig. 158—Single Riveted Butt Joints.

Example 4. Corner of Wrought-iron Tank. This exercise is to illustrate the connection of plates which are at right angles to one another by means of angle irons. Fig. 159 is a plan and elevation of the corner of a wrought-iron tank. The sides of the tank are riveted to a vertical angle iron, the cross section of which is clearly shown in the plan. Another angle iron of the same dimensions is used in the same way to connect the sides with the bottom. The sides do not come quite up to the corner of the vertical angle iron, excepting at the bottom where the horizontal angle iron comes in.

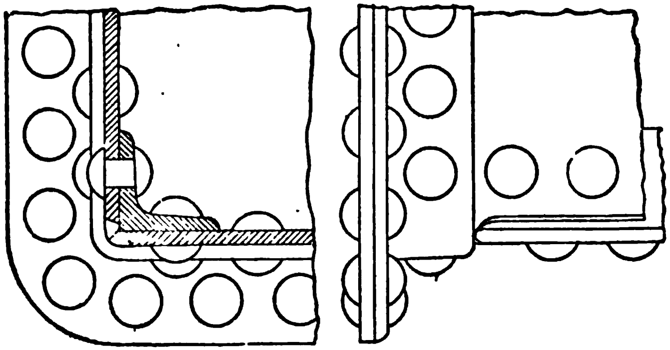


Fig. 159—Corner of Wrought-iron Tank.

At this point the vertical plates meet one another, and the edge formed is rounded over to fit the interior of the bend of the horizontal angle iron so as to make the joint tight. Draw this example half size.

The dimensions are as follows: angle irons 2½ inches×2½ inches×⅜ inch, plates ⅜ inch thick, rivets ¾ inch diameter and 2 inches pitch.

Example 5. Gusset Stay. In order that the flat ends of a steam boiler may not be bulged out by the pressure of the steam they are strengthened by means of stays. One form of boiler stay, called a gusset stay, is shown in Fig. 160. This stay consists of a strip of wrought-iron plate which passes

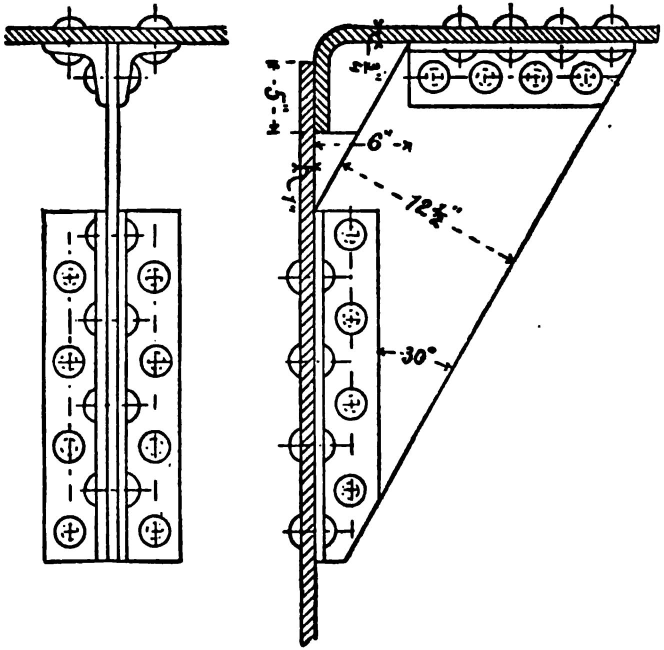


Fig. 160—Gusset Stays.

in a diagonal direction from the flat end of the boiler to the cylindrical shell. One end of this plate is placed between and riveted to two angle irons which are riveted to the shell of the boiler.

A similar arrangement connects the other end of the stay plate to the flat end of the boiler. In this example the stay or gusset plate is ¾ of an inch thick, the angle irons are 4 inches broad and ½ inch thick. The rivets are 1 inch in diameter. The same figure also illustrates the most common method of connecting the ends of a boiler to the shell. The end plates are flanged or bent over at

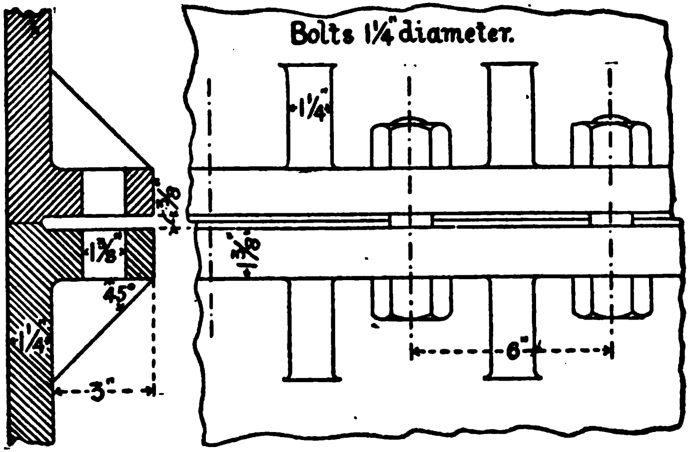


Fig. 161—Flanged Joint for Cast-iron Plates.

right angles and riveted to the shell as shown. The radius of the inside curve at the angle of the flange is 1¼ inches. Draw this example to a scale of 3 inches to 1 foot.

Example 6. Flanged Joint for Cast-iron Plates. Draw the views shown in Fig. 161. Draw also a plan. The bolts and nuts must be shown in each view. The holes for the bolts are square, and the bolts have square necks. Draw this example half full size.

Pillow Block. One form of pillow block is shown in Fig. 162. A is the block proper, B the sole-plate through which pass the holding down bolts. C is the cap. Between the block and the cap, is the brass bushing which is in halves.

In the block illustrated the journal is lubricated by a needle lubricator, this consists of an inverted glass bottle fitted with a wood stopper, through a hole in which passes a piece of wire, which has one end in the oil within the bottle, and the other resting on the journal of the shaft. The wire or needle does not fill the hole in the stopper, but if the needle is kept from vibrating the oil does not escape owing to capillary attraction. When, however, the shaft rotates, the needle begins to vibrate, and the oil runs down slowly on to the journal, oil is therefore only used when the shaft is running.

Example 7. Pillow Block for a Four-inch Shaft. Draw the views shown of this block in Fig. 162. Scale 6 inches to 1 foot.

Proportions of Pillow Blocks. The following rules may be used for proportioning pillow blocks for shafts up to 8 inches diameter. It should be remembered that the proportions used by different

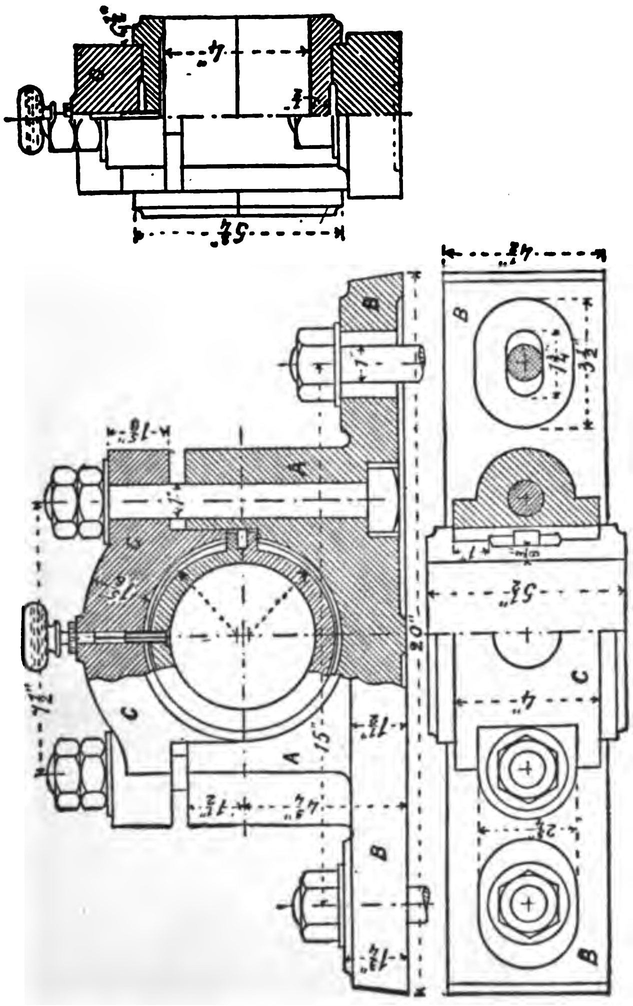


Fig. 162—Pillow Block with Brass Bushing.

makers vary considerably, but the following rules represent average practice:

Diameter of journal	$=d$
Length of journal	$=l$
Height to centre	$=1.05d+.5$
Length of base	$=3.6d+5$
Width of base	$=.8l$
" block	$=.7l$
Thickness of base	$=.3d+.3$
" cap	$=.3d+.4$
Diameter of bolts	$=.25d+.25$
Distance between centres of cap bolts	$=1.6d+1.5$
" " " base bolts	$=2.7d+4.2$
Thickness of step at bottom. . .	$=t=$ 09$d+.15$
" " sides . .	$=\frac{3}{4}t$

The length of the journal varies very much in different cases, and depends upon the speed of the shaft, the load which it carries, the workmanship of the journal and bearing, and the method of lubrication. For ordinary shafting one rule is to make l=d+1. Some makers use the rule l=1.5d, others make l=2d.

Example 8. Sole Plate for a Pillow Block. Draw the views for a sole plate for a pillow block as shown in Fig. 163. Draw also an end elevation. Scale—Half size.

Example 9. Bracket for Pillow Block. Draw the side and end elevations shown in Fig. 164, and from the side elevation project a plan. Scale—Half size.

Example 10. Wall Bracket and Bearing. Draw the side and end elevation partly in section as shown in Fig. 165, and project a complete plan below. Scale—Half size.

Pulleys. Let two pulleys A and B be connected by a belt, and let their diameters be D_1 and D_2; and let their speeds, in revolutions per minute, be N_1 and N_2 respectively. If there is no slipping,

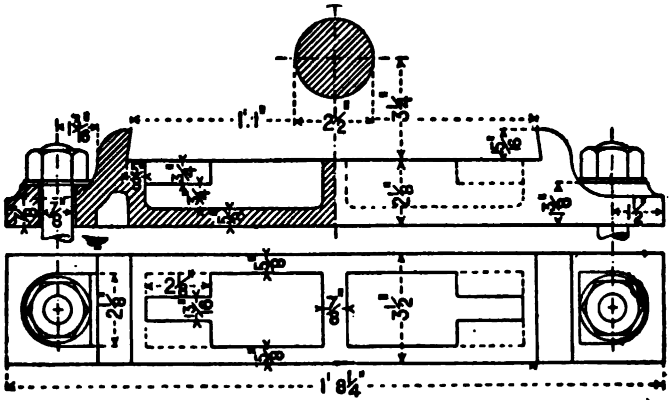


Fig. 163—Sole Plate for a Pillow Block.

the speeds of the rims of the pulleys will be the same as that of the belt, and will therefore be equal. Now the speed of the rim of A is evidently $=D_1 \times 3.1416 \times N_1$, while the speed of the rim of B is $=D_2 \times 3.1416 \times N_2$. Hence $D_1 \times 3.1416 \times N_1 = D_2 \times 3\ 1416 \times N_2$, and therefore

$$\frac{N_1}{N_2} = \frac{D_2}{D_1}.$$

Pulleys for Flat Belts. In cross section the rim of a pulley for carrying a flat belt is generally curved as shown in Fig. 166, but very often the cross section is straight. The curved cross section of the rim tends to keep the belt from coming off as long as the pulley is rotating. Sometimes the

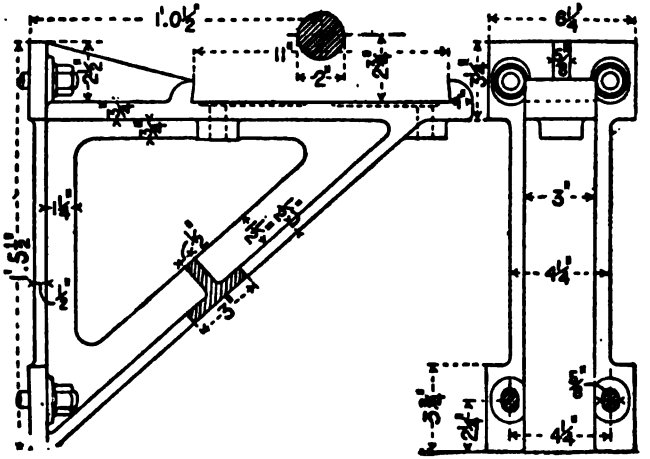


Fig. 164—Bracket for a Pillow Block.

rim of the pulley is provided with flanges which keep the belt from falling off.

Pulleys are generally made entirely of cast iron, but a great many pulleys are now made in which the center or hub only is of cast iron, the arms being of wrought iron cast into the hub, while the rim is of sheet iron.

The arms of pulleys when made of wrought iron are invariably straight, but when made of cast iron they are very often curved. In Fig. 166 which shows an arrangement of two cast-iron pulleys, the arms are straight. Through unequal cooling, and therefore unequal contraction of a cast-iron pulley in the mould, the arms are generally in a state of

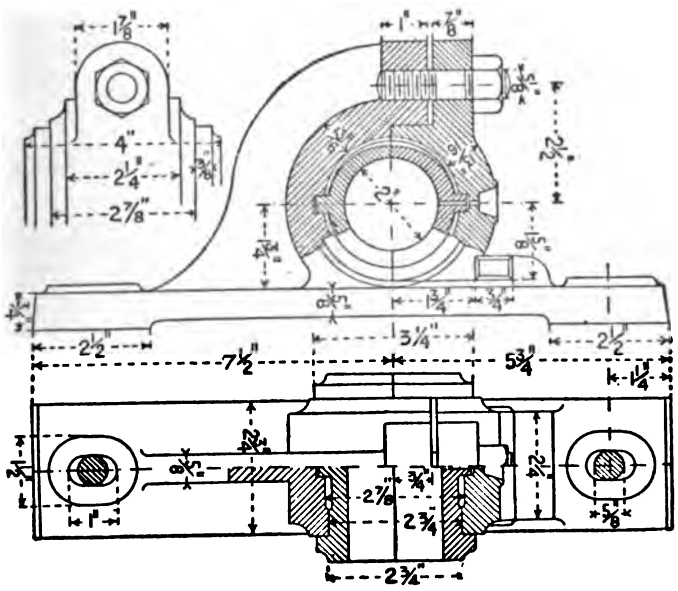


Fig. 165—Wall-bracket and Bearing.

tension or compression, and if the arms are straight they are very unyielding, so that the result of this initial stress is often the breaking of an arm, or of the rim where it joins an arm. With the curved arm, however, its shape permits it to yield, and thus cause a diminution of the stress due to unequal contraction.

The cross section of the arms of cast-iron pulleys is generally elliptical.

Example 11. Tight and Loose Pulleys. Fig. 166 shows an arrangement of tight and loose pul-

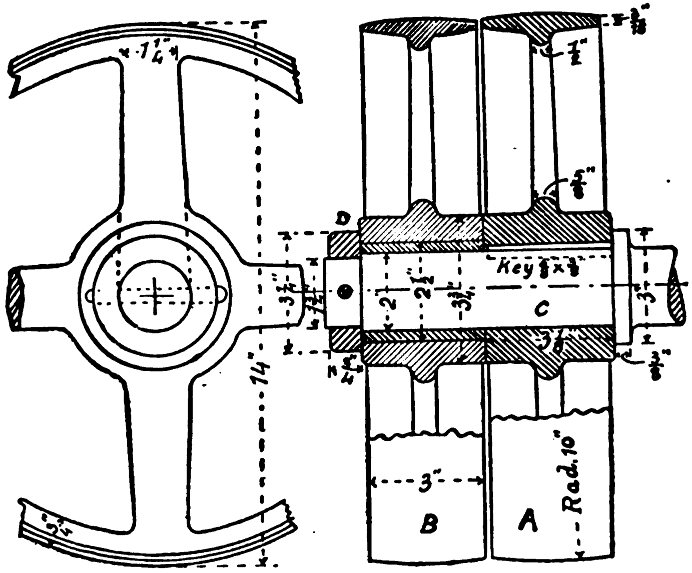


Fig. 166—Tight and Loose Pulleys.

leys. A is the rast pulley, secured to the shaft C by a sunk key, B is the loose pulley, which turns freely upon the shaft. The loose pulley is prevented from coming off by a collar D, which is secured to the shaft by a tapered pin as shown.

The nave or boss of the loose pulley is here fitted with a brass bushing, which may be renewed when it becomes too much worn. Draw the elevations shown, completing the left-hand one. Scale 6 inches to 1 foot.

By the above arrangement of pulleys a machine may be stopped or set in motion at pleasure. When the driving belt is on the loose pulley the machine is at rest, and when it is on the tight pulley the machine is in motion. The driving belt is shifted from the one pulley to the other by pressing on that side of the belt which is advancing towards the pulleys.

Gear Wheels. Let two smooth rollers be placed in contact with their axes parallel, and let one of them rotate about its axis, then if there is no slipping the other roller will rotate in the opposite direction with the same surface velocity, and if D_1, D_2 be the diameters of the rollers, and N_1, N_2 their speeds in revolutions per minute, it follows as in belt gearing that

$$\frac{N_1}{N_2}=\frac{D_2}{D_1}$$

If there be considerable resistance to the motion of the follower slipping may take place, and it may stop. To prevent this the rollers may be provided with teeth, then they become spur wheels, and if the teeth be so shaped that the ratio of the speeds of the toothed rollers at any instant is the same as that of the smooth rollers, the surfaces of the latter are called the pitch surfaces of the former.

Pitch Circle. A section of the pitch surface of a toothed wheel by a plane perpendicular to its axis is a circle, and is called a pitch circle. We may also say that the pitch circle is the edge of the pitch surface. The pitch circle is generally traced on the side of a toothed wheel, and is rather nearer the points of the teeth than the roots.

Pitch of Teeth. The distance from the center of one tooth to the center of the next, or from the front of one to the front of the next, measured at the pitch circle, is called the pitch of the teeth. If D be the diameter of the pitch circle of a wheel, n the number of teeth, and p the pitch of the teeth, then $D\times 3.1416=n\times p$.

By the diameter of a wheel is meant the diameter of its pitch circle.

Form and Proportions of Teeth. The ordinary form of wheel teeth is shown in Fig. 167. The curves of the teeth should be cycloidal curves, although they are generally drawn in as arcs of circles. It does not fall within the scope of this work to discuss the correct forms of gear teeth.

Example 12. Spur Gear. Fig. 167 shows the elevation and sectional plan of a portion of a cast-iron spur gear. The diameter of the pitch circle is 23⅞ inches, and the pitch of the teeth is 1½ inches, so that there will be 50 teeth in the gear. The gear has six arms. Draw a complete elevation of the gear and a half sectional plan, also a half-plan without any section. Draw also a cross section of one arm. Scale 3 inches to 1 foot.

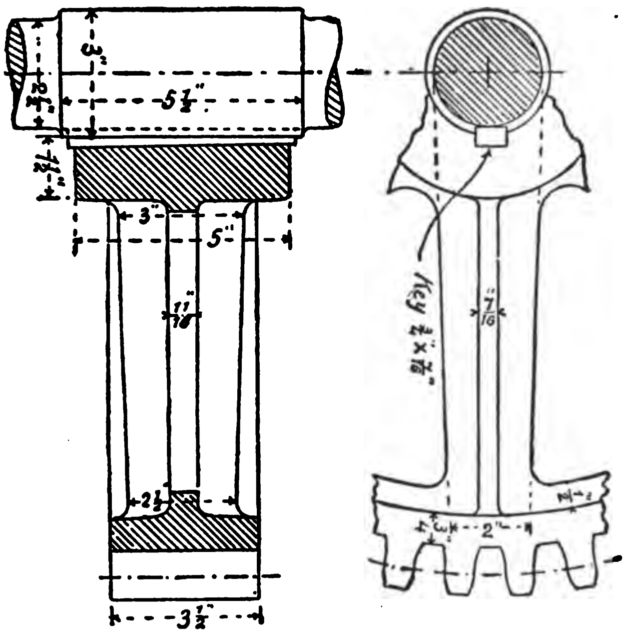


Fig. 167—Portion of a Cast-iron Spur Gear.

Mortise Gears. When two gears meshing together run at a high speed the teeth of one are made of wood. These teeth, or cogs, as they are generally called, have tenons formed on them, which fit into mortises in the rim of the gear. This gear with the wooden teeth is called a mortise gear.

Coupling Rods. A rod used to transmit the motion of one crank to another is called a coupling rod. A familiar example of the use of coupling rods will be found in the locomotive. Coupling rods are made of wrought iron or steel, and are generally of rectangular section. The ends are now generally made solid and lined with solid brass bushes, without any adjustment for wear. This form of coupling rod end is found to answer very well in locomotive practice where the workmanship and arrangements for lubrication are excellent. When the brass bush becomes worn it is replaced by a new one.

Fig. 168 shows an example of a locomotive coupling rod end for an outside cylinder engine. In this case it is desirable to have the crank-pin bearings for the coupling rods as short as possible, for a connecting rod and coupling rod in this kind of engine work side by side on the same crank-pin, which, being overhung, should be as short as convenient for the sake of strength. The requisite bearing surface is obtained by having a pin of large diameter. The brass bush is prevented from rotating by means of the square key shown. The oil-box is cut out of the solid, and has a wrought-iron cover slightly dovetailed at the edges. This cover fits into a check round the top inner edge of the box, which is originally parallel, but is made to close on the dovetailed edges of the cover by riveting. A hole in the center of this cover, which gives access to the oil-box, is fitted with a screwed-brass plug. The brass plug has a screwed hole in

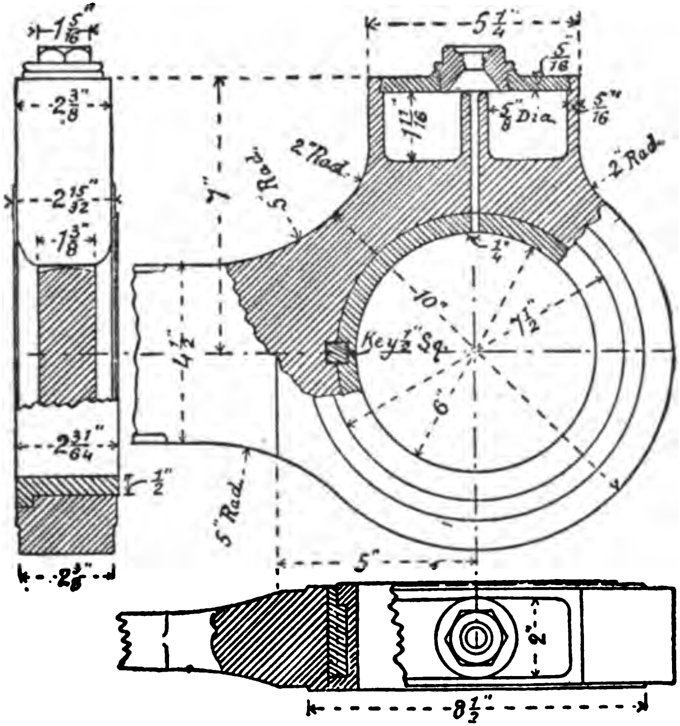


Fig. 168—Locomotive Coupling-rod End.

the center, through which oil may be introduced to the box. Dust is kept out of the oil-box by screwing into the hole in the brass plug a common cork. The oil is carried slowly but regularly from the oil-box over to the bearing by a piece of cotton wick.

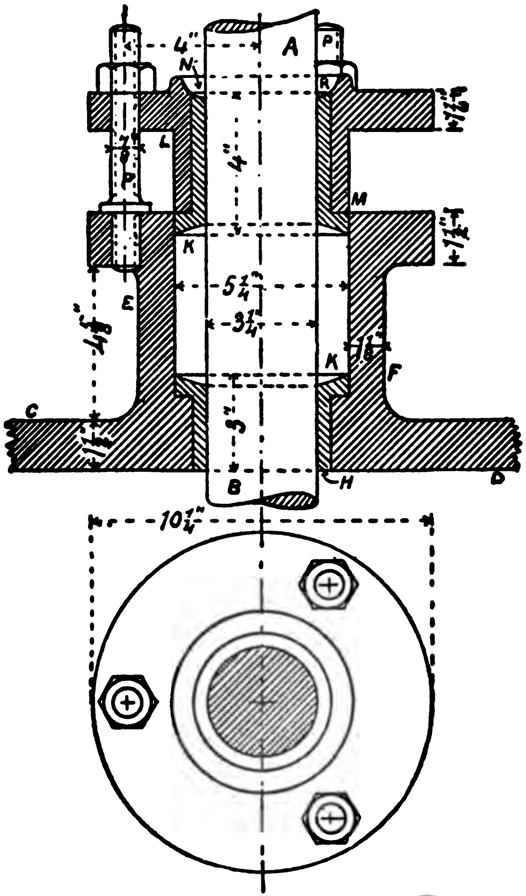


Fig. 169—Gland and Stuffing-box.

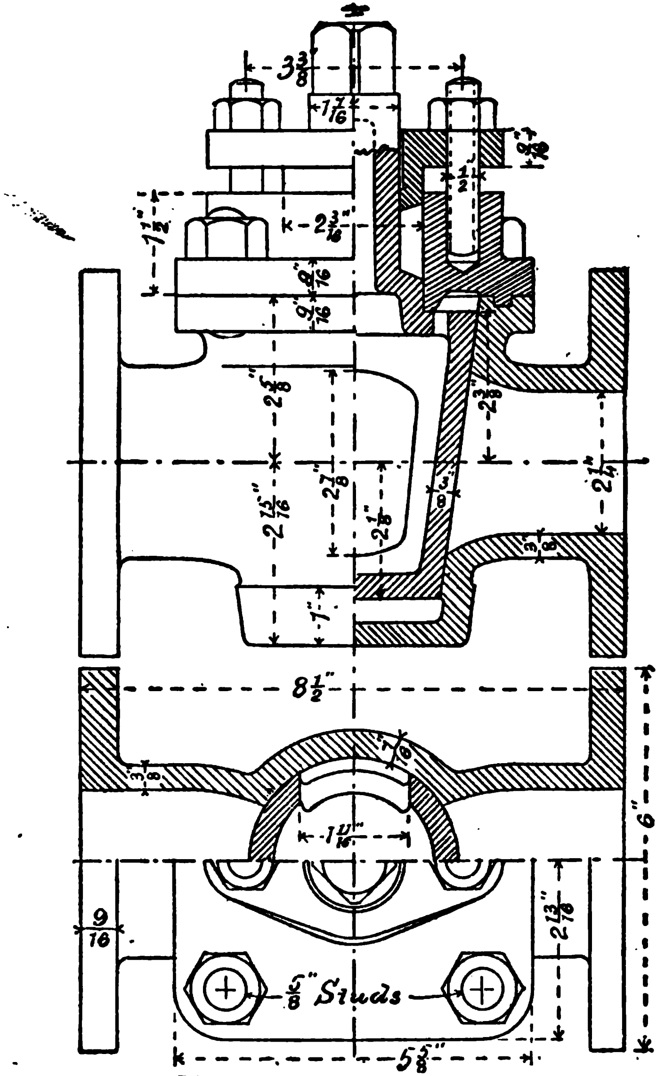


Fig. 170—Water or Steam Cock.

Example 13. Coupling Rod End. Draw first the side elevation and plan, each partly in section as shown in Fig. 168. Then instead of the view to the left, which is an end elevation partly in section, draw a complete end elevation looking to the right, and also a complete vertical cross section through the center of the bearing. Scale 6 inches to 1 foot.

Stuffing-boxes. In Fig. 169 is shown a gland and stuffing-box for the piston rod of a vertical engine. A B is the piston rod, C D a portion of the cylinder cover, and E F the stuffing-box. Fitting into the bottom of the stuffing-box is a brass bush H. The space K around the rod A B is filled with packing, of which there is a variety of kinds, the simplest being greased hempen rope. The packing is compressed by screwing down the cast-iron gland L M, which is lined with a brass bush N. In this case the gland is screwed down by means of three stud-bolts P, which are screwed into a flange cast on the stuffing-box. Surrounding the rod on the top of the gland there is a recess R for holding the lubricant.

The object of the gland and stuffing-box is to allow the piston rod to move backwards and forwards freely without any leakage of steam.

Example 14. Gland and Stuffing-box for a Vertical Rod. Draw the views shown in Fig. 169 to the dimensions given. Scale 6 inches to 1 foot.

Water or Steam Cock. Fig. 170 shows a cock of considerable size, which may be used for water

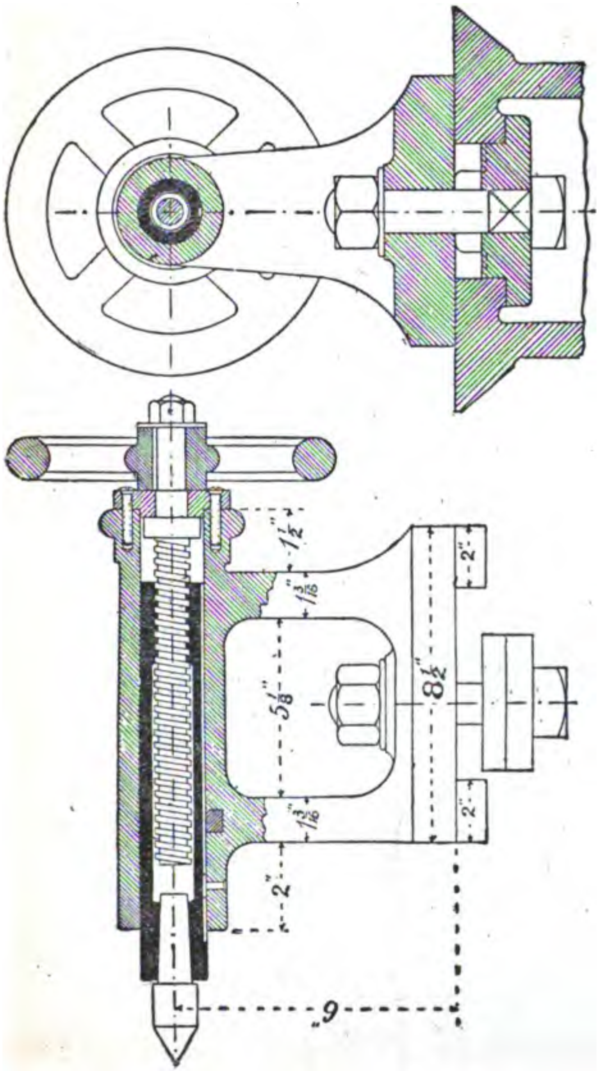


Fig. 171—Tailstock for 12-inch Lathe.

or steam under high pressure. The plug in this example is hollow, and is prevented from coming out by a cover which is secured to the casing by

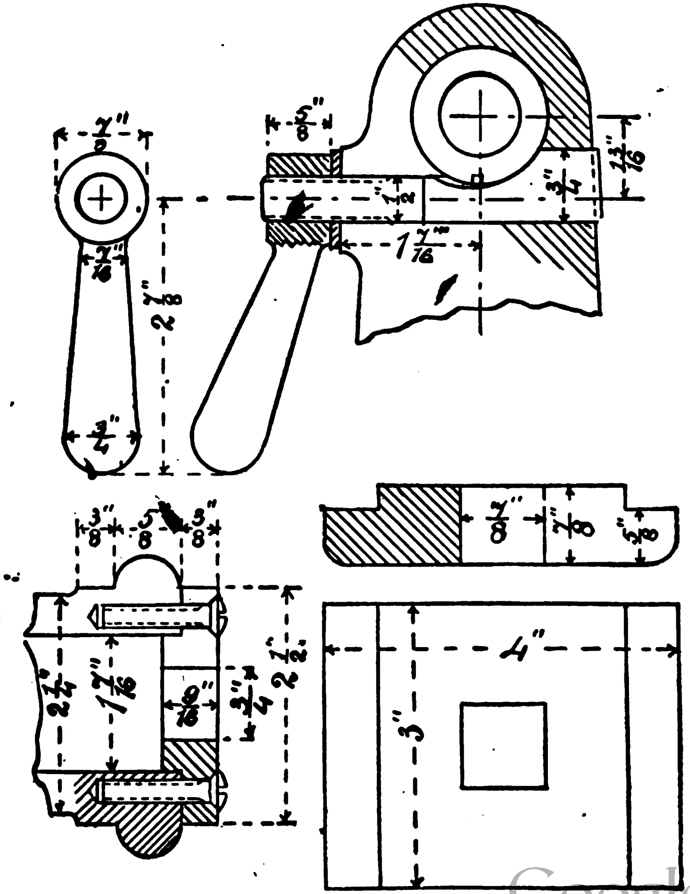


Fig. 172—Details of Tailstock.

four stud bolts. An annular ridge of rectangular section projecting from the under side of the cover, and fitting into a corresponding recess on the top of the casing, serves to ensure that the cover and plug are concentric, and prevents leakage.

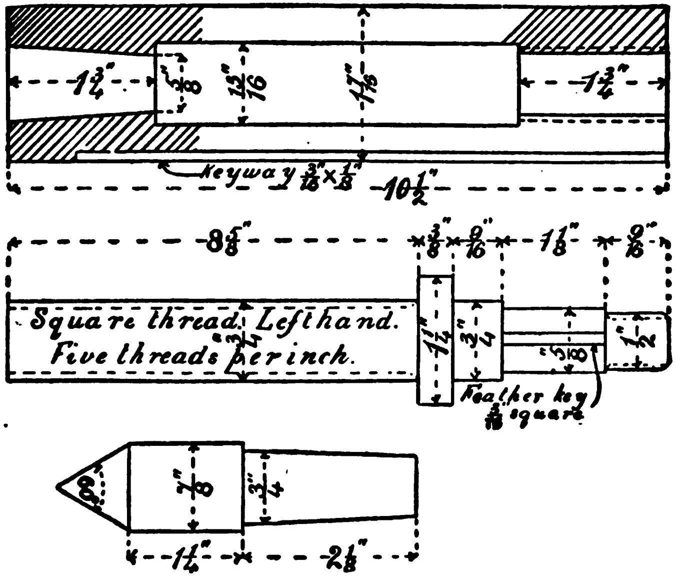


Fig. 173—Details of Tailstock.

Leakage at the neck of the plug is prevented by a gland and stuffing-box. The top end of the plug is made square to receive a handle for turning it. The size of a cock is taken from the bore of the pipe in which it is placed, thus Fig. 170 shows a 2½-inch cock.

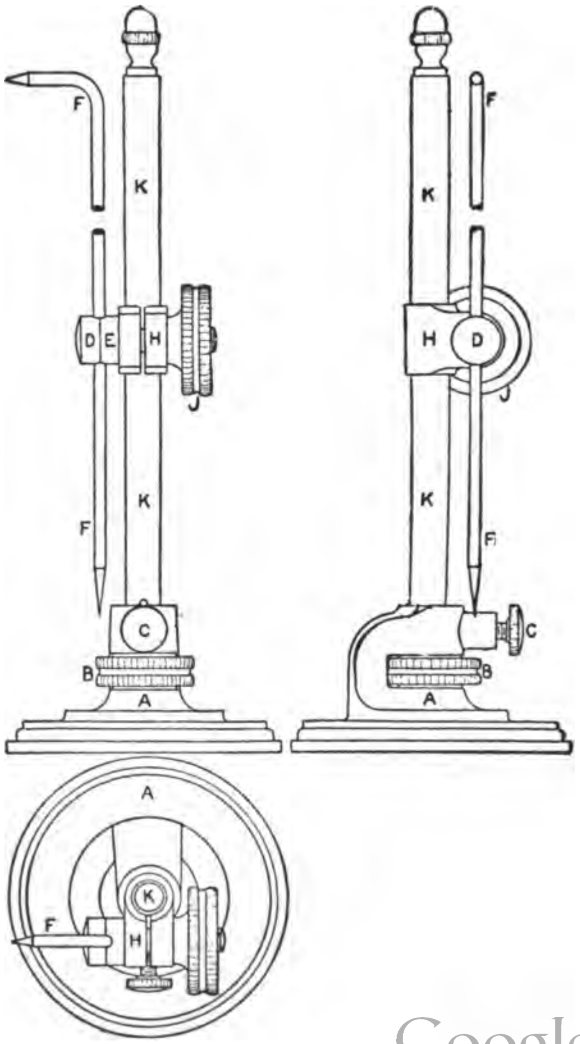


Fig. 174—Surface Gauge.

Example 15. 2½-inch Steam or Water Cock. First draw the views of this cock shown in Fig. 170, then draw a half end elevation and half cross section through the center of the plug. Scale 6 inches to 1 foot.

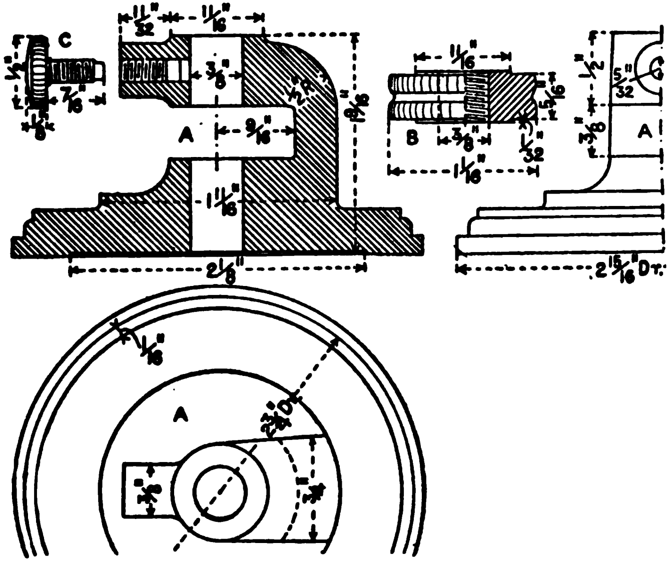


Fig. 175—Details of Surface Gauge.

Instead of drawing the parts of the pipe on the two sides of the plug in the same straight line as in Fig. 170, one may be shown proceeding from the bottom of the casing, so that the fluid will have to pass through the bottom of the plug and through one side. This is a common arrangement.

All the parts of the valve and casing in this example are made of brass.

Example 16. Tailstock for 12-inch Lathe. Two views of this tailstock are shown in Fig. 171. On

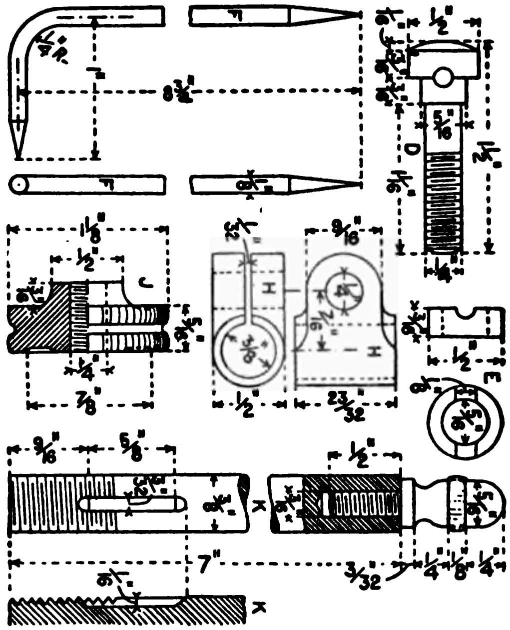


Fig. 176—Details of Surface Gauge.

one of these views a few of the principal dimensions are marked. The details, fully dimensioned, are shown separately in Figs. 172 and 173.

Explain clearly how the center is moved backwards and forwards, and also how the spindle containing it is locked when it is not required to move.

Draw, half-size, the views shown in Fig. 171, and from the left-hand view project a plan. Draw

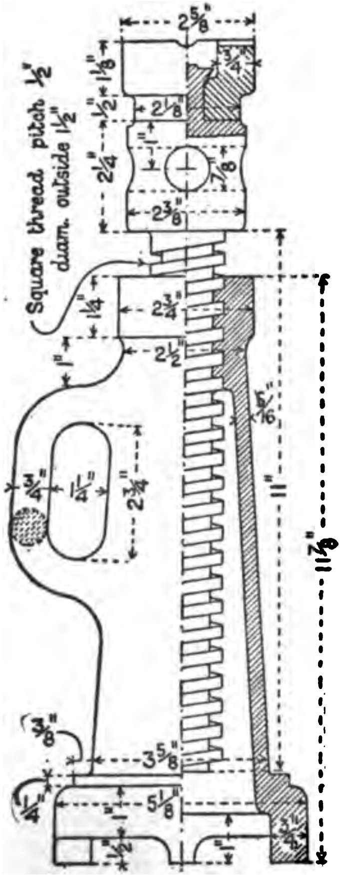


Fig. 177—Jack Screw.

also the detail of the locking arrangement shown in Fig. 172.

Example 17. Surface Gauge. First draw, full

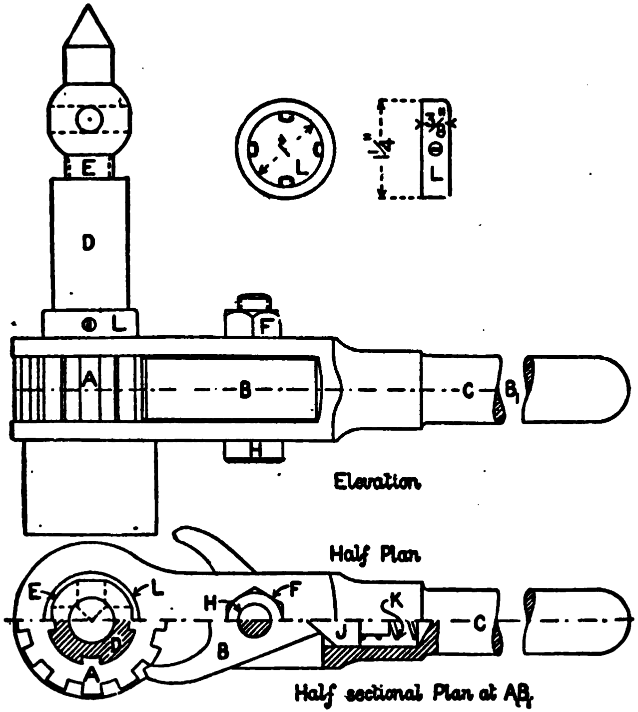


Fig. 178—Reversible Ratchet-drill.

size, all the details separately, as shown in Figs. 175 and 176, then draw, full size, the plan and two elevations of the tool complete, as shown in Fig. 174.

F is the scriber which may be clamped at any part of the straight portion, between D and E. The scriber may also be placed at any angle to

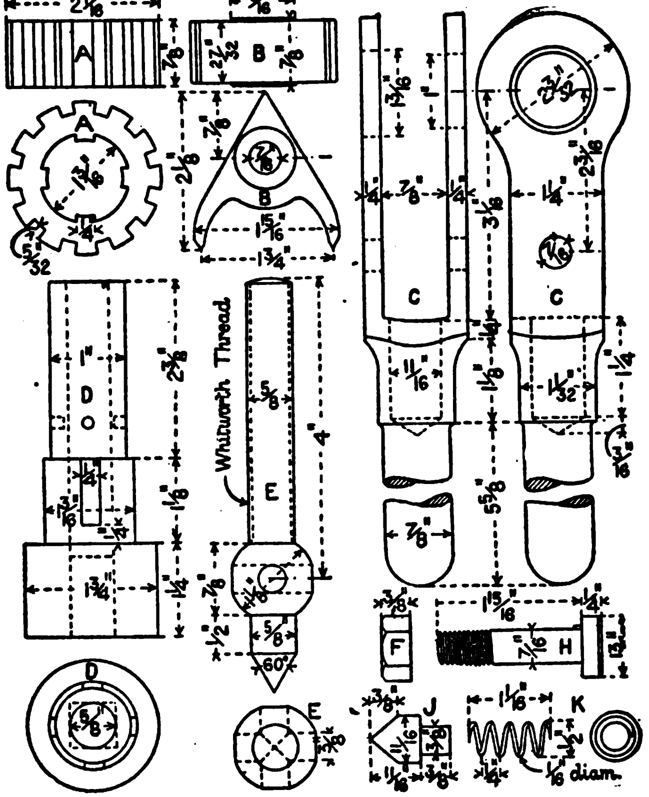


Fig. 179—Details of Ratchet-drill.

the horizontal, and the point at which it is clamped may be placed at any height from the

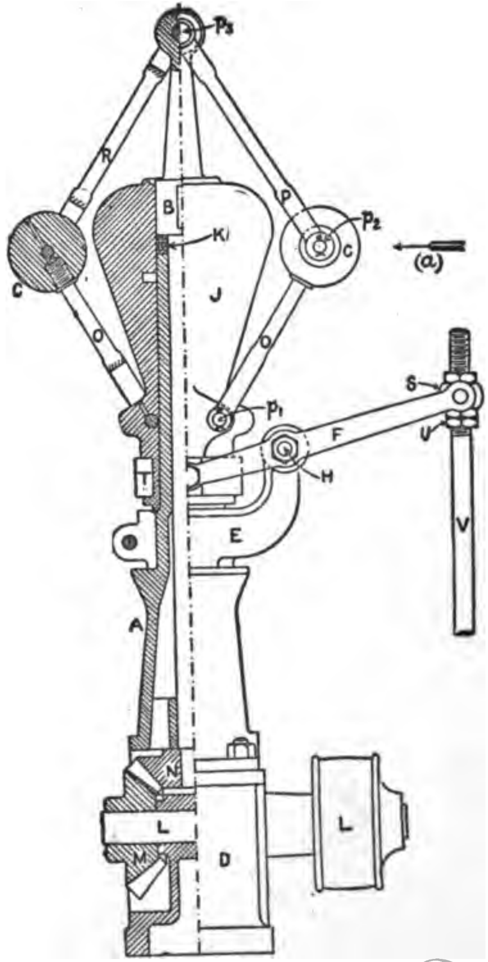


Fig. 180—Steam Engine Governor.

base A within the limits of the upright K. D and E are carried by the clamp H, which embraces the upright K. By turning the milled nut J the scriber is fixed in position in relation to K. A fine vertical adjustment is obtained by rotating the milled nut B. After all adjustments have been made, K is locked in position by the set-screw C.

Example 18. Jack Screw. From the half eleva-

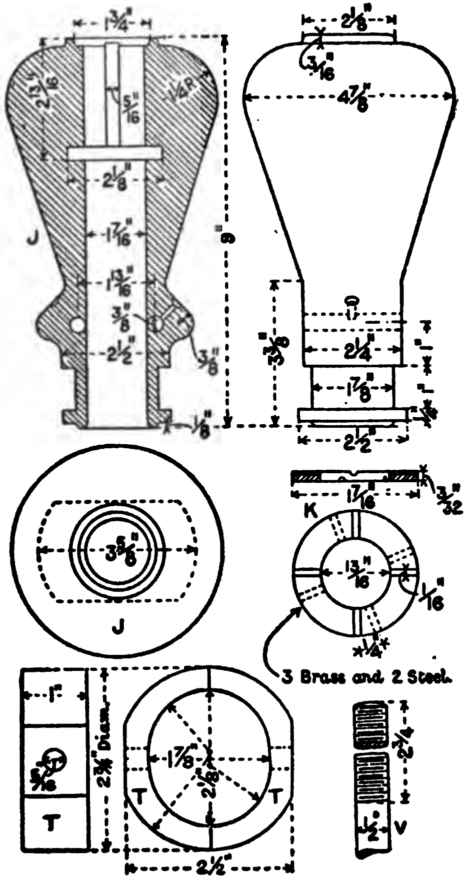


Fig. 181—Details of Governor

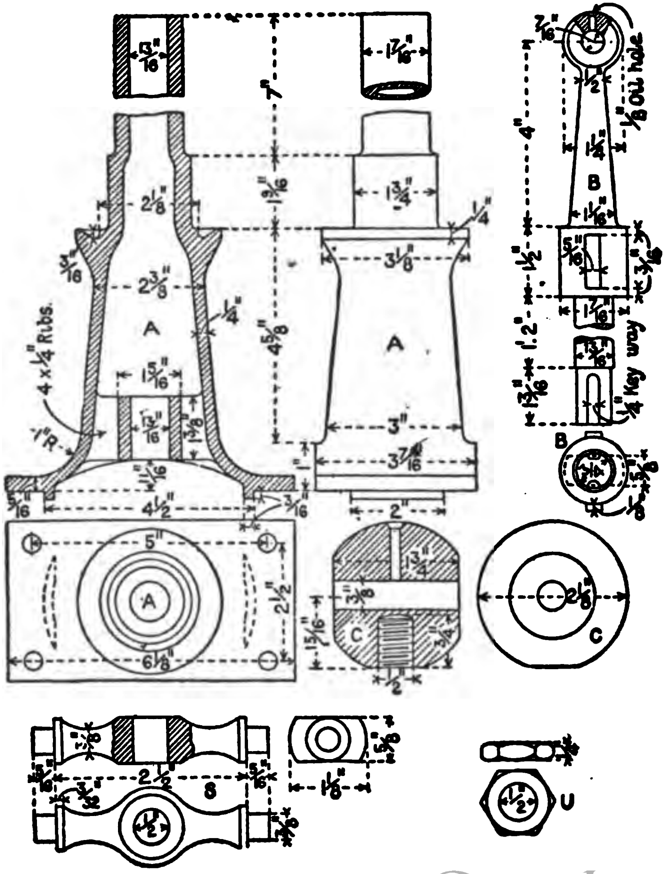


Fig. 182—Details of Governor.

tion and half section shown in Fig. 177 make working drawings of the separate parts of the screw-jack, then draw the views shown below of the complete machine. Scale 6 inches to 1 foot.

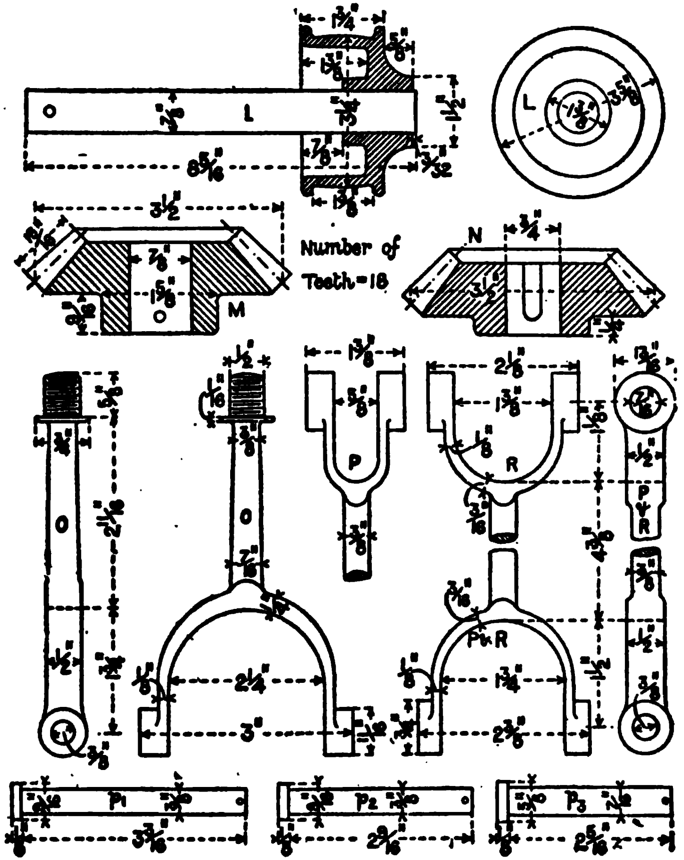


Fig. 183—Details of Governor.

Example 19. Reversible Ratchet-drill. Draw, full size, the views shown in Fig. 178 of a reversible ratchet-brace. Draw also the details separately, as shown in Fig. 179. All the dimensions are to be obtained from the detailed drawings.

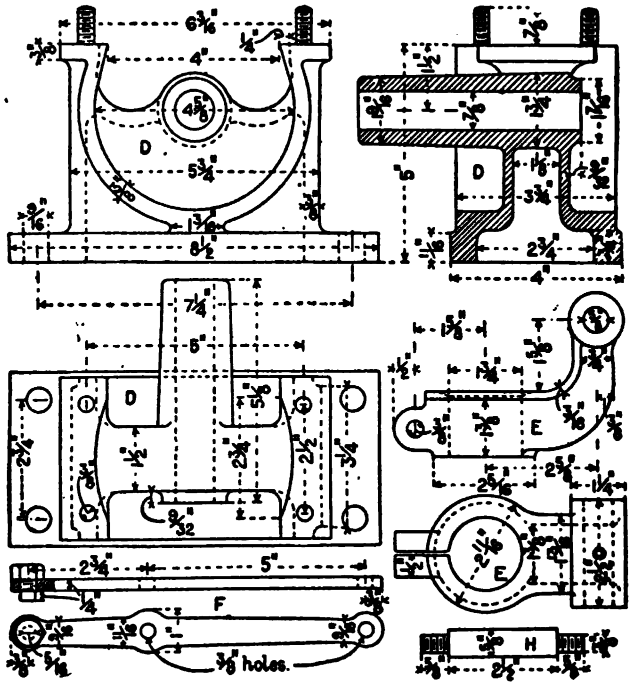


Fig. 184—Details of Governor.

Example 20. Steam Engine Governor. Draw the half elevation and half section of the governor complete, as shown in Fig. 180. Draw also a plan and an elevation looking in the direction of the arrow (a). Scale 6 inches to a foot. All the dimensions are to be taken from the illustrations of the details shown in Figs. 181, 182, 183 and 184.

The governor illustrated is used on an engine having a cylinder 8 inches in diameter, with a piston stroke of 16 inches. The crank-shaft runs at about 110 revolutions per minute, and the governor-spindle is driven at three times the speed of the crank-shaft. The governor controls the expansion valve. This type of governor is known as the "Porter" governor, from the name of the inventor.

TECHNICAL DEFINITIONS

The unit of work is the work done in lifting one pound through a height of one foot, or work done when a resistance of one pound is overcome through a space of one foot, and is called the foot-pound.

The number of units of work performed=P×S where P equals the force applied, or the resistance overcome in pounds, and S equals the space moved over in feet.

Force is any action which can be expressed simply by weight, and which can be realized only by an equal amount of reaction, and is the first element in dynamics. All bodies in nature possess the incessant virtue of attracting one another by gravitation, which action is recognized as force.

Velocity is speed or rate of motion, and is the second element in dynamics.

Time implies a continuous perception recognized as duration, or that measured by a clock, and is the third element in dynamics.

Power is the product of force and velocity, that is to say, a force multiplied by the velocity with which it is acting is the power in operation. Power is the differential of work, or any action that produces work, whether mental or physical. Power multiplied by the time of action is work, work divided by time is power.

Work is the product obtained by multiplying together the three simple elements, force, velocity, and time.

The energy of a body is its capacity for performing work.

The potential energy, or the energy stored in a body, is the product of the effort and the distance through which it is capable of acting.

Kinetic energy, or accumulated work of a moving body, is the product of the mass and half the square of its velocity, or the weight of the body multiplied by the height from which it must fall to gain its velocity.

Gravity is the mutual tendency which all bodies of nature have to approach each other, or the tendency of any falling body to approach the center of the earth.

The mass of a body is its weight divided by 32.2.

The acceleration of motion is the rate of change in the velocity of a moving body, which is increased at different intervals of time.

The unit of acceleration is that which imparts unit change of velocity to a moving body in unit time, or an acceleration of one foot per second in one second.

The acceleration due to gravity varies at different places on the earth's surface. It is reckoned at 32.2 feet per second in this country, and is generally indicated by the letter **g.**

Retarded motion. The motion of a body, instead of being accelerated, may be retarded, that is, its velocity may decrease at different intervals of time.

Varied motion is usually understood to refer to a moving body, when the change varies in either accelerated or retarded motion, at different intervals of time.

Inertia is that quality inherent in matter whereby it is absolutely passive or indifferent to a state of motion.

A couple consists of two parallel forces which are equal, and act in opposite directions.

The weight of a body is the pressure which the mutual attraction of the earth and the body causes that body to exert on another with which it is in contact=mass multiplied by 32.2.

Linear Velocity is the rate of motion in a straight line, and is measured in feet per second, or per minute, or in miles per hour.

MATERIALS USED IN MACHINE CONSTRUCTION

Cast Iron. The essential constituents of cast iron are iron and carbon, the latter forming from 2 to 5 per cent. of the total weight. Cast iron, however, usually contains varying small amounts of silicon, sulphur, phosphorus, and manganese.

In cast iron the carbon may exist partly in the free state and partly in chemical combination with the iron.

Chilled Castings. When grey cast iron is melted a portion of the free carbon combines chemically with the iron, this, however, separates out again if the iron is allowed to cool slowly, but if it is suddenly cooled a greater amount of the carbon remains in chemical combination, and a whiter and harder iron is produced. Advantage is taken of this in making chilled castings. In this process the whole or part of the mould is lined with cast iron, which, being a comparatively good conductor of heat, chills a portion of the melted metal next to it, changing it into a hard white iron to a depth varying from 1/8 to 1/2 an inch. To protect the cast-iron lining of the mould from the molten metal it is painted with loam.

Malleable Cast Iron. This is prepared by imbedding a casting in powdered red hematite, an oxide of iron, and keeping it at a bright red heat for a length of time varying from several hours to several days according to the size of the casting. By this process a portion of the carbon in the casting is removed, and the strength and toughness of the latter become more like the strength and toughness of wrought iron.

Wrought Iron. This is nearly pure iron, and is made from cast iron by the puddling process, which consists chiefly of raising the cast iron to a high temperature in a reverberatory furnace in the presence of air, which unites with the carbon and passes off as gas. In other words the carbon is burned out. The iron is removed from the puddling furnace in soft spongy masses called blooms, which are subjected to a process of squeezing or hammering called shingling. These shingled blooms still contain enough heat to enable them to be rolled into rough puddled bars. These puddled bars are of very inferior quality, having less than half the strength of good wrought iron. The puddled bars are cut into pieces which are piled together, reheated, and again rolled into bars, which are called merchant bars. This process of piling, reheating, and re-rolling may be repeated several times, depending on the quality of iron required. Up to a certain point the quality of the iron is improved by reheating and rolling or hammering, but beyond that a repetition of the process diminishes the strength of the iron.

The process of piling and rolling gives wrought iron a fibrous structure. When subjected to vibrations for a long time, the structure becomes crystalline and the iron brittle. The crystalline structure induced in this way may be removed by the process of annealing, which consists in heating the iron in a furnace, and then allowing it to cool slowly.

Forging and Welding. The process of pressing or hammering wrought iron when at a red or white heat into any desired shape is called forging. If at a white heat two pieces of wrought iron be brought together, their surfaces being clean, they may be pressed or hammered together, so as to form one piece. This is called welding, and is a very valuable property of wrought iron.

Steel. This is a compound of iron with a small percentage of carbon, and is made either by adding carbon to wrought iron, or by removing some of the carbon from cast iron.

In the cementation process, bars of wrought iron are imbedded in powdered charcoal in a fireclay trough, and kept at a high temperature in a furnace for several days. The iron combines with a portion of the carbon to form blister steel, so named because of the blisters which are found on the surface of the bars when they are removed from the furnace.

The bars of blister steel are broken into pieces about 18 inches long, and tied together in bundles by strong steel wire. These bundles are raised to a welding heat in a furnace, and then hammered or rolled into bars of shear steel.

To form cast steel the bars of blister steel are broken into pieces and melted into crucibles.

In the Siemens-Martin process for making steel, cast and wrought iron are melted together on the hearth of a regenerative gas-furnace.

Bessemer steel is made by pouring melted cast iron into a vessel called a converter, through which a blast of air is then urged. By this means the carbon is burned out, and comparatively pure iron remains. To this is added a certain quantity of spiegeleisen, which is a compound of iron, carbon, and manganese.

Hardening and Tempering of Steel. Steel, if heated to redness and cooled suddenly, as by immersion in water, is hardened. The degree of hardness produced varies with the rate of cooling; the more rapidly the heated steel is cooled, the harder does it become. Hardened steel is softened by the process of annealing, which consists in heating the hardened steel to redness, and then allowing it to cool slowly. Hardened steel is tempered, or has its degree of hardness lowered, by being heated to a temperature considerably below that of a red heat, and then cooling suddenly. The higher the temperature the hardened steel is raised to, the lower does its temper become.

Case-hardening. This is the name given to the process by which the surfaces of articles made of wrought iron are converted into steel, and consists in heating the articles in contact with substances rich in carbon, such as bone-dust, horn shavings, or yellow prussiate of potash. This process is generally applied to the articles after they are completely finished by the machine tools or by hand. The coating of steel produced on the article by this process is hardened by cooling the article suddenly in water.

Copper. This metal has a reddish brown color, and when pure is very malleable and ductile, either when cold or hot, so that it may be rolled or hammered into thin plates, or drawn into wire. Slight traces of impurities cause brittleness, although from 2 to 4 per cent. of phosphorus increases its tenacity and fluidity. Copper is a good conductor of heat and of electricity. Copper is largely used for making alloys.

Alloys. Brass contains two parts by weight of copper to one of zinc. Muntz metal consists of three parts of copper to two of zinc. Alloys consisting of copper and tin are called bronze or gun-metal. Bronze is harder the greater the proportion of tin which it contains, five parts of copper to one of tin produce a very hard bronze, and ten of copper to one of tin is the composition of a soft bronze. Phosphor bronze contains copper and tin with a little phosphorus, it has this advantage over ordinary bronze, that it may be remelted without deteriorating in quality. This alloy also has the advantage that it may be made to possess great strength accompanied with hardness, or less strength with a high degree of toughness.

Wood. In the early days of machines wood was largely used in their construction, but it is now used to a very limited extent in that direction. Beech is used for the cogs of mortise gears. Yellow pine is much used by pattern-makers. Box, a heavy, hard, yellow-colored wood, is used for the sheaves of pulley blocks, and sometimes for bearings in machines. Lignum-vitae is a very hard dark-colored wood, and remarkable for its high specific gravity, being 1 1-3 times the weight of the same volume of water. This wood is much used for bearings of machines which are under water.

Shafting. Shafting is nearly always cylindrical and made of wrought iron or steel. Cast iron is rarely used for shafting.

Axles are shafts which are subjected to bending without twisting.

The parts of a shaft or axle which rest upon the bearings or supports are called journals, pivots, or collars.

In journals the supporting pressure is at right angles to the axis of the shaft, while in pivots and collars the pressure is parallel to that axis.

Shafts may be solid or hollow. Hollow shafts are stronger than solid shafts for the same weight of material. Thus a hollow shaft having an external diameter of 10¼ inches and an internal diameter of 7 inches would have about the same weight as a solid shaft of the same material 7½ inches in diameter, but the former would have about double the strength of the latter. Hollow shafts are also stiffer and yield less to bending action than solid shafts, which in some cases, as in propeller shafts, is an objection.

Twisting Moment. Let a shaft carry a lever, wheel, or pulley of radius R inches, and let a force of P lbs. act at the outer end of the radius, and at right angles to it. The force P produces a twisting action on the shaft, which is measured by the product $P \times R$. This product $P \times R$ is called the twisting moment or torque on the shaft; and if P is in lbs. and R in inches, the twisting moment is $P \times R$ inch-pounds. The twisting moment in foot-pounds is got by dividing the twisting moment in inch-pounds by 12.

If the shaft makes N revolutions per minute, the horse-power which is being transmitted is

$$\frac{2 \times R \times 3.1416 \times P \times N}{12 \times 33{,}000} \text{ or } \frac{2 \times 3.1416 \times T \times N}{12 \times 33{,}000},$$

where T is the twisting moment in inch-pounds.

Resistance of Shafts to Torsion. The resistance of a shaft to torsion is directly proportional to the cube of its diameter. Thus if the diameter be doubled, the strength is increased eight (2^3) times. Let there be two shafts of the same material, and having diameters D_1 and D_2; and let the twisting moments which they support when strained to the same extent be T_1 and T_2 respectively; then $T_1 : T_2 :: D_1^3 : D_2^3$, or $T_1 D_2^3 = T_2 D_1^3$.

Moment of Resistance. The stress produced in a shaft which is subjected to twisting is a shearing stress. This stress is not uniform, being greatest at the outside of the shaft and diminishing uniformly towards the center, where it is nothing. Let **f** be the greatest shearing stress on the shaft and **d** its diameter. Then the moment of resistance of the shaft to torsion which balances the twisting moment is

$$\frac{3.1416}{16} d^3 f, \text{ so that } T = PR = \frac{3.1416}{16} d^3 f.$$

In determining the safe twisting moment for a mild steel shaft, **f** may be taken equal to 9000 lbs. per square inch.

Box Couplings. The coupling illustrated in Fig. 185 consists of a solid box made of cast-iron, bored out to fit the shafts, whose ends are made to butt together inside the box. The box may be secured to the shafts by means of a sunk key which extends the whole length of the box. A better arrangement is to use two keys, both driven from the same end of the box, as shown in Fig. 185. With two keys it is not so important that the keyways in the shafts have exactly the same depth. Two keys may be more tightly driven in, and are easier to drive back than a single key of the same total length. There must, however, be a clearance space between the head of the forward key, and the point of the hind one, so as to ensure that the latter is driven in with the same degree of tightness as the former. In driving the keys back also, they can be started separately, and therefore more easily, when this clearance space is allowed. Fig. 185 shows the ends of the shafts enlarged where the keyways are cut, so that the latter do not weaken the shafts, the amount of the enlargement being such that the bottom of the keyway touches the outside of the shaft.

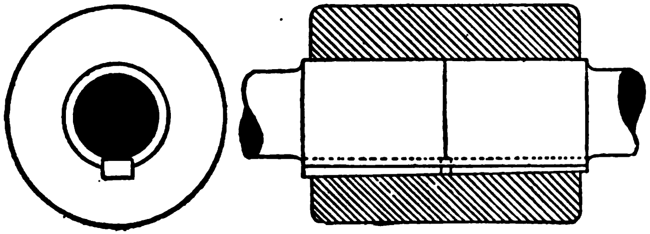


Fig 185—Box Shaft Coupling.

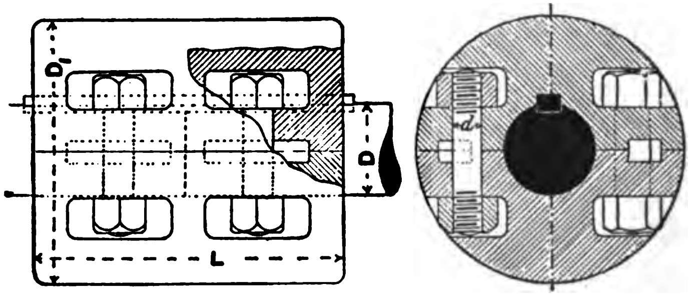


Fig. 186—Split Shaft Coupling.

Split Couplings. This form of coupling, which is shown in Fig. 186, is very easily put on or taken off, it has no projecting parts, the bolts being completely covered, and, like the solid couplings, it may be used as a driving pulley, or a driving pulley may be placed on it. In making this coupling the faces for the joint between the two halves of the box are first planed. The bolt-holes are then drilled and the two halves bolted together with pieces of paper between them; then the muff is bored out to the exact size of the shaft. When

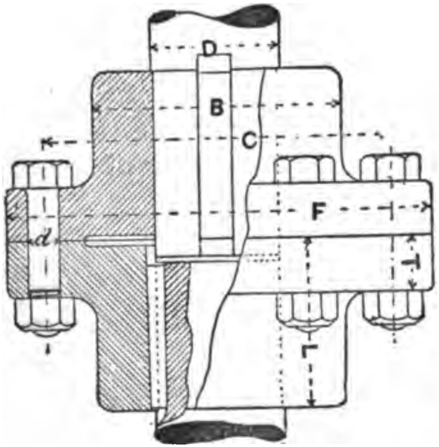


Fig. 187—Cast-iron Flange Coupling.

the paper is removed and the box put on the shaft and bolted up, the box gripes the shaft firmly. The key has no taper and should fit on the sides only.

DIMENSIONS OF SPLIT COUPLINGS.

Diam. of shaft, D	1½	1¾	2	2¼	2½	2¾	3	3½	4
Diam. of Box, D_1	4½	5¼	5¾	6	6½	7¼	7⅞	9¾	10½
Length of Box, L	6	7	8	9	10	11	12	14	16
Diam. of Bolts, d	½	⅝	⅝	⅝	¾	⅞	⅞	⅞	⅞
Number of Bolts	4	4	4	4	4	4	4	6	6

Cast-Iron Flange Coupling. In this form of coupling, which is shown in Fig. 187, there are cast-iron pieces or bosses, provided with flanges which are keyed to the ends of the shafts to be connected. These flanges are fastened together by means of bolts and nuts as shown. Sometimes the shaft is enlarged where it enters the coupling, so as to allow for the weakening effect of the key-way, but more frequently it is parallel throughout, or very slightly reduced, as shown in Fig. 187, so as to form a shoulder, which prevents the shaft going farther into the coupling.

DIMENSIONS OF CAST-IRON FLANGE COUPLINGS.

Diam. of Shaft. D.	Diam. of Flange F.	Thickness of Flange T.	Diam. of Boss B.	Depth at Boss L.	Number of Bolts.	Diam. of Bolts d.	Diameter of Bolt Circle C.
1	5 5-8	3-4	2 5-8	2 1-16	3	1-2	4 1-4
1 1-4	6 13-16	13-16	3 1-16	2 5-16	3	5-8	5 1-16
1 1-2	7 1-4	7-8	3 1-2	2 5-8	3	5-8	5 1-2
1 3-4	7 11-16	1	3 15-16	2 7-8	4	5-8	5 15-16
2	8 7-8	1 1-16	4 3-8	3 3-16	4	3-4	6 3-4
2 1-4	9 1-16	1 1-8	4 3-4	3 7-16	4	3-4	7 1-8
2 1-2	10 9-16	1 1-4	5 5-16	3 3-4	4	7-8	8 1-8
2 3-4	11	1 5-16	5 3-4	4 1-16	4	7-8	8 9-16
3	12 3-8	1 7-16	6 1-4	4 5-16	4	1	9 1-2
3 1-4	12 5-8	1 1-2	6 5-8	4 5-8	4	1	9 13-16
3 1-2	13 1-8	1 5-8	7 1-8	4 7-8	4	1	10 5-16
3 3-4	13 9-16	1 11-16	7 9-16	5 3-16	4	1	10 3-4
4	14	1 3-4	8	5 7-16	6	1	11 1-4
4 1-4	14 7-16	1 7-8	8 7-16	5 3-4	6	1	11 5-8
4 1-2	15 5 8	2	8 7-8	6	6	1 1-8	12 1-2
4 3-4	16 1-8	2 1-16	9 3-8	6 5-16	6	1 1-8	13
5	17 5-16	2 1-8	9 13 16	6 5-8	6	1 1-4	13 13-16
5 1-4	17 3-4	2 1-4	10 1-4	6 7-8	6	1 1-4	14 1-4
5 1-2	18 3-16	2 5-16	10 3-4	7 1-4	6	1 1-4	14 11-16
5 3-4	19 1-2	2 7-16	11 1-4	7 7-16	6	1 3-8	15 5-8
6	19 7-8	2 1-2	11 5-8	7 3-4	6	1 3-8	16

Gib-Heads on Keys. When the point of a key cannot be conveniently reached for the purpose of driving it out, the head should be formed as shown in Fig. 188. This is known as a gib-head.

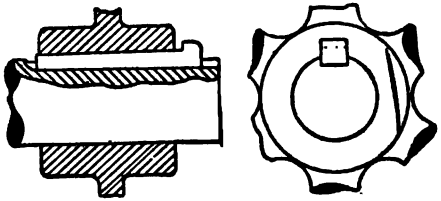


Fig. 188—Gib-head Key.

Sliding or Feather Keys. The function of a sliding or feather key is to secure a piece to a shaft, so far as to prevent the one from rotating without the other, but at the same time allow of a relative motion in the direction of the axis of the shaft. This form of key has no taper, and it is

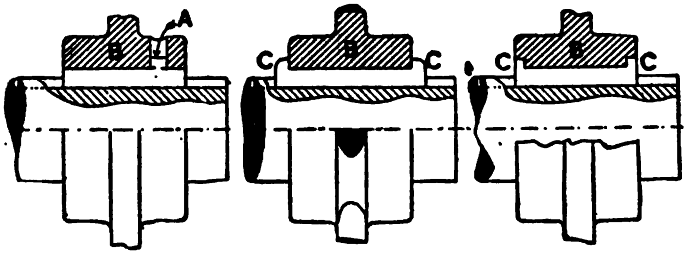


Fig. 189—Sliding Feather-keys.

generally secured to the piece carried by the shaft, in which case it is made a sliding fit in the key-way of the shaft. But the feather-key may be fixed to the shaft and made a sliding fit in the piece carried by it.

Examples of feather-keys which slide in the key-way of the shaft are shown in Fig. 189. In the left-hand view the key has a projecting pin, A, formed on it, which enters a corresponding hole in the piece B carried by the shaft. In the other two views gib-heads, C, are formed on the ends of the key, which serve the same purpose as the pin

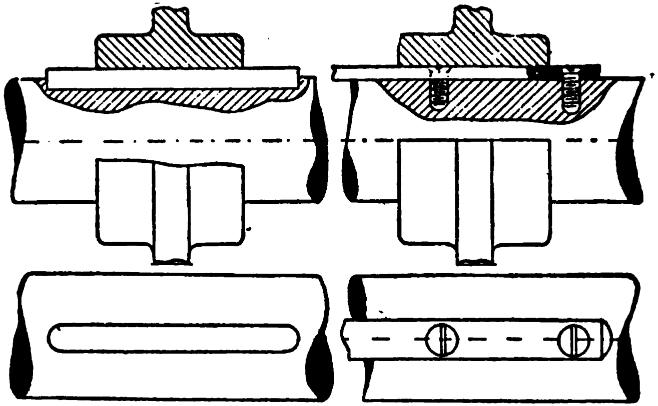


Fig. 190—Fixed Feather-keys.

A in the left-hand view, namely, to ensure that the key and the piece B remain or move together.

Fig. 190 shows two examples of feather-keys which are fixed to the shaft. In the left-hand view the key is sunk into the shaft, and in the right-hand view the key is either a saddle-key or a key on a flat, and is secured to the shaft by screws as shown. In these cases the key must be long enough to permit of the necessary sliding motion.

Dimensions of Keys.

D=diameter of shaft.
B=breadth of key.
T=thickness of sunk key.
T_1=thickness of flat key, also=thickness of saddle-key. Taper of key 1/8-inch per foot of length.

D.	B.	T.	T_1	D.	B.	T.	T_1
3/4	5/16	1/4	3/16	4	1 1/8	1/2	7/16
1	3/8	1/4	3/16	4 1/2	1 1/4	9/16	1/2
1 1/4	7/16	1/4	3/16	5	1 3/8	5/8	1/2
1 1/2	1/2	5/16	3/16	5 1/2	1 1/2	11/16	9/16
1 3/4	9/16	5/16	1/4	6	1 5/8	3/4	5/8
2	5/8	5/16	1/4	7	1 7/8	13/16	11/16
2 1/4	11/16	3/8	1/4	8	2 1/8	15/16	3/4
2 1/2	3/4	3/8	5/16	9	2 3/8	1	7/8
2 3/4	13/16	7/16	5/16	10	2 5/8	1 1/16	15/16
3	7/8	7/16	5/16	11	2 7/8	1 3/16	1 1/16
3 1/2	1	1/2	3/8	12	3 1/8	1 1/4	1 1/8

The proportions of the gib-head for a key, Fig. 188, may be h=thickness of key, l=1½h.

Screwed Cast-Iron Flanges for Wrought-Iron Pipes. In a paper read before the American Society of Mechanical Engineers, Mr. E. F. C. Davis described the joint used for the steam-pipes in the coal mines of the Philadelphia and Reading Coal and Iron Company. The pipes are of wrought-iron, and carry cast-iron flanges of the form shown in Fig. 191. The flange is screwed tightly on the pipe, and the end of the latter is faced off flush with the facing piece, which is cast on the former. One of the two flanges which are to be bolted together has cast on its face a number of lugs, which have their inner faces bored to fit the facing piece on the other flange, and thus ensure the pipes being in line. The joint is made steam-tight by a gum-joint ring which is placed between the abutting ends of the pipes and within the circle of the lugs, so that the latter keep the ring central.

The following table gives the dimensions in inches adopted for this pipe joint:

A.	B.	N_1.	C.	D.	E.	F.	G.	N_2.	H.	J.	K.
3	7 3/4	4	6	3/4	5	3/4	1/2	4	7/8	3/4	1/2
3 1/2	8 1/2	4	6 3/4	3/4	5 1/2	3/4	1/2	4	7/8	3/4	1/2
4	9 1/2	4	7 1/2	7/8	6	7/8	1/2	4	7/8	3/4	1/2
5	10 1/2	4	8 1/2	7/8	7	7/8	1/2	4	7/8	3/4	1/2
6	12	6	10	7/8	8	1	1/2	4	7/8	3/4	1/2
7	13	6	11	7/8	9	1	1/2	4	7/8	3/4	1/2
8	14	6	12	7/8	10	1 1/4	1/2	6	7/8	1	5/8
10	16 1/4	8	14	1	12	1 1/4	1/2	6	7/8	1	5/8

N_1=number of bolts. N_2=number of lugs.

Jaw Coupling. For large and slow moving shafts, the cast-iron jaw coupling shown in Fig. 192 is very simple and effective. In Fig. 192 one-half of the coupling is shown fitted with a feather-key, so that this half may be disconnected from the other or geared with it at pleasure. If the jaws are shaped as shown in Fig. 193, the two halves of the coupling are more easily put into gear, but in this case the motion must always take place in the same direction.

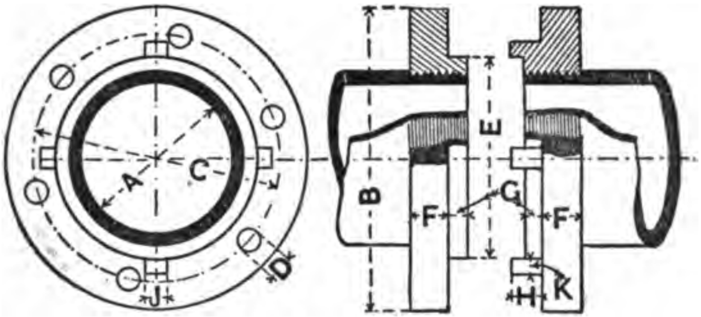


Fig. 191—Cast-iron Flanges for Wrought-iron Pipes.

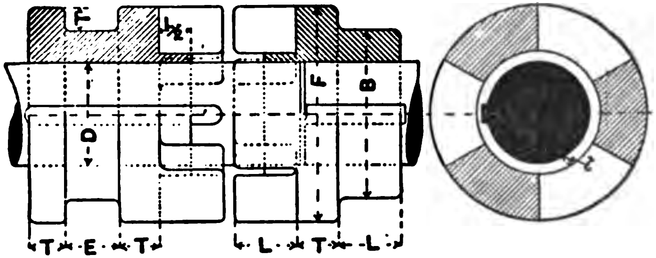


Fig. 192—Square-jaw Detachable Coupling.

Band Friction Clutch. In the friction clutch, shown in Fig. 194, there is a sleeve, A, which is keyed to the shaft and also attached to the friction band, B, by means of bolts, as shown. The friction band, B, encircles the boss, C, of the wheel or pulley, the latter being loose on the sleeve, A. The band, B, may be bound to, or released from, the boss, C, by the action of right and left-handed screws controlled by the sliding sleeve, D, and levers, E. It is evident that the band, B, moves with

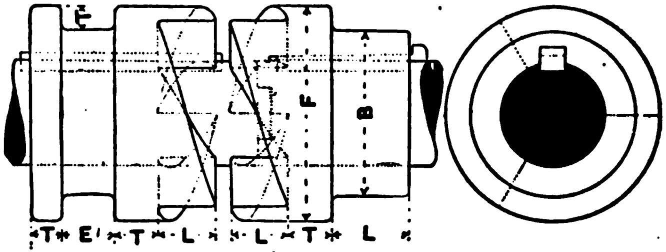


Fig. 193—Spiral-jaw Detachable Coupling.

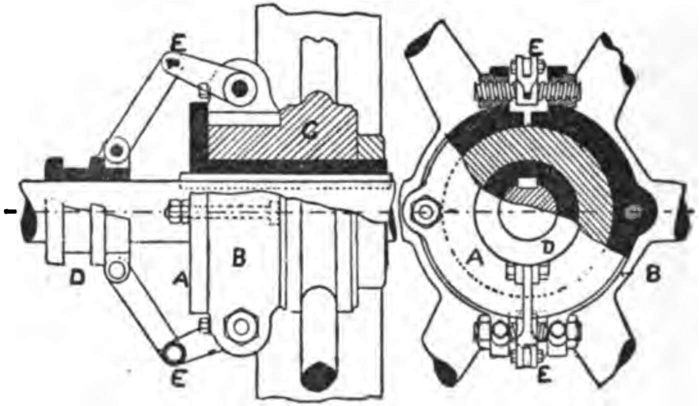


Fig. 194—Band Friction Clutch.

the shaft, and that the wheel or pulley will only rotate when the band, B, is tight on the boss, C. When used as a shaft coupling the boss, C, is prolonged and keyed to one of the shafts, the sleeve, A, being keyed to the other.

Cone Friction Clutch. The friction clutch, shown in Fig. 195, although simpler in construction than those which have already been described, is open to the objection that it requires a much greater force to put it into gear, and also this force, acting parallel to the axis of the shaft,

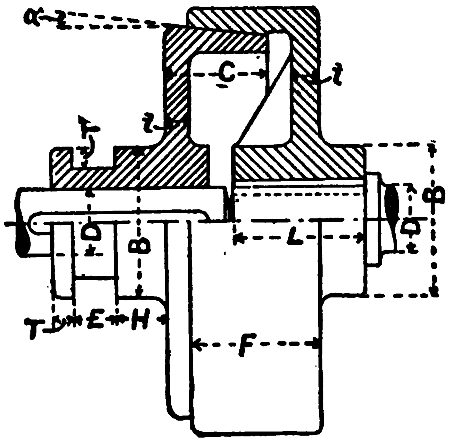


Fig. 195—Cone Friction Clutch.

causes an objectionable end thrust. The mean diameter of the conical part may be from four to eight times the diameter of the shaft, being larger the greater the amount of power which the clutch has to transmit. The inclination a of the slant side of the cone to its axis may vary from four degrees to ten degrees. The other proportions may be as follows:

B=2 D+1.	E=.4 D+.4.
C=1.5 D.	T=.3 D+.3.
F=1.8 D.	t=.2 D+.1.
H=.5 D.	

Transmission of Motion by Belts. If motion be transmitted from one pulley to another by means of a thin inextensible belt as in Fig. 196, every part of the latter will have the same velocity, and the outer surface of the rim of each pulley will

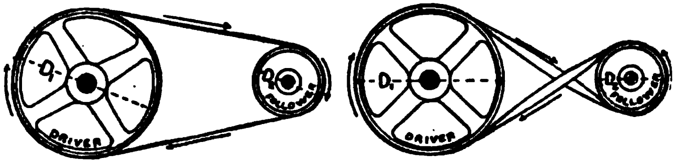


Fig. 196—Belt Transmission of Power.

have the same velocity as the belt. This fact enables us to prove the formula connecting the speeds of two pulleys with their diameters. Let D_1 and D_2 be the diameters of the driver and follower respectively, and let N_1 and N_2 denote their speeds in revolutions per minute. The speed of the outer surface of the rim of the driver$=D_1\times 3.1416\times N_1$, and the speed of the outer surface of the rim of the follower$=D_2\times 3.1416+N_2$, but each of these is equal to the speed of the belt, therefore, $D_1\times 3.1416\times N_1=D_2+3.1416+N_2$; that is, $D_1N_1=D_2N_2$ or $\frac{N_2}{N_1}=\frac{D_1}{D_2}$. This formula is true whether the belt is open or crossed, but the direction of the motion will not be the same in each of these cases, as is shown by the arrows. With an open belt the pulleys rotate in the same direction, while with a cross belt, the pulleys rotate in opposite directions.

Example 1. The driving pulley is 3 feet 6 inches in diameter, and it makes 100 revolutions per minute. The driver pulley is 2 feet 6 inches in diameter. To find its speed.

$$D_1N_1=D_2N_2$$

$$42\times100=30\times N_2$$

$$\text{therefore } N_2=\frac{42\times100}{30}=140 \text{ rev. per minute.}$$

Example 2. A belt moving with a velocity of 1000 feet per minute passes over a pulley 3 feet 3 inches in diameter. To find the number of revolutions made by the pulley in one minute.

$$\text{Circumferential speed of pulley}=\frac{39\times3.1416\times N}{12}=1000,$$

$$\text{therefore } N=\frac{1000\times12}{39\times3.1416}=97.94 \text{ revolutions per minute.}$$

Split Pulleys. For convenience in fixing pulleys on shafts it is a common practice to make them in halves, which are bolted together as shown in Fig. 197, which illustrates an example of a cast-iron split pulley 20 inches by 6 inches for a 2-inch shaft. By leaving a small clearance space between the two halves of the pulley at the hub, the latter may be tightened on to the shaft so firmly by means of the bolts that no key is necessary.

Wrought-Iron Pulleys. A great number of wrought-iron pulleys are now made, and they possess several important advantages over cast-iron ones. They are much lighter, and, being built up, they are free from the initial strains which exist in cast-iron pulleys due to unequal contraction in cooling. They are also safer at high speeds, not

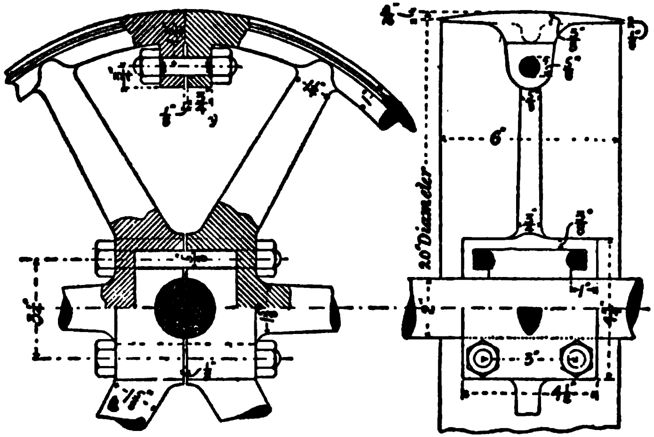


Fig. 197—Split Pulley.

only because wrought-iron has a greater tenacity than cast-iron, but because if a wrought-iron pulley should burst, it will not fly to pieces like a cast-iron one, since cast-iron is so much more brittle than wrought-iron. Wrought-iron pulleys can be made of any diameter required, but it is when they are of large diameter that their superiority over cast-iron pulleys is most decided.

In a wrought-iron pulley the rim is made of sheet-iron, and riveted to the arms, which are made from bar-iron. The hub is sometimes also made of wrought-iron, but generally it is made of cast-iron.

The differences in the design of wrought-iron pulleys are chiefly in the form of the arms.

Crank-Disks. In small engines, and in engines which run at a high speed, a cast-iron disk fre-

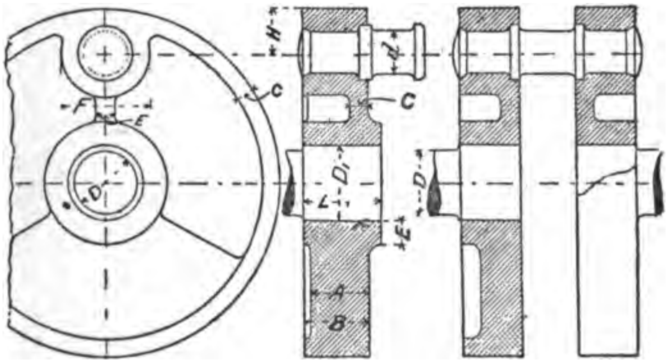


Fig. 198—Crank Disks.

quently takes the place of the ordinary crank. This disk is hollowed out on the side next the crank-pin, as shown in Fig. 198, and the extra weight on the opposite side balances the crank-pin, and the part of the connecting-rod which revolves with it. Two crank-disks may be used to take the place of a double-armed crank.

The following rules may be used in proportioning crank-disks:

D_1=D to 1.2D.	E=.4D.
B=.7D to D.	F=2d.
A=.9B.	H=d to 1.5d.
C=.25D.	L=B to 1.25B.

A Stuffing-Box is used where a sliding or rotating piece passes through the end or side of a vessel containing a fluid under pressure. The stuffing-box allows the sliding or rotating piece to move

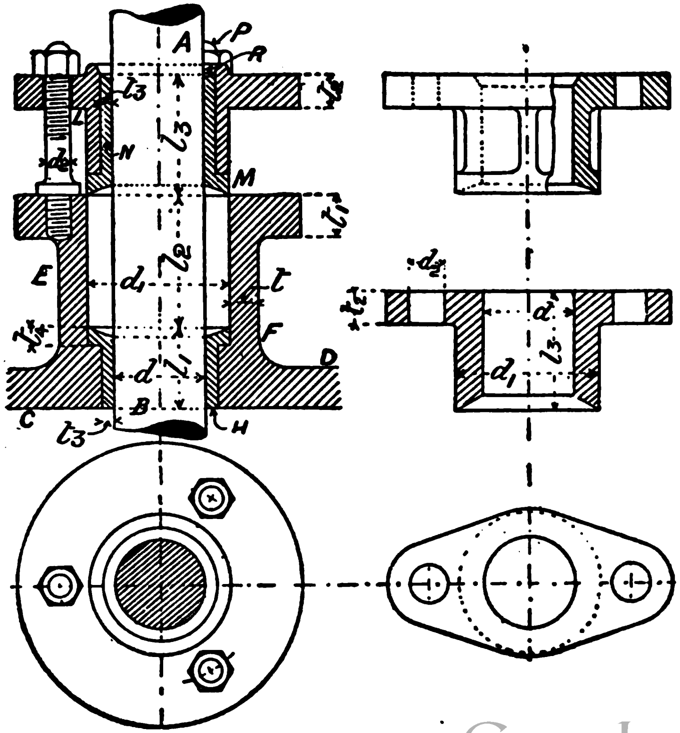


Fig. 199—Piston Rod Stuffing-box.

freely, without allowing any leakage of the fluid. Applications of the stuffing-box are found in the steam-engine where the piston-rod passes through the cylinder cover, and where the valve spindle passes through the valve casing; also at the trunnions of the cylinder in an oscillating engine, and where the shaft of a centrifugal pump passes through the pump casing. Stuffing-boxes are also used to permit of the expansion and contraction of steam pipes.

Fig. 199 shows an ordinary form of stuffing-box for the piston-rod of a vertical engine. AB is the piston-rod, CD a portion of the cylinder cover, and EF the stuffing-box. Fitting into the bottom of the stuffing-box is a brass bush, H. The space around the rod AB is filled with packing, of which there are a great many kinds, the simplest being greased hempen rope. The packing is compressed by screwing down the gland LM by means of the bolts P. When more than two bolts are used, the gland flange is generally made circular as shown in the lower left-hand view. For two bolts the gland flange is of the form shown in the lower right-hand view. When the gland is made of cast-iron it is generally lined with a brass bushing. When the gland is of brass no lines are necessary.

Steam Cock. Fig. 200 shows a good example of a cock, suitable for steam or water, and adjacent to it is a table of dimensions, taken from actual practice, for four different sizes. The two parts of

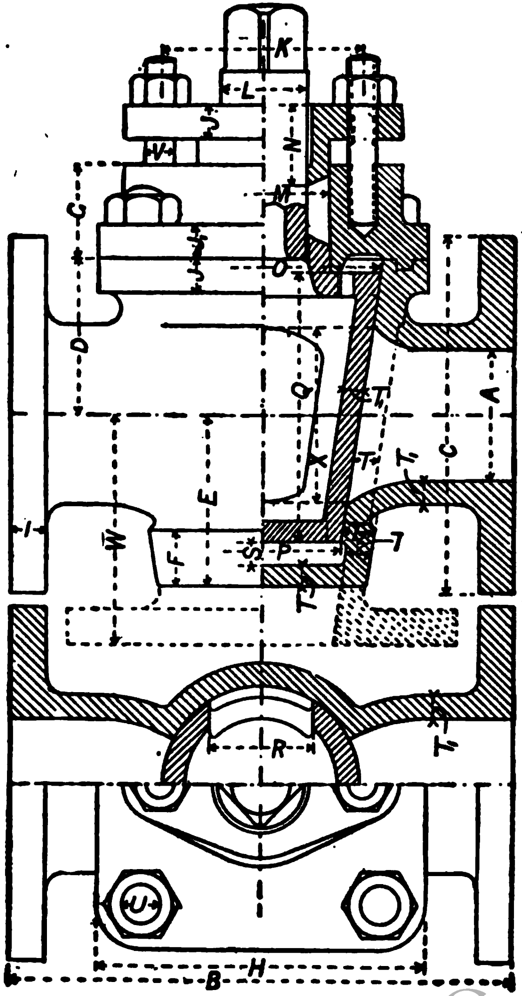


Fig. 200—Steam Cock.

the pipe meeting at the plug may be in the same straight line, or one may proceed from the bottom of the casing, as shown by the dotted lines.

A	1 3/4	2	2 1/4	2 1/2	N	1 3/16	1 1/4	1 5/16	1 3/8
B	7 1/4	7 7/8	8 1/2	9	O	3	3 3/8	3 13/16	4 3/16
C	5	5 3/4	6	6 3/8	P	2 1/16	2 3/8	2 11/16	3
D	1 7/8	2 3/16	2 5/8	2 3/4	Q	3 1/2	4	4 1/2	5
E	2 7/16	2 3/4	2 15/16	3 5/16	R	1 5/16	1 1/2	1 11/16	1 13/16
F	7/8	1	1	1 1/8	S	3/8	3/8	3/8	7/16
G	1 3/8	1 7/16	1 1/2	1 9/16	T	3/8	3/8	7/16	7/16
H	4 1/2	5 1/4	5 5/8	6	T_1	5/16	5/16	3/8	3/8
I	1/2	17/32	9/16	5/8	T_2	7/16	7/16	1/2	1/2
J	1/2	17/32	9/16	5/8	U	1/2	5/8	5/8	5/8
J_1	7/16	15/32	1/2	9/16	V	1/2	1/2	1/2	5/8
K	2 7/8	3 1/4	3 3/8	3 11/16	W	3 3/8	3 3/4	3 7/8	4 1/8
L	1 1/4	1 3/8	1 7/16	1 1/2	X	2 1/4	2 9/16	2 7/8	3 1/8
M	1 7/8	2	2 3/16	2 1/4					

Shaft Hanger with Adjustable Bearing. Figure 201 shows an excellent form of hanger and bearing for a shaft. The bearing is very long, and is held at the center of its length on spherical seats, which are formed on the ends of the vertical adjusting screws. The spherical seats permit of a slight angular movement of the bearing, a movement which is necessary with such a long bearing, to ensure that the axis of the bearing coincides with the axis of the shaft. The bearing and the vertical adjusting screws are made of cast-iron.

Locomotive Connecting-Rod End. A modified form of box end is shown in Fig. 202. This is the design adopted on some roads for the large or crank-pin ends of the connecting-rods. The end of the rod is forked, and the open end is closed by a block which is held in position by a bolt. This bolt has a slight taper, and is screwed at both ends and provided with nuts, so that it may be easily tightened up, and also easily withdrawn. The

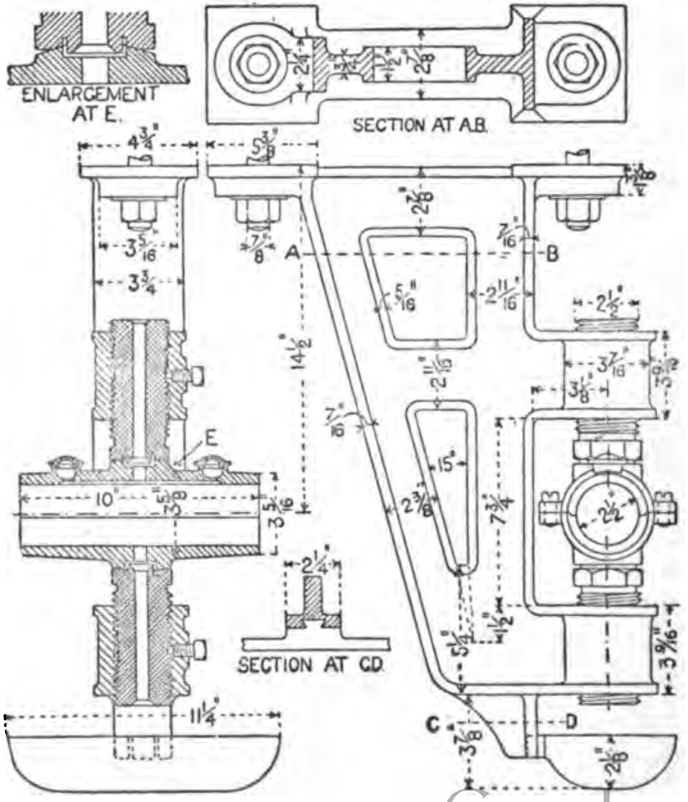


Fig. 201—Shaft-hanger with Adjustable Bearing.

brasses, which have flanges on each side, are tightened up by a wedge-shaped block attached by two pins to a bolt screwed at both ends.

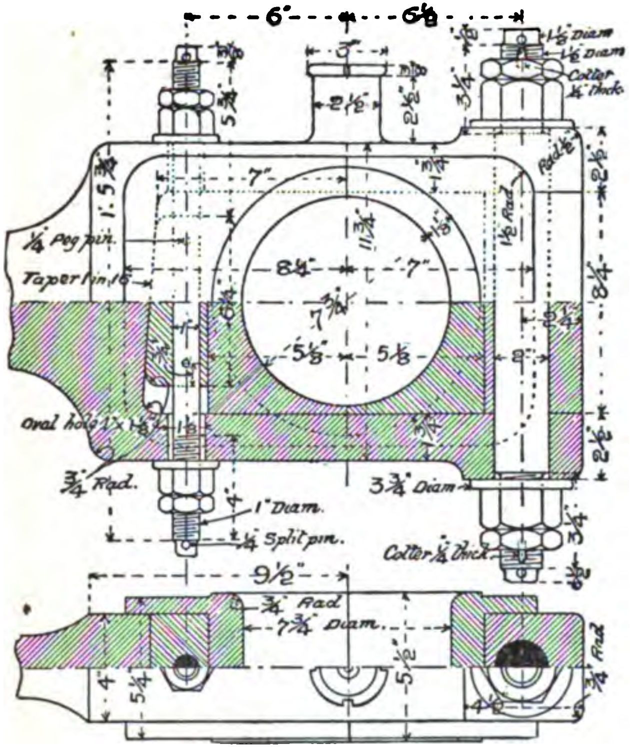


Fig. 202—Locomotive Connecting-rod End.

Since the angular motion of a long connecting-rod is small, the wear of the brasses at the cross-head end is slight. For this reason the bearing at the cross-head end of locomotive connecting-rods is sometimes made solid.

Locomotive Cross-Head. Fig. 203 shows a form of cross-head used on certain railroads. In this form the cross-head and slide-blocks are made in one piece of cast-steel. The cross-head pin is tapered, and carries a phosphor bronze bushing or

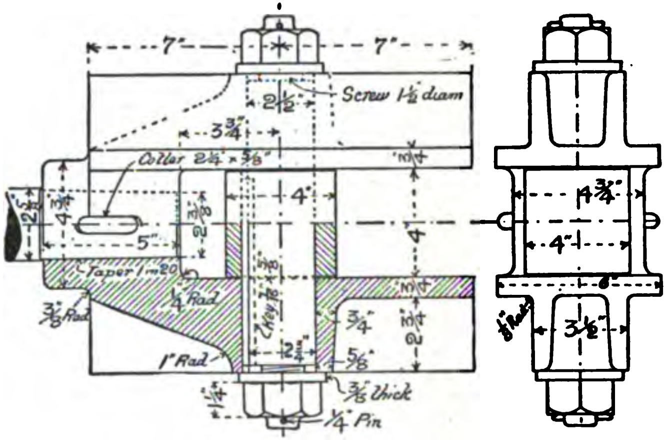


Fig. 203—Locomotive Cross-head.

sleeve at its center, upon which works the connecting-rod end, the latter being solid and fitted with a hardened steel bushing. The phosphor bronze bushing is prevented from rotating on the cross-head pin by a sunk key, which also prevents the pin from rotating.

Horsepower Transmitted by Ropes. Let T_1 be the tension on the tight or driving side of a rope, and T_2 the tension on the slack side. The driving force is then $T_1 - T_2 = P$. Let HP be the horsepower transmitted by one rope, and V the velocity of the rope in feet per minute, then

$$HP = \frac{VP}{33{,}000} \text{ and } P = \frac{33{,}000 HP}{V}$$

The following table has been calculated on the assumption that $\frac{T_1}{T_2} = 4$, and that the greatest stress on the rope is 140 pounds per square inch of the cross section of the rope, so that the driving force $P = T_1 - T_2$, is 105 pounds per square inch of the cross section of the rope. The formula for the horsepower for one rope then becomes

$$HP = \frac{D^2 \times .7854 \times 105V}{33{,}000} = \frac{D^2V}{400}$$

very nearly, where D is the diameter of the rope. If C, the circumference of the rope, be used instead of the diameter, then

$$HP = \frac{C^2V}{3949.44} \text{ or very nearly } \frac{C^2V}{4000}.$$

Diam. of Rope in Inches.	Circum. of Rope in Inches.	Horse Power Transmitted by one Rope when the Speed in Feet per Minute is:						
		3000	3500	4000	4500	5000	5500	6000
1	3.14	7.50	8.75	10.00	11.25	12.50	13.75	15.00
$1\frac{1}{8}$	3.53	9.48	11.07	12.66	14.24	15.82	17.40	18.98
$1\frac{1}{4}$	3.93	11.72	13.67	15.62	17.58	19.53	21.48	23.44
$1\frac{3}{8}$	4.32	14.18	16.54	18.91	21.27	23.63	26.00	28.36
$1\frac{1}{2}$	4.71	16.87	19.69	22.50	25.31	28.12	30.94	33.75
$1\frac{5}{8}$	5.10	19.80	23.11	26.41	29.71	33.01	36.31	39.61
$1\frac{3}{4}$	5.50	22.97	26.80	30.62	34.45	38.28	42.11	45.94
$1\frac{7}{8}$	5.89	26.37	30.76	35.15	39.55	43.95	48.34	52.73
2	6.28	30.00	35.00	40.00	45.00	50.00	55.00	60.00

HORSEPOWER OF GEARS

1. When the circular pitch is given—to find the horsepower capable of being transmitted by cast-iron gears with cut teeth: Multiply the pitch diameter of the gear by the circular pitch of the teeth, by the width of the teeth (all in inch measurements), and by the number of revolutions of the gear per minute. Divide the product by 550 and the result will be the horsepower the gear is capable of transmitting.

Let **D** be the pitch diameter of the gear, **C** the **circular pitch** and **E** the width of the tooth (all in inch measurements), **R** the number of revolutions of the gear per minute and **H. P.** the horsepower the gear is capable of transmitting, then

$$HP = \frac{D \times C \times F \times R}{550} \qquad (1.)$$

Example: What horsepower will the following cast-iron gear with cut teeth transmit at 100 revolutions per minute? The circular pitch of the gear is 2 inches, the number of teeth 33 and the width of the face of the tooth 2 inches.

Answer: As the pitch diameter of the gear is approximately 21 inches, then

$$HP = \frac{21 \times 2 \times 2 \times 100}{550} = 15.27$$

Note: A cast-iron gear with cut teeth of 1 inch circular pitch and 1.048 inches width of tooth and with 33 teeth will transmit 1 horsepower at 50 revolutions per minute. As the pitch diameter of the gear is approximately 10½ inches, then

$$\frac{10.5 \times 1 \times 1.048 \times 50}{550} = 1 \text{ horsepower.}$$

2. When the diameter pitch is given to find the horsepower capable of being transmitted by cast-iron gears with cut teeth: Multiply the pitch diameter of the gear by the width of the tooth (both in inch measurements), and by the number of revolutions of the gear per minute. Divide the product by the **Diametral pitch** and by 175, and the result will be the horsepower the gear is capable of transmitting.

Let **D** be the pitch diameter of the gear, **F** the width of the tooth (both in inch measurements), **R** the number of revolutions of the gear per minute of the gear, **P** the diametral pitch and **H. P.** the horsepower, then

$$HP = \frac{D \times F \times R}{P \times 175} \qquad (2)$$

Example: What horsepower will the following cast-iron gear with cut teeth transmit at 100 revolutions per minute? The diametral pitch of the gear is 1½, the width of the face of the tooth 2 inches, and the pitch diameter 20 inches.

Answer: $\frac{20\times2\times100}{1.5\times175}=15.24$ horsepower.

3. To find the horsepower capable of being transmitted by a gear with cut teeth of any given material. Multiply the results obtained by Rule 1 or 2, or by Formula 1 or 2, by the coefficients for the various metals given herewith.

Cast iron being taken as 1 or unity, then: Malleable Iron=1.25, Brass=1.33, Bronze=1.66, Gun Metal=2.00, Phosphor Bronze=3.00, Wrought-Iron=3.33, Steel=4.00.

Example: If a cast-iron gear of given dimensions will transmit 2 horsepower, what horsepower will a similar gear if made of phosphor bronze?

Answer: As the coefficient for phosphor bronze is 3, then $2\times3=6$ horsepower that the gear will transmit if made of phosphor bronze in place of cast iron.

Note: If the **diametral** instead of the **circular pitch** be given. To find the circular pitch of the teeth, divide 3.1416 by the diametral pitch of the gear.

Example: Required the circular pitch of the teeth of a gear of 4 diametral pitch?

Answer: 3.1416 divided by 4, gives .7854 as the circular pitch in inches of the gear teeth.

Example: What is the circular pitch of a gear of 2 diametral pitch?

Answer: 3.1416 divided by 2, gives 1.5708 inches as the circular pitch of the gear teeth.

Transmission of Motion by Gears.

Motion is in many cases transmitted by means of gear wheels, and accordingly as the driving and driven are of equal or unequal diameters, so are equal or unequal velocities produced.

When time is not taken into account. Divide the greater diameter, or number of teeth, by the lesser diameter, or number of teeth, and the quotient is the number of revolutions the lesser will make for 1 of the greater.

Example: How many revolutions will a pinion of 20 teeth make for 1 of a gear with 125 teeth?

Answer: $125\div20=6.25$, or 6¼ revolutions.

Intermediate gears of any diameter, used to connect other gears at any required distance apart, cause no variation of velocity more than otherwise would result if the first and last gears were in mesh.

To find the number of revolutions of the last, to 1 of the first, in a train of gears and pinions. Divide the product of all the teeth in the driving by the product of all the teeth in the driven gears, and the quotient will equal the ratio of velocity required.

Example: A gear of 42 teeth giving motion to one of 12 teeth, on which shaft is a pulley of 21 inches diameter, driving one of 6 inches diameter, required the number of revolutions of the last pulley to one of the first gear.

Answer: $(42\times21)\div(12\times6)=12.25$, or $12\frac{1}{4}$ revolutions.

Where increase or decrease of velocity is required to be communicated by gears, it has been demonstrated that the number of teeth on the pinion should not be less than 1 to 6 of its wheel, unless there be other reasons for a higher ratio.

When time must be regarded. Multiply the diameter, or number of teeth in the driving gear, by its velocity in any given time, and divide the product by the required velocity of the driven gear, the quotient equals the number of teeth, or diameter of the driven gear, to produce the velocity required.

Example: If a gear containing 84 teeth makes 20 revolutions per minute, how many teeth must another contain to work in contact, and make 60 revolutions in the same time?

Answer: $(84\times20)\div60=28$ teeth.

The distance between the centers and velocities of two gears being given, to find their proper diameters. Divide the greatest velocity by the least. The quotient is the ratio of diameter the wheels must bear to each other. Hence, divide the distance between the centers by the ratio plus 1. The quotient will equal the radius of the smaller gear, and subtract the radius thus obtained from the distance between the centers, the remainder will equal the radius of the other gear.

Example: The distance of two shafts from center to center is 50 inches, and the velocity of one shaft is 25 revolutions per minute, the other shaft is to make 80 revolutions in the same time. Required the proper diameters of the gears at the pitch lines.

Answer: $80\div25=3.2$, the ratio of velocity, and $50\div(3.2+1)=11.9$, the radius of the smaller wheel; then $50-(11.9\times38.1)$ the radius of the larger gear. Their diameters are therefore $11.9\times2=23.8$, and $38.1\times2=76.2$ inches.

To obtain or diminish an accumulated velocity by means of gears and pinions, or gears, pinions, and pulleys, it is necessary that a proportional ratio of velocity should exist, and which is obtained thus: Multiply the given and required velocities together, and the square root of the product is the mean or proportionate velocity.

Example: Let the given velocity of a gear containing 54 teeth equal 16 revolutions per minute, and the given diameter of an intermediate pulley equal 25 inches, to obtain a velocity of 81 revolutions in a machine. Required the number of teeth in the intermediate gear, and the diameter of the last pulley.

Answer: $\sqrt{81\times 16}=36$ the mean velocity, $(54\times 16)\div 36=24$ teeth, and $(25\times 36)\div 81=11.1$ inches, the diameter of the pulley.

Diametral Pitch System of Gears.

The **Diametral pitch** system is based on the number of teeth to one inch diameter of the pitch circle. Formulas are herewith given so that if the number of teeth in the gear and the diametral pitch are known, the pitch diameter of the gear may be found, also the outside diameter, the working depth and clearance at the bottom of the tooth. Let **P** be the pitch diameter in inches, **D** the diametral pitch of the gear, **C** the circular pitch in inches, **O** the outside diameter in inches, **T** the thickness of the tooth at the pitch line in inches, **W** the working depth of the tooth in inches, and **N** the number of teeth in the gear, then

P = Pitch diameter	$=\frac{N}{D}$	(1.)
O = Outside diameter	$=P+\frac{2}{D}$	(2.)
D = Diametral pitch	$=\frac{N}{P}$	(3.)
C = Circular pitch	$=\frac{3.142}{D}$	(4.)
W = Working depth of tooth	$=\frac{2}{D}=2\div D$	(5.)
N = Number of teeth	$=P\times D$	(6.)
T = Thickness of tooth	$=1.571\div D$	(7.)
Clearance at bottom of tooth	$=\frac{0.157}{D}$	(8.)

Example: Required, the pitch diameter of a gear with 20 teeth and 4 diametral pitch.

Answer: From Formula 1, as the pitch diameter is equal to the number of teeth divided by the diametral pitch, then 20 divided by 4 equals 5, as the required pitch diameter in inches.

Example: What is the outside diameter of the same gear?

Answer: From Formula 2, as the pitch diameter is 5 inches and the diametral pitch 4, then 4 plus 2-4 equals 4½ as the proper outside diameter for the gear.

Example: What should be the diametral pitch of a gear with 30 teeth and 6 inches pitch diameter?

Answer: From Formula 3, 30 divided by 6 equals 5, as the diametral pitch to be used for the gear.

Example: Required the circular pitch of the teeth of a gear whose diametral pitch is 6.

Answer: From Formula 4, 3.142 divided by 6 gives 0.524 inches as the circular pitch of the teeth of the gear.

Example: What should be the working depth of a tooth of 4 diametral pitch?

Answer: From Formula 5, 2 divided by 4 gives 0.5 or one-half an inch as the working depth of the tooth.

Example: How many teeth are there in a gear of 7 inches pitch diameter and 7 diametral pitch?

Answer: From Formula 6 the number of teeth is equal to 7 multiplied by 7, or 49 teeth in the gear.

Example: What is the thickness at the pitch line of a tooth of 8 diametral pitch?

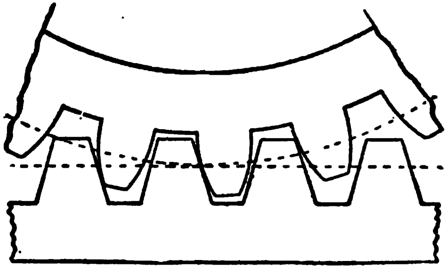


Fig. 204—Rack with Straight Face Involute Teeth.

Answer: By Formula 7 the thickness of the tooth at the pitch line is 1.571 divided by the diametral pitch, then 1.571÷8 gives 0.196 inches as the thickness of the tooth.

Example: What should be the correct clearance at the bottom of a tooth of 3 diametral pitch?

Answer: From Formula 8 the clearance at the bottom of the tooth is equal to 0.157 divided by 3, which gives 0.052 as the required clearance.

When the pitch circle becomes of infinite diameter, as in a rack, the base circle will also become of infinite diameter, and the involute will become a straight line. Hence, in a rack which gears with a wheel having involute teeth, the teeth are straight on face and flank, as shown in Fig. 204. The faces and flanks are at right angles to the path of contact, and therefore make an angle of 75 degrees with the pitch line.

Table No. 10 gives the dimensions of Involute Tooth Spur Gears from 1 to 16 Diametral pitch.

DIMENSIONS OF INVOLUTE TOOTH SPUR GEARS.

Diametral Pitch.	* Circular Pitch.	Width of Tooth on Pitch Line.	Working Depth of Tooth	Actual Depth of Tooth.	Clearance at Bottom of Tooth.
1	3.142	1.571	2.000	2.157	0.157
2	1.571	0.785	1.000	1.078	0.078
3	1.047	0.524	0.667	0.719	0.052
4	0.785	0.393	0.500	0.539	0.039
5	0.628	0.314	0.400	0.431	0.031
6	0.524	0.262	0.333	0.360	0.026
7	0.447	0.224	0.286	0.308	0.022
8	0.393	0.196	0.250	0.270	0.019
10	0.314	0.157	0.200	0.216	0.016
12	0.262	0.131	0.167	0.180	0.013
14	0.224	0.112	0.143	0.154	0.011
16	0.196	0.098	0.125	0.135	0.009

*The circular pitch corresponding to any diametral pitch number, may be found by dividing the constant 3.1416 by the diametral pitch.

EXAMPLE: What is the circular pitch in inches corresponding to 4 diametral pitch?

ANSWER: Dividing 3.1416 by 4 gives 0.7854 inches as the required circular pitch.

Worm Gearing. A screw which gears with the teeth of a wheel is called a worm, and the wheel is called a worm wheel. In worm gearing the axis of the worm is usually at right angles to the axis of the wheel, but this is not absolutely necessary.

If a section of the worm and wheel be taken by a plane containing the axis of the worm, the teeth of the wheel and the threads of the worm in this section should be the same as for an ordinary toothed wheel and a rack. The curves of the section of the teeth may be cycloidal, but since the teeth of a rack to gear with a wheel with involute teeth are straight from root to point, it is better to make the teeth of a worm wheel of the involute shape, because then the tool for cutting the worm is of a very simple form.

In designing a steam boiler for a given engine, the probable indicator diagram is first drawn, and from this the volume of steam used, at a particular pressure, in one stroke is determined. From a table of the properties of steam which is usually given in treatises on the steam-engine, the weight of a cubic foot of this steam may be found, and from this the weight of steam used in one stroke is calculated. Multiplying the weight of steam used in one stroke by the number of strokes per hour, the weight of steam used per hour is determined.

PROPERTIES OF SATURATED STEAM

Absolute Pressure in lbs. per square inch.	Temperature in degrees Fahrenheit.	Total Units of Heat in 1 lb. weight of Steam	Weight of one cubic foot of Steam in lbs.	Absolute Pressure in lbs. per square inch.	Temperature in degrees Fahrenheit.	Total Units of Heat in 1 lb. weight of Steam.	Weight of one cubic foot of Steam in lbs.
14.7	212.0	1178.1	.038	85	316.1	1209.9	.198
25.	240.1	1186.6	.062	95	324.1	1212.3	.219
35.	259.3	1192.5	.085	110	334.6	1215.5	.252
45.	274.4	1197.1	.108	125	344.2	1218.4	.286
55.	287.1	1201.0	.131	145	355.6	1221.9	.329
65.	298.0	1204.3	.153	165	366.0	1224.9	.371
75.	307.5	1207.2	.175	185	375.3	1227.8	.414

In actual practice, the amount of water evaporated in the boiler is from 1.2 to 1.8 times the amount shown by the indicator diagram of the engine.

Example: To find the weight of water which must be evaporated per hour by a boiler to supply steam to an engine having a cylinder 10 inches in diameter, with a piston stroke of 18 inches. Steam cut off at one-third of the stroke. Revolutions per minute 100. Pressure of steam 50 pounds per square inch by gauge, or 65 pounds per square inch absolute.

Volume of steam used in one stroke

$$= \frac{10^2 \times .7854 \times 18}{3 \times 1728} \text{ cubic feet.}$$

Weight of one cubic foot of steam at an absolute pressure of 65 pounds per square inch, from the Table = .153 pound.

Weight of steam used in one stroke,

$$= \frac{10^2 \times .7854 \times 18 \times .153}{3 \times 1728} \text{ pounds.}$$

Weight of steam used in one minute,

$$= \frac{10^2 \times .7854 \times 18 \times .153 \times 2 \times 100}{3 \times 1728} \text{ pounds.}$$

Weight of steam used in one hour,

$$=\frac{10^2\times.7854\times18\times.153\times2\times100\times60}{3\times1728}\text{pounds.}$$

$$=503.3 \text{ pounds.}$$

In addition to the above quantity of steam, there will be that required to fill the clearance spaces in the cylinder, also a quantity to make up for the loss due to condensation in the cylinder and steam pipe. Allowing a margin of 40 per cent, the boiler will require to evaporate 503.3× 1.4=704.6 pounds, say 705 pounds of water per hour under the given pressure.

Equivalent Evaporation from and at 212°. For the purpose of comparison it is usual to state the weight of steam produced in a boiler on the assumption that the feed water is supplied at a temperature of 212° F., and that it is evaporated at this temperature.

Let W = weight of steam produced at any given temperature or pressure.

H = total heat in 1 pound weight of this steam.

t = temperature of feed water.

W_1 = equivalent weight of steam at 212 degrees temperature produced from feed water at 212 degrees.

Then $W_1(1178.1-212)=W(H-t)$

$$\text{and } W_1=\frac{W(H-t)}{966.1}$$

Example: To determine the equivalent evaporation from and at 212° in the boiler for the engine in the example worked out in the preceding article, supposing that the feed water is supplied at a temperature of 60°.

$$W_1=\frac{705(1204.3-60)}{966.1}=\frac{705\times1144.3}{966.1}=835 \text{ pounds.}$$

Evaporative Performances of Steam Boilers. Theoretically 1 pound of coal should evaporate from 12 to 16 pounds of water from and at 212°, the amount depending on the quality of the coal. The following table gives the weight of water evaporated from and at 212° by 1 pound of average coal in various types of boilers:

Type of Boiler	Water evaporated from and at 212° per pound of Coal.
	Pounds.
Vertical cross-tube boilers	5 to 7
Vertical multitubular boilers	6 " 9
Cornish boilers	7 " 9
Lancashire boilers	8 " 10½
Sectional or water-tube boilers	8 " 10
Marine boilers	8 " 10
Locomotive boilers	8½ " 11
Torpedo-boat boilers	7 " 8½

Vertical Cross Tube Boilers. Vertical boilers possess the advantage of taking up a comparatively small amount of floor area. In its simplest form the vertical boiler consists of a cylindrical shell surrounding a nearly cylindrical fire-box, in the bottom of which is the grate. A tube, called an uptake, passes from the crown of the fire-box to the crown of the shell, where it is connected to a chimney. To increase the amount of heating surface and improve the circulation of the water, and also to increase the strength of the fire-box, the latter is fitted with one or more cross-tubes as shown in Fig. 205.

The vertical seam of the fire-box shell may be a single riveted joint, but in the best work the joint is lap welded. The fire-box shell slopes to the vertical at the rate of ½ inch to ¾ inch per foot of length.

The cross-tubes are either flanged and riveted to the fire-box or they are welded to it. With welded joints in the fire-box double thicknesses of plates are avoided and the chances of overheating at the joints reduced. When the cross tubes are welded in, however, it is more difficult to renew them if they should wear out before the fire-box.

The cross tubes are placed slightly inclined to ensure a more efficient circulation of the water.

The uptake is connected to the crown of the fire-box and to the crown of the outside shell by flanged joints as shown in Fig. 205, or by welded angle iron rings which are riveted to the crowns and to the uptake.

The part of the uptake which passes through the steam space is very liable to become overheated, and to prevent this it is enlarged in diameter from the top to the low-water level and lined with fire-clay. A cast-iron liner is sometimes introduced

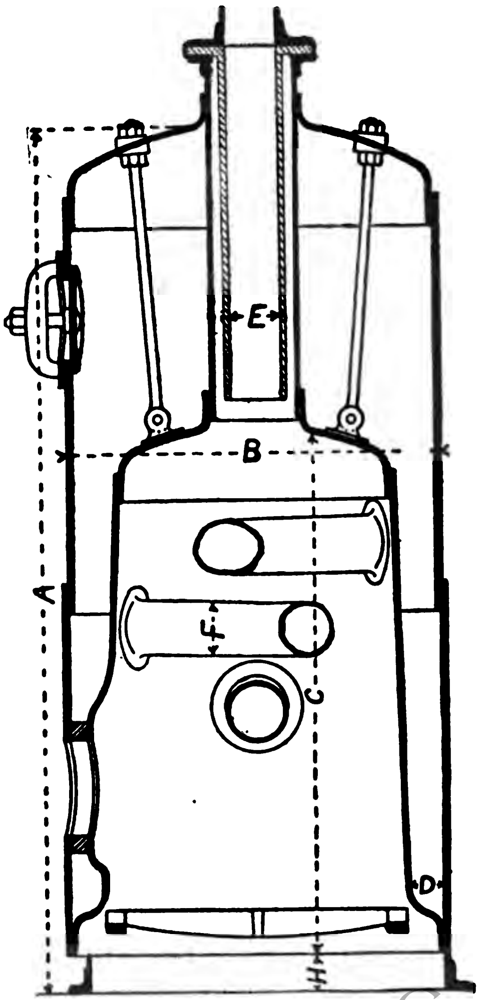


Fig. 205—Vertical Cross Tube Boiler.

for the same purpose. The cast-iron liner may fit close into the uptake, or it may be separated from it all round by an air space not exceeding ¾ inch wide as shown in Fig. 205.

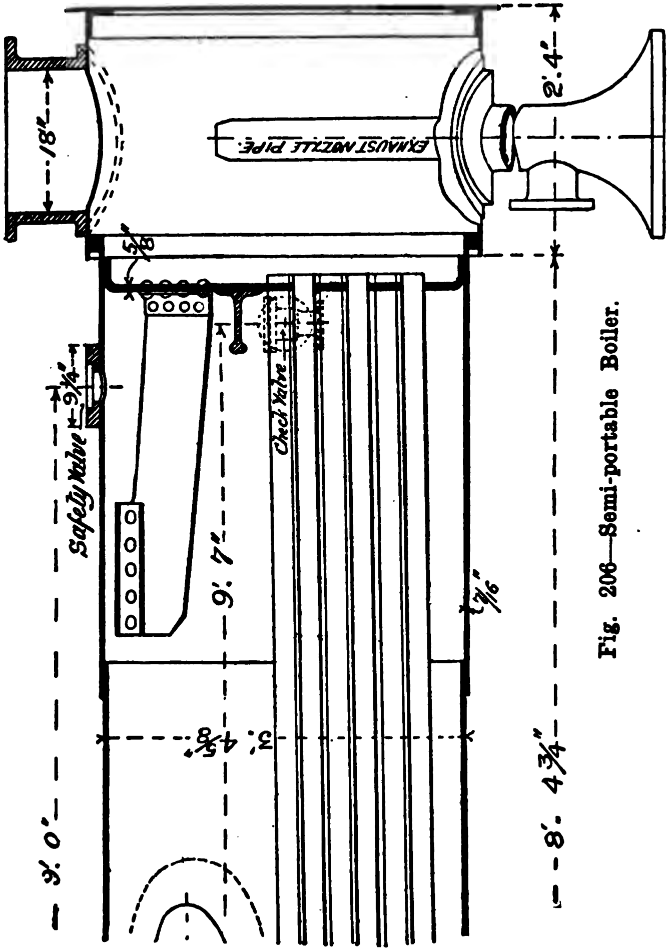


Fig. 206—Semi-portable Boiler.

Semi-Portable Boiler. Boilers of the locomotive type are now largely used for supplying steam to engines for many purposes on land, and they are also used in torpedo boats. Boilers of this class, when used in a fixed position on land, are sometimes called semi-portable, and sometimes semi-fixed. Fig. 206 shows a longitudinal section of the boiler. The shell plates are of steel, and the internal fire-box of steel of special quality. The plates are flanged by hydraulic machinery, and angle-irons are dispensed with, except at the front end of the smoke-box, and there a flanged ring is used.

The edges of the plates are planed, and the outer face of the flange of the smoke-box tube plate is turned. All the rivet-holes are drilled after the plates have been bent in position, and the riveting is done by machinery.

The circumferential seams of the barrel are double riveted, with rivets ¾ inch diameter at 3¼ inches pitch. The width of the lap is 3⅛ inches, and the distance between the center lines of the two rows of rivets is 1⅝ inches.

The longitudinal seams of the barrel are double riveted, butt joints, strapped outside and inside. The rivets are ¾ inch diameter at 3 3-16 inches pitch. The distance between the center lines of the two inner of the four rows of rivets is 3 inches. The distance between the center line of each outer row and the center line of the adjacent inner row is 1⅞ inches. The total width of the butt straps is 9⅜ inches.

The tubes have an external diameter of 2½ inches, and they are ⅛ inch thick.

The smoke-box tube plate and the back end plate are stayed to the shell by long gusset stays, and they are also stiffened by **T**-irons. The sides of the inner fire-box are stayed to the outer fire-box by screwed stays. The crown of the inner fire-box is stayed by girder stays, which are placed transversely as shown.

The boiler is supported at the fire-box end on a cast-iron frame, not shown in the illustrations, which serves as an ash-pit. The smoke-box end is supported on a hollow cast-iron pillar, into which the exhaust steam from the engine is led on its way to the chimney.

There is a total heating surface of 290.5 square feet, and a grate area of 11.2 square feet.

The working steam-pressure is 140 pounds per square inch.

This boiler, which is a 20 nominal horsepower boiler, is capable of supplying steam to a compound engine having high and low pressure cylinders of 9 inches and 14 inches diameter respectively, with a piston stroke of 16 inches, the crank-shaft making 135 revolutions per minute.

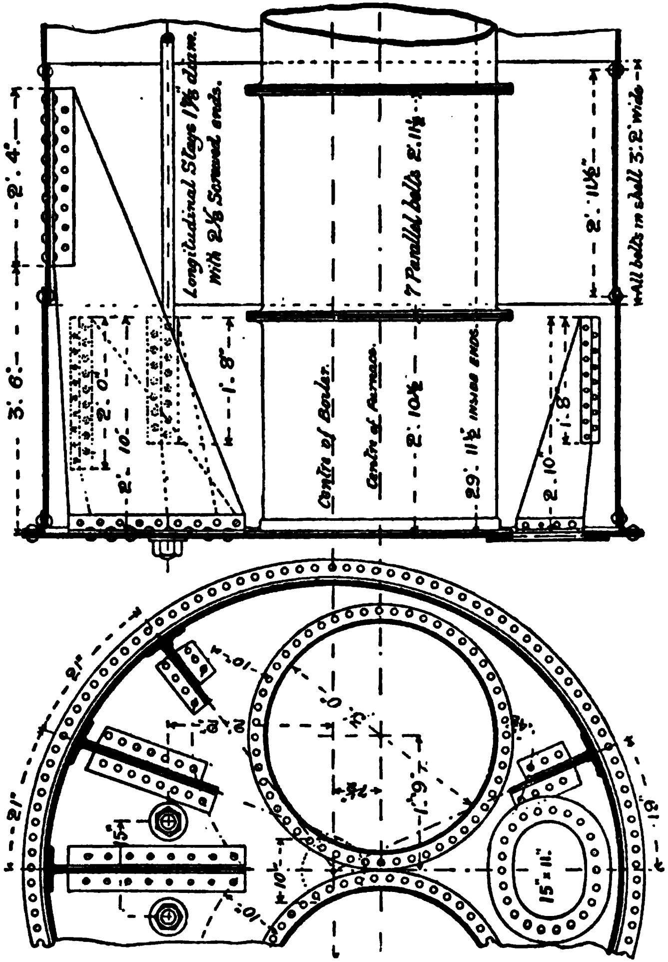


Fig. 207—Gusset Stays.

Gusset Stays. A gusset stay is a diagonal stay in which a flat plate is used instead of a bar or rod.

The most important application of the gusset stay is to be found in Cornish and Lancashire boilers for staying the flat ends to the cylindrical shell.

The following description of the arrangement of the gusset stays in a Lancashire boiler, 7 feet 6 inches in diameter, for a working pressure of 100 pounds per square inch, is given:

To arrange the staying so that it shall give adequate support to the flat ends without rendering them unnecessarily rigid, is a point of considerable importance in boilers of the single or double flued internally fired class. If the ends be made too stiff, there is a serious risk of grooving being set up, either in the end plate at the edge of the upper part of the furnace tube angle iron, or at the root of the angle iron itself. This is more particularly the case at the front end, and arises from the varying thrust of the upper portion of the furnace tube upon the end plate. To avoid the risk of grooving, therefore, a certain space should be allowed between the rivets of the furnace tube angle iron and the lowest rivets of the gussets. This is a point in which a mistake is often made, and, with a desire to render the end plate sufficiently strong, the gussets are extended until they almost touch the furnace tube angle iron, the result being that a grooving action is set up when the boiler is put to work, and, although the defect under such circumstances may not be a source of danger, yet it gives rise to considerable annoyance and inconvenience, and is sure sooner or later to necessitate extensive repairs.

The arrangement of staying shown in Fig. 207 is the outcome of extensive experience, and represents, in fact, the most modern practice of the best makers of this class of boiler.

The arrangement of the gussets, it will be seen, follows a simple geometrical arrangement. The gussets are pitched uniformly at a distance of 21 inches apart, measured along the circumference of the shell, except at the bottom of the front end, where the pitch is reduced to 19 inches, with a view to bringing them as close to the mudhole mouthpiece as possible, and thus assist in supporting the flat space below the tubes. At the back end, as there is no mudhole to interfere with the arrangement, a single central gusset stay is adopted.

To ascertain the horsepower when the average pressure upon the piston in pounds per square inch is known.

Find the area of the piston in square inches, by multiplying the square of its diameter by 0.7854.

Find the total pressure in pounds on the piston by multiplying its area by the average effective pressure in pounds per square inch. The average effective pressure is the average pressure in pounds per square inch less 14.7, which must be deducted to allow for the atmospheric pressure against the piston.

Find the useful piston travel in feet per minute by multiplying twice the length of the piston stroke in feet by the number of revolutions per minute of the crank shaft, for a double-acting steam engine. Find the energy in foot pounds per minute by multiplying the total pressure in pounds on the piston by the useful piston travel in feet per minute.

The horsepower may then be ascertained by dividing the energy in foot-pounds per minute by 33,000.

While there are numerous formulas in use for calculating the horsepower of an engine, one of the most simple is as follows:

$$HP = \frac{P \times L \times A \times N}{33{,}000}$$

Where **P** is the average effective pressure in pounds per square inch, **L** twice the length of the piston stroke in feet, **A** the area of the piston in square inches and **N** the number of revolutions of the crank shaft per minute.

Length of Stroke of Piston. If the speed of the piston in feet per minute **S**, and the number of revolutions, **R**, of the crank shaft per minute are given, then the length of the stroke l in feet is given by the formula $l = \frac{S}{2R}$.

No definite rule can be given for the length of the stroke. In single cylinder engines the stroke of the piston is generally made to depend on the diameter of the cylinder, but the relation is very variable, some engineers make the length of the stroke equal to twice the diameter of the cylinder. In locomotive engines the stroke of the pistons varies from 1.2 to 1.55 times the diameter of the cylinders.

Speed of Piston. The speed of a piston is usually given in feet per minute, and is the distance in feet which it goes in one minute. This is the mean speed. The speed varies from nothing at the beginning and end of each stroke to a maximum near the middle of the stroke. The mean speed of the piston is determined by multiplying the length of the stroke in feet by the number of strokes per minute.

In case of a locomotive engine, if l=length of stroke of pistons in feet, D=diameter of driving wheels in feet, M=speed of train in miles per hour, and S=speed of pistons in feet per minute, then

$$S=\frac{M\times 5280\times 2\times l}{D\times 3.1416\times 60}=\frac{56.02Ml}{D}$$

For engines of the same class the speed of piston is generally greater, the greater the length of the stroke, and may be taken as proportional to the cube root of the stroke.

The following table gives speeds of pistons to be met with in ordinary practice:

Class of Engine.	Speed of Piston in Feet per Minute.
Ordinary direct-acting pumping engines (non-rotative)	90 to 130
Ordinary horizontal engines	200 to 400
Horizontal compound and triple-expansion mill engines	400 to 800
Ordinary marine engines	400 to 650
Engines for large high-speed steamships	700 to 900
Locomotive engines	800 to 1000
Engines for torpedo-boats	1000 to 1200

Clearance and Clearance Volume. The term clearance as applied to steam cylinders may mean the distance between the cylinder cover and the piston when the latter is nearest to the cover, or it may mean the volume of the space between the piston and the steam valve when that space is least—that is, when the piston is at the beginning of its stroke.

Clearance in a steam cylinder is necessary to provide for any slight inaccuracy in the setting of the cylinder in relation to the crank shaft, to provide for inequalities on the surfaces of the piston and the cylinder cover, to provide for the slight errors which may occur in the lengths of the piston-rod, connecting-rod, and crank arms, and to provide for the wear which takes place at the cross-head, crank-pin, and crank-shaft bearings.

The amount of the clearance varies with the size of the engine, being about three-eighths of an inch in small engines, and seven-eighths of an inch in large engines. In horizontal engines the clearance is generally the same at both ends of the cylinder, but in inverted cylinder engines, such as are now used in steamships, the clearance at the lower end is usually about one and a half times the clearance at the upper end.

The clearance volume is usually expressed as a percentage of the volume swept through by the piston in one stroke, and it varies from 2 to 15 per cent in different cases.

Classification of Valves. A valve is a piece of mechanism for controlling the magnitude or direction of the motion of a fluid through a passage. The seat of a valve is the surface against which it presses when closed, and the face of the valve is the portion of its surface which comes in contact with its seat. Valves may be classified according to the means by which they are moved. In one class the valves are moved by the pressure of the fluid. Nearly all pump valves belong to this class. The valves belonging to this class are automatic in their action, and they permit the fluid to pass in one direction only. Flap valves, flexible disc valves, lift valves (including rigid disc valves with flat seats, disc valves with bevelled edges fitting on conical seats, and ball valves), belong to the class of valves moved by the fluid. In another class the valves are moved by hand or by external mechanism, so that the motion of the valve is independent of the motion of the fluid.

Since many of the valves belonging to the first class mentioned above may be converted into valves of the second class without altering the construction of the valves themselves, a better classification is as follows: flap valves, which bend or turn upon a hinge, lift valves, which rise perpendicularly to the seat, sliding valves, which move parallel to the seat.

Piston Valves. To overcome the friction of a slide valve of large area, working under a high steam pressure, requires the expenditure of a considerable amount of power. This waste of power may be reduced by fitting the back of the valve with a relief frame containing packing rings which press against the back of the valve casing, and so cut off a portion of the area of the valve from the pressure of the steam, but this and other arrangements for partly balancing the valve have not proved quite satisfactory.

The great waste attending the use of large slide valves under high pressure steam has led engineers to adopt piston valves, which, although usually much more expensive to construct than ordinary slide valves, require very much less power to work them.

A piston valve is really a slide valve in which the face and seat are complete cylindrical surfaces. A piston valve is perfectly balanced so far as the steam pressure is concerned, and the only friction to be overcome is that due to the small side pressure necessary to keep the valve steam tight. Piston valves are made steam-tight in much the same way as ordinary pistons, but since the amount of the motion of the valve is small compared with that of the engine piston, the wear is small, and the springs therefore may be stiff with very little range.

Cylinder Flange. The thickness of the cylinder

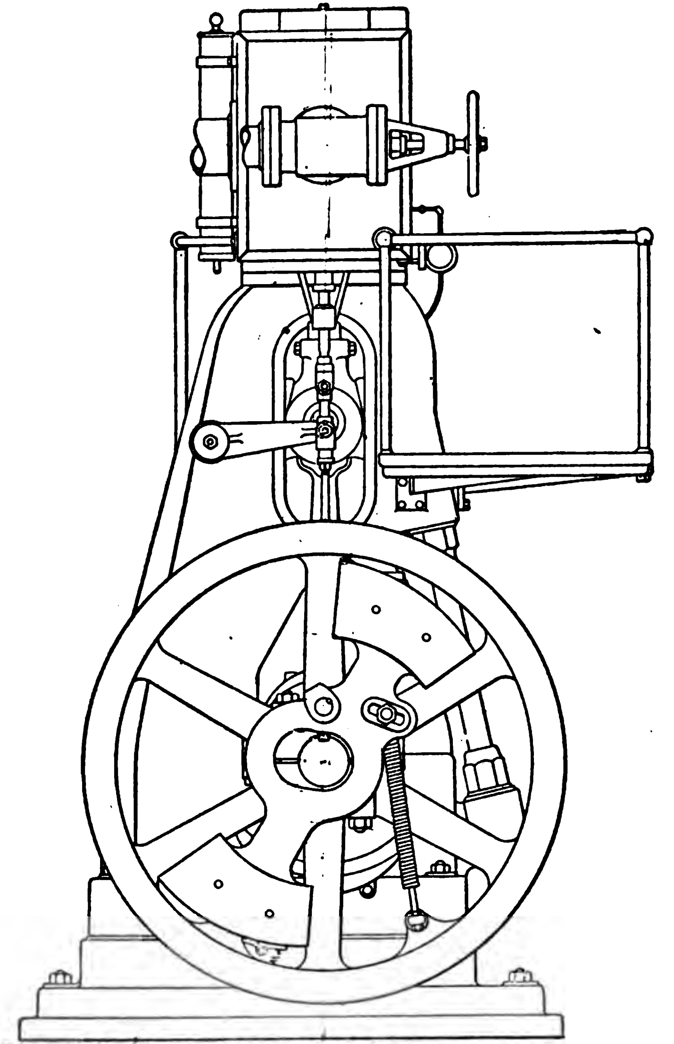


Fig. 208—Simple Expansion, Piston-valve Engine, end Elevation.

flange varies in practice from 1.2 to 1.4 times the thickness of the cylinder barrel. The width of the flange is determined by the size of the bolts for securing the cover to the cylinder. The distance from the center of the bolts to the outside of the flange should not be less than $d+\frac{1}{4}$ inch, and need not be more than $1\frac{1}{2}d$, where d is the diameter of the bolt over the threads.

Bolts for Cylinder Cover. The bolts used for securing the cylinder cover to the cylinder are nearly always stud bolts. Stud bolts are preferred to bolts with heads for two reasons: first, the cylinder flange may be narrower when stud bolts are used, second, bolts with heads cannot be removed without interfering with the lagging round the cylinder.

Let d = nominal diameter of bolts in inches.
d_1 = diameter of bolts at bottom of screw thread in inches.
n = number of bolts.
f = stress on bolts in pounds per square inch of net section.
D = diameter of cylinder.
p = pressure of steam in pounds per square inch.

Then $.7854 d_1^2 n f = .7854 D^2 p$

$$\text{and } d_1 = D\sqrt{\frac{p}{nf}}.$$

Bolts of less than ⅝-inch diameter should not be used for cylinder covers, and the stress f should be less for small bolts than for large ones. f may be taken at 4000d. but should not exceed 6000.

The number of bolts depends on their distance apart, which, again, depends on the thickness of the flange of the cover and the pressure of the steam. One rule gives the maximum pitch of the bolts equal to $40\sqrt{\frac{t}{p}}$, where t is the thickness of the flange in inches.

Simple Expansion, Piston Valve Engine. Figs. 208 and 209 show elevations of a simple expansion, piston valve steam engine. The main bearings are ring oiling, with a babbitted shell for the lower half which rests on a broad seat in the casting, thus giving firm support to the crank shaft and correct alignment. Encircling the shaft are bronze oil rings, running on the shaft midway of the bearings. Oil grooves in the babbitt shell are so cut that the oil can only get out of the bearings by working towards each end, whence it flows back to the reservoir in the center.

Compound and Multiple Stage Expansion Engines. The greater the amount of the expansion of the steam in a steam cylinder, the greater, theoretically, is the amount of work obtained from a given weight of steam. But when steam expands its temperature falls, consequently the steam cylinder is heated by the high pressure steam at the beginning of the stroke, a result which is followed by a partial condensation of that steam. Then, as the steam expands, its temperature falls, and so does that of the cylinder, part of the heat of the

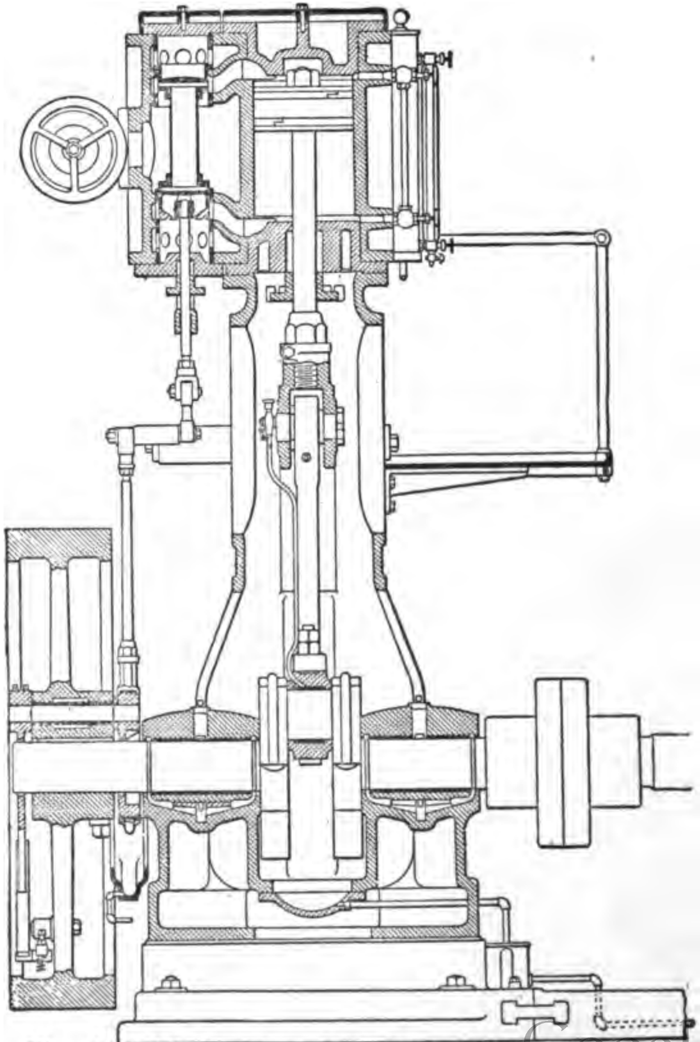


Fig. 209—Simple Expansion, Piston-valve Engine, Side Elevation.

latter going to warm the steam and re-evaporate the water deposited at the beginning of the stroke. It is, therefore, evident that with a great range of temperature in the cylinder, consequent on a high rate of expansion, a portion of steam may be condensed at the beginning of the stroke, and reconverted into steam towards the end of the stroke, and thus pass through the cylinder without doing work.

To obtain the advantage following the high rate of expansion, and to obviate to some extent the loss due to the fall in temperature of the expanded steam, the compound engine was introduced. In the compound engine the steam is allowed to expand to a certain extent in one cylinder, and is then passed into a larger cylinder and allowed to expand still further. In this way the range of temperature in each cylinder is much less than it would be if the whole expansion was carried out in one cylinder, and any condensed steam, re-evaporated at the end of the stroke in the first cylinder, does work in the second. But, neglecting the losses due to condensation and wire-drawing of the steam, the total work done in the two cylinders is the same as if the steam was used in the larger or low-pressure cylinder only, the total amount of expansion being the same in both cases.

The range of temperature may be still further reduced by expanding the steam successively in three cylinders as in triple expansion engines, and still further by expanding successively in four cylinders as in quadruple expansion engines.

Ratios of Cylinder Volumes in Compound and Multiple Stage Expansion Engines. When steam is expanded in two or more cylinders successively, the considerations which determine the relative volumes of the cylinders are: The distribution of the power between the cylinders, the distribution of the initial loads on the pistons, and the range of temperature in each cylinder. When there is a separate crank for each cylinder it is very desirable that the total power should, as nearly as possible, be equally divided between the cylinders, and also that the initial or maximum loads on the pistons should be nearly equal. In all cases also the range of temperature should be as nearly as possible the same in each cylinder.

No hard and fast rules can be given for the relative volumes of the cylinders of compound and multiple stage expansion engines. In actual practice the ratios of the volumes of the cylinders vary considerably. The following rules and tables are based on the averages of a large number of examples from recent practice, and may therefore be of service in determining, provisionally, the relative sizes of the cylinders.

P=Pressure of steam in boiler by gauge in pounds per square inch.

Compound or two stage expansion condensing engines.

$$\frac{\text{Vol. of L.P. cylinder}}{\text{Vol. of H.P. cylinder}} = \frac{4P+40}{100}.$$

The following examples have been worked out by the above rule, the volume of the high-pressure cylinder being taken as 1.

Boiler Pressure by Gauge.	60	70	80	90	100	110	120
Vol. of H.P. cylinder....	1.	1.	1.	1.	1.	1.	1.
Vol. of L.P. cylinder	2.8	3.2	3.6	4.	4.4	4.8	5.2

Triple or three stage expansion condensing engines.

$$\frac{\text{Vol. of I.P. cylinder}}{\text{Vol. of H.P. cylinder}} = \frac{P+100}{100}.$$

$$\frac{\text{Vol. of L.P. cylinder}}{\text{Vol. of H.P. cylinder}} = \frac{4P+50}{100}.$$

The following examples have been worked out by the preceding rules, the volume of the high-pressure cylinder being taken as 1.

Boiler Pressure by Gauge.	120	130	140	150	160	170	180
Vol. of H.P. cylinder....	1.	1.	1.	1.	1.	1.	1.
Vol. of I.P. cylinder	2.2	2.3	2.4	2.5	2.6	2.7	2.8
Vol. of L.P. cylinder	5.3	5.7	6.1	6.5	6.9	7.3	7.7

Jet Condensers—Quantity of Injection Water. The terminal pressure in the low-pressure cylinder of a steam engine may be taken at from 5 to 10 pounds per square inch absolute, so that every pound weight of steam as it passes into the condenser will contain from 1131 to 1140 British thermal units of heat above that contained by 1 pound of water at 32° Fahrenheit. This steam is condensed to water having a temperature of 100° to 120°, by mixing it with water of the ordinary temperature. If the temperature of the injection water is 50° and that of the hot well 110°, then every pound of injection water will take up 110—50=60 units of heat. If the total heat in each pound of steam as it leaves the cylinder be taken at 1140 above that contained by water at 32°, then each pound of steam in condensing must give up 1140+32—110=1062 units.

Hence the weight of water to condense 1 pound of steam $= \frac{1062}{60} = 17.7$ pounds.

Let H = number of units of heat in 1 pound weight of steam above that contained by 1 pound of water at 32 degrees.

T = temperature of hot well.

t = temperature of injection water.

W = weight of injection water (in pounds) required for each pound of steam.

Then $W = \frac{H+32-T}{T-t}$

A common rule is, weight of injection water= 25 to 30 times the weight of the steam to be condensed.

The volume of a jet condenser should be proportioned according to the volume of the low-pressure cylinder. The ratio of the volume of the condenser to that of the low-pressure cylinder varies greatly in practice. It should not be less than 1/4, but we know of examples from recent practice where it is as high as 1 1/4. A common rule is to make the volume of the condenser half that of the low-pressure cylinder exhausting into it.

The area of the injection orifice is given by the formula $A = \frac{W}{26v}$. Where

A=area of valve in square inches.

W=weight of injection water required per minute in pounds.

v=velocity of water through the orifice in feet per second.

In many cases in practice v may be taken at 20 feet per second, then, $A = \frac{W}{520}$

Surface Condensers. Since the feed water for the boiler is taken from the hot well of the engine, it is evident that if the injection water is of a character which would be injurious to the boiler if pumped into it, there is then a serious objection to a jet condenser. The difficulty is got over by using a surface condenser. In marine engines where the injection water is taken from the sea, surface condensers are always adopted. Surface condensers are either cylindrical or rectangular shells, and are made of brass, cast-iron, wrought-iron, or steel. The end or tube plates are gen-

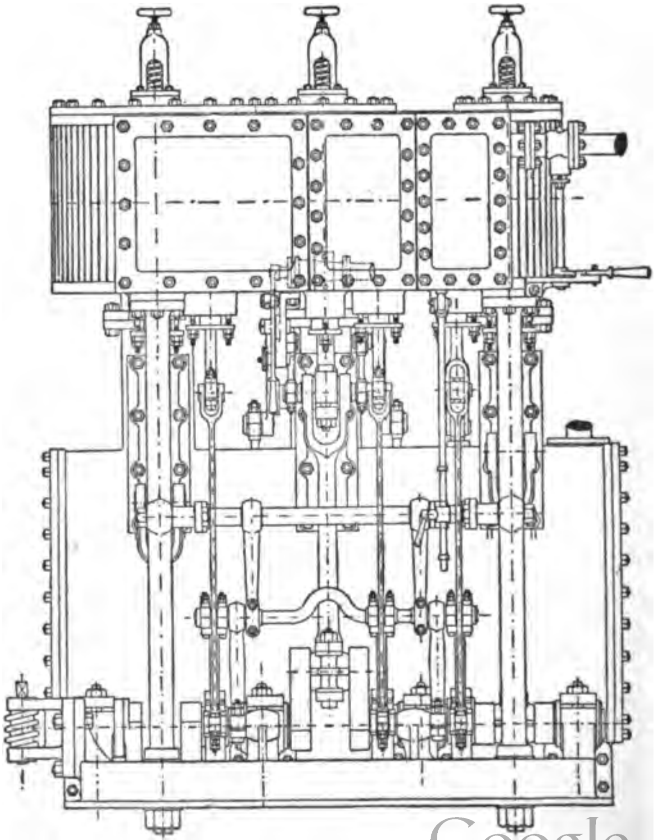


Fig. 210—Triple Expansion Marine Engine, Side Elevation.

erally made of rolled brass. This form of condenser contains a large number of tubes, which pass from one end of the condenser to the other. The tubes are made of brass, and are solid drawn, and they are sometimes tinned outside and inside. They vary in diameter from ½ to 1 inch, but generally they are ¾ inch in diameter outside. The thickness of the tubes is from 16 B. W. Gauge to 19 B. W. Gauge. For ¾-inch tubes, the pitch, or distance from center to center, varies from 1 1/16 inch to 1¾ inches. The length of the tubes varies greatly, depending on the size and design of the condenser. In some cases the length is over 18 feet.

Triple Expansion Marine Engines. Figs. 210 and 211 show elevations of the engines complete, which have been prepared from the working drawings of the makers.

The cylinders are placed in the order, high, intermediate, low, and their diameters are 8 inches, 13 inches, and 21 inches respectively. All the pistons have a stroke of 16 inches. The cylinders are in one casting, and are supported at the back of the engine on three hollow cast-iron columns cast on the condenser. At the front the cylinders are supported by two turned wrought-iron columns, which are flanged at their upper ends, and firmly secured at their lower ends to the bed of the engine.

The guides for the crossheads are formed on the columns on the condenser.

The condenser is of cast-iron in one casting, and contains 228 tubes, giving 220 square feet of cooling surface. The tube plates are made of brass,

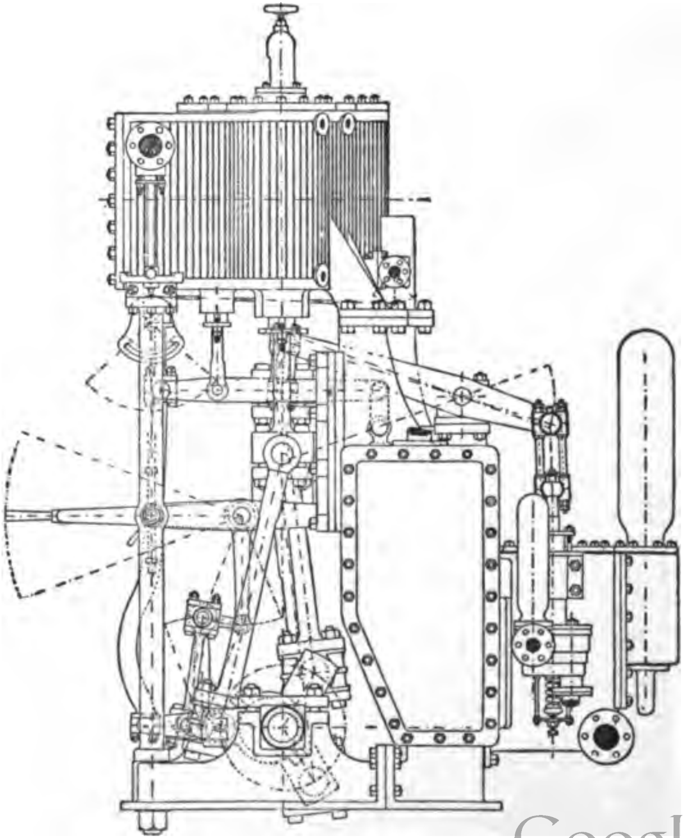


Fig. 211—Triple Expansion Marine Engine, End Elevation.

and are 4 feet 11 inches apart. The circulating or cooling water enters the condenser at the bottom, and passes through the lower nest of 114 tubes, and back through the upper nest of 114 tubes. The cover on one end of the condenser has cast on it, on the inside, an air vessel, which serves to reduce the shock due to any irregularity in the flow of the water which enters at that end. The chamber at the same end of the condenser is divided horizontally by a partition, which is cast on the cover and round the air vessel just mentioned. The steam from the low-pressure cylinder passes through the hollow column under it to the condenser, where it passes round the tubes and is condensed and drawn off at the bottom by the air-pump.

The air-pump is a vertical single-acting bucket pump 9 inches in diameter, and the circulating pump is a double-acting piston pump 5 inches diameter, also vertical.

There is one bilge pump and one feed pump, each 1¾ inches in diameter.

All the pumps have a stroke of 8 inches.

The crank shaft is forged and in one piece. The three cranks are equally inclined to one another. The main and crank pin bearings are each 4 inches in diameter. The thrust is taken by a single collar 8 inches diameter forced on the shaft.

The eccentric sheaves are forged on the crank shaft, they are each 7½ inches in diameter, and have an eccentricity of 1¾ inches.

In an important class of mechanisms, it is not so much the modification of velocity, as the paths which the different points of the mechanism trace out, which is of interest. Very frequently some point or tool is required to trace out a particular curve, such as a circle, a straight line, an ellipse, or a helix; and this has to be done mechanically by a combination of links. If the force to be transmitted is small, the combination is termed an instrument; if considerable, a machine.

From a mechanical point of view, the circle is the easiest curve to generate. If a point is required to move in a circular arc, it need only be attached by a link of constant length to a spindle which rotates in fixed bearings, as in the ordinary crank shaft, arm, and pin arrangement. In the case of a circle, therefore, the curve is generated, that is to say, a previously existing circle is not merely used as a copy. But if any other curve, such as a straight line or ellipse, has to be traced out, we must either copy a previously existing straight line or ellipse, or else, by means of a kinematic chain consisting entirely of turning pairs, generate the required curve. We now proceed to discuss those mechanisms which either generate or copy some particular curve.

Parallel Motions. By far the most important mechanisms are those which either generate or copy a straight line. They are usually referred to as parallel motions.

Parallel motions may be divided into two classes, namely—

(1) Those consisting entirely of turning pairs, and in which, therefore, a straight line is either exactly or approximately generated;

(2) Those containing one or more sliding pairs on which the accuracy of the line traced out depends, and which, therefore, may be looked upon as copying machines.

Peaucellier's Cell. Consider, first, those parallel motions which generate a mathematical straight line. The most familiar example is the mechanism known as **Peaucellier's Cell.** It consists of a jointed rhombus or cell, ABCD, the links comprising it being all of the same length (Fig. 212). The pins B and C are coupled to a fixed center, P_1, by two links, P_1B and P_1C, of equal length; while the pin A is coupled to a second fixed center, P_2, by a link, P_2A, equal in length to the distance P_1P_2 between the two centers, so that when motion takes place, A is constrained to describe a circular arc passing through P_1. Under these conditions, the fourth pin, D, will trace out a straight line perpendicular to P_1P_2. It will be noticed that all the links in the chain move parallel to one plane.

To prove this statement, it is clear that in all positions of the mechanism the points P_1, A, and D are collinear. Moreover, since the diagonals AD, BC of the cell bisect each other at right angles,

$$\begin{aligned} P_1A \times P_1D &= (P_1N - NA)\ (P_1N + NA) \\ &= P_1N^2 - NA^2 \\ &= (P_1B^2 - NB^2) - (AB^2 - NB^2) \\ &= P_1B^2 - AB^2; \end{aligned}$$

so that, since the links P_1B and AB are of constant length, it follows that in all positions of the mechanism the product $P_1A \times P_1D$ is constant.

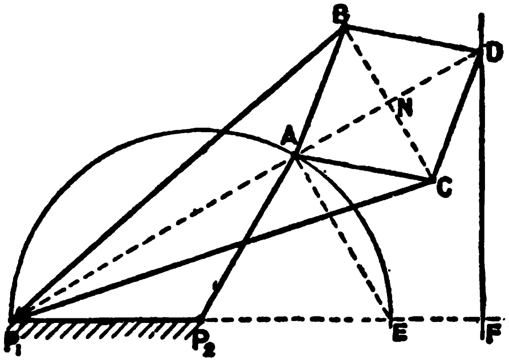


Fig. 212.

Now let the circle described by A meet the line of centers in E, and draw DF perpendicular to the line of centers. Since the angles DAE and DFE are each a right angle, the quadrilateral DAEF may be inscribed in a circle, and consequently the product $P_1E \times P_1F$ is equal to the product $P_1A \times P_1D$. and is therefore constant. But $P_1E = 2 \times P_2A$, and is constant; hence in all positions of the mechanism the distance P_1F is constant, from which it follows that the locus of D is the line DF. In Fig. 212, the center P_1 lies outside the rhombus; but it might equally well lie inside it, as shown in Fig. 213. Precisely the same argument is applicable to either figure.

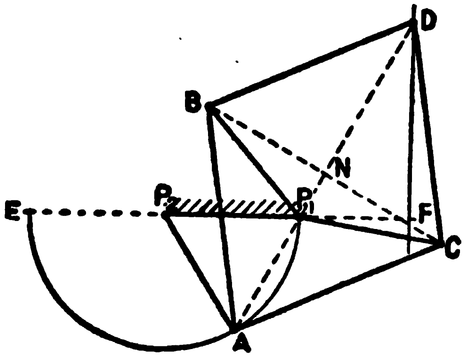


Fig. 213.

Hart's Parallel Motion. Peaucellier's cell is not the only combination of links which generates a true straight line. Any set of links whatever which makes the product, $P_1A \times P_1D$ a constant, where P_1 is a fixed center, will enable D to trace out a straight line, provided A traces out a circle which passes through P_1. A second combination of links satisfying this condition is due to **Hart**, and consists of a crossed parallelogram. In Fig. 214 the links LM, KN are equal, as also are KL and MN. If the links were opened out, the four links would form a parallelogram; hence the term

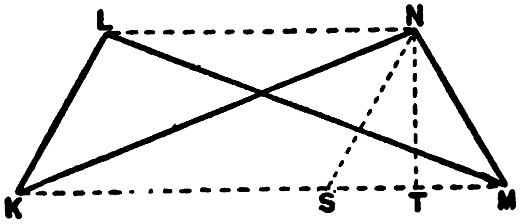


Fig. 214.

"crossed parallelogram." It is clear that in all positions of the linkage the lines LN and KM are parallel; and, moreover, the product $LN \times KM$ is constant. The latter statement becomes clear if NS be drawn parallel to KL, and NT perpendicular to KM; hence, since NS=LK=NM, T is the middle point of SM. Also $LN \times KM = KS \times KM = (KT-TS)\ (KT+ST) = KT^2-ST^2 = (KN^2-NT^2) -(SN^2-NT^2) = KN^2-SN^2 = KN^2-LK^2 =$ constant, since KN, LK are links of invariable length. Suppose, then, that three points, P_1, A, D (Fig. 215), lying in one line parallel to either LN or KM are taken, so that, in all positions of the mechanism, the points, P_1, A, D will be collinear. Then, clearly, P_1A is a constant proportion of LN and P_1D of KM; and consequently, since $LN \times KM$ is constant, $P_1A \times P_1D$ is constant also. If, therefore, P_1 be fixed, and, by means of a link, P_2A, turning about a second fixed center P_2, the point A is constrained to describe a circle which

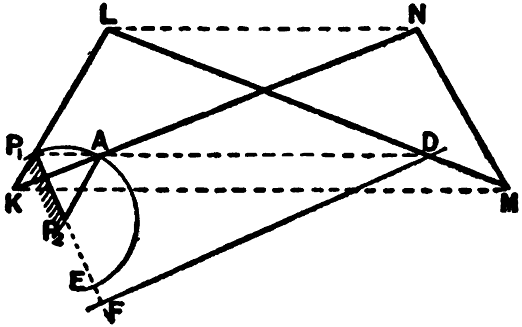


Fig. 215.

passes through P_1, the point D will trace out a true straight line, perpendicular to the fixed link P_1P_2.

It will be noticed that Peaucellier's motion contains eight elements, whilst Hart's contains only six. True straight lines may also be generated by using higher pairs.

Scott-Russell Parallel Motion. If, instead of generating a true straight line, the object is to correctly copy a straight line, or to generate an approximate straight line, mechanisms consisting only of four elements may be used. Thus, for example, in the double-slider crank chain shown in Fig. 216, there are two blocks connected by a link of invariable length—the blocks sliding in two perpendicular slots—so that the mechanism

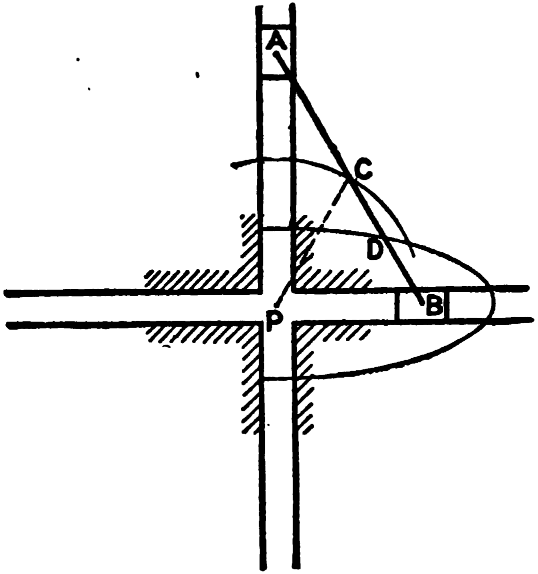


Fig. 216.

consists of two turning and two sliding pairs. If C be the central point of the link AB, and P the point of intersection of the central lines of the slots, it is clear that the length of the line PC is equal to either AC or CB, and is therefore constant. Consequently, as the blocks slide in their respective slots, the point C will trace out a circle of center P, and the mechanism will not be constrained in any way by adding a crank, PC, turning about the center P. In that case one of the blocks may be dispensed with, and the mechanism shown in Fig. 217 obtained. So long as PC, CA, CB are all equal, the point A will describe a vertical straight line when B moves along the

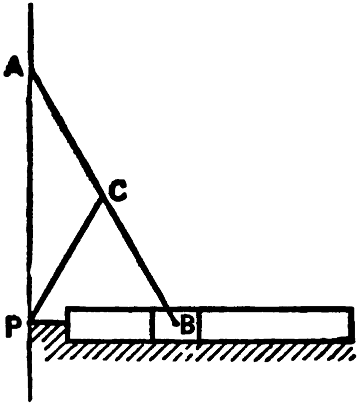


Fig. 217.

horizontal slot. The accuracy of the line traced out by A will depend entirely upon the accuracy of the line traced out by B, so that this mechanism is distinctly a copying machine. The block B is guided in its straight-line path by contact with the surfaces of the slot; but the description of how a plane surface is produced is more a matter of workshop practice than of kinematics, and it will be found in most text-books which deal with workshop appliances. The mechanism represented in Fig. 216 is usually known as the **Scott-Russell Parallel Motion.**

The Tchebicheff's Parallel Motion. A second parallel motion, consisting of four turning pairs, which generates an approximate straight line, is

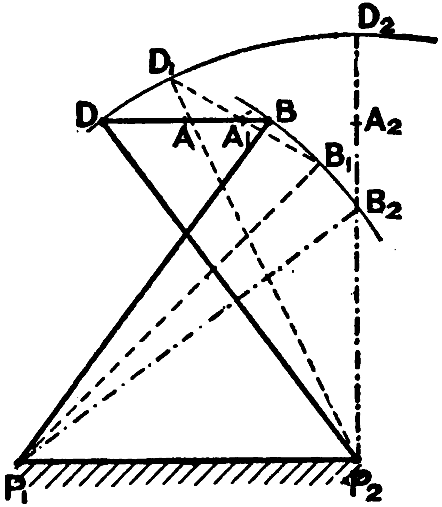


Fig. 218.

Tchebicheff's. The two levers, P_1B and P_2D, are of equal length, and are crossed, and the coupler DB, in the mean position of the mechanism, is parallel to the fixed link (Fig. 218). The tracing point, A, is the middle point of the coupler, and, very approximately, traces out a straight line parallel to the fixed link. Thus, in the position of the mechanism represented by the dotted lines, the central point of the coupler is A_1, which practically lies on the line BD. The proportions of the mechanism will, as in the grasshopper motion, depend on the limits of the motion. For example, if the coupler is vertical when either lever is vertical, and if, then, the tracing point lies exactly in the line BD produced (as shown in Fig. 218), it may be readily shown that if the fixed link P_1 P_2 be denoted by unity, the length of either lever

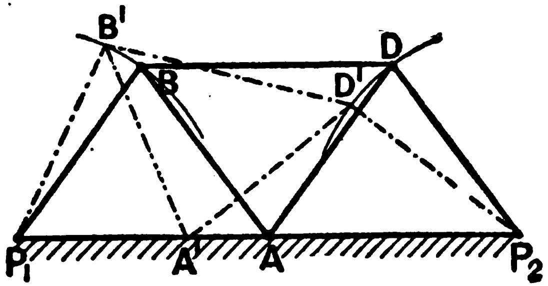


Fig. 219.

will be represented by 1.25, and of the coupler by 0.5. These proportions at once follow from the geometry of the mechanism, and may be left as an exercise to the reader. With these proportions, it will be noticed that the tracing point is moving in a direction exactly parallel to the fixed link in the extreme positions, as well as in the mean position, of the mechanism.

Roberts' Parallel Motion. In **Roberts'** motion (Fig. 219) the levers, P_1B and P_2D, are equal, and in the mean position of the mechanism the coupler, BD, is parallel to the fixed link; but, unlike Tchebicheff's, the levers are not crossed. The tracing point A does not lie in the coupler, but at the apex of the isosceles triangle BAD, the apex of which lies on the line of centers P_1P_2. For sufficiently small displacements, the point A approximately traces out the straight line P_1P_2. Moreover, if in the extreme positions of the mechanism the point A coincides with P_1 and P_2, it follows

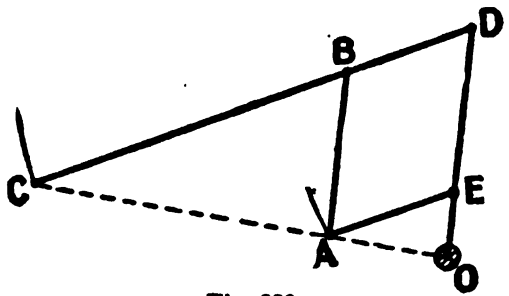


Fig. 220.

that the links BA and AD must be equal in length to either of the levers, and that the coupler must be half the length of the fixed link. Also, to allow this extent of motion, the levers must not be less than a certain length, which will depend upon the length of the coupler. As a limiting case, when A′ coincides with P_1, the points B′, D′ P_2 must lie on one straight line, and the point D′ will lie immediately above the mid-point of P_1P_2. Under these conditions, and remembering that the coupler is half the length of the fixed link, it may be at once shown that the length of the levers must be 1.186 times the length of the coupler, or 0.593 times the length of the fixed link. Thus, calling the fixed link 1, the length of the coupler is 0.5, and the minimum length of the remaining four links 0.593. The longer, however, the length of the levers, the more accurate the motion.

The Pantograph. The preceding mechanisms, consisting entirely of turning pairs, show how a

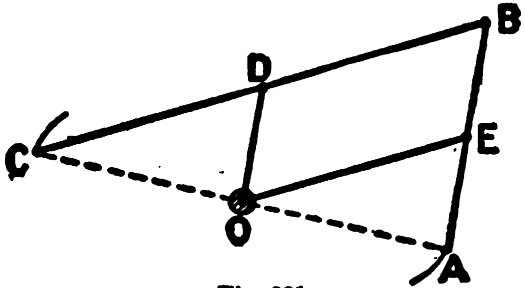


Fig. 221.

straight line may be exactly or very approximately generated. Scott-Russell's motion is an illustration of a copying machine, the accuracy of the line traced out depending upon the accuracy of the line copied, and it only truly describes a straight line provided the initial line is perfectly straight. A true copying machine is one which exactly reproduces the motion of the tracing point on a different or on the same scale, all the irregularities in the original being reproduced in the copy. As copying mechanisms are very frequently associated with parallel motions, it will be advisable, at this stage, to consider them.

The most familiar copying mechanism is the pantograph, which may exist in various forms, such, for example, as are shown in Figs. 220 to 223. In each of the first three figures there are four links, which form a parallelogram; and if the proportions are such that the points O, A, and

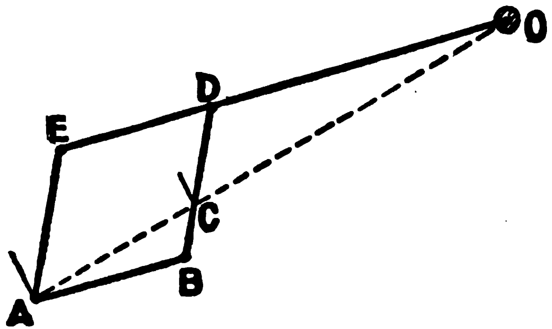


Fig. 222.

C are collinear in one position, they are collinear in all positions of the mechanism. In each figure, O is a fixed center, and the point C traces out a curve exactly similar to that traced out by A, whatever the shape of that curve may be. This follows from the fact that the ratio of the radii from the fixed point O to the loci of C and A is always constant and equal to

$\frac{OC}{OA}$, that is to say, to $\frac{DC}{DB}$. In Fig. 221, if D and E are the middle points of BC and BA respectively, the curve traced out by C will be exactly the same size as that traced out by A. In Fig. 223 the links CG, CE are parallel to AH, AF respectively.

The pantograph mechanism is employed to determine the section of steel rails, tyres, and similar bodies, and in engraving machines, beam engines, indicators, etc.

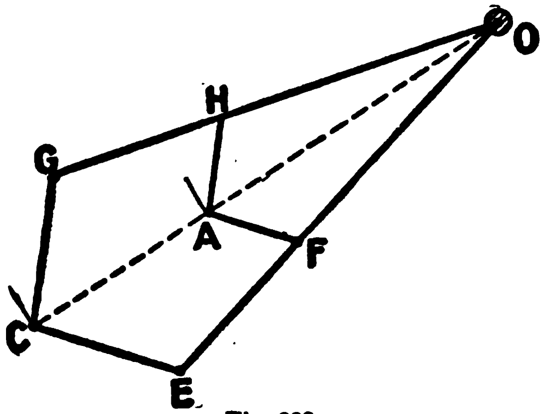


Fig. 223.

Rotary Pumps and Blowers. The method of action of a rotary pump will be evident from Figs. 224, 225 and 226, which represent a section of the pump perpendicular to the axes of rotation. The curved plates L and M, exactly similar in shape, are keyed to the two shafts P_1 and P_2, which rotate with equal but opposite angular velocities in bearings in the casing C. The equivalent pitch circles of the plates or pistons are represented by the two chain-dotted circles of equal diameter; and the sides of the casing are arcs of circles having P_1 and P_2 as centers. The pistons are, therefore, always in contact with the casing at one or other of the extremities of their major axes, and their shape is such that they are always in contact with each other. The suction pipe is coupled to the casting at the flange S, and the

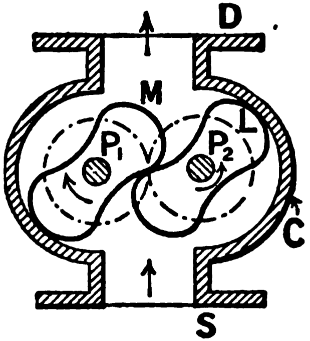


Fig. 224.

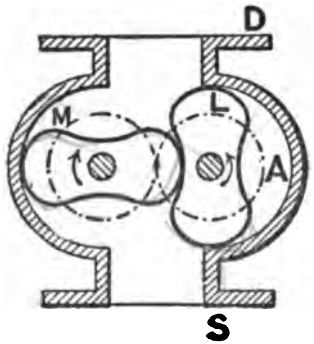


Fig. 225.

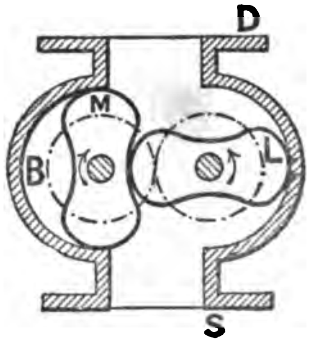


Fig. 226.

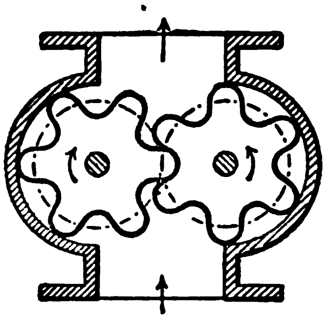


Fig. 227.

delivery pipe at the flange D. As shown in Fig. 224, the piston L is rotating in a counter-clockwise direction, and the piston M in a clockwise direction. When the shafts have turned through a certain angle, the pistons will be as shown in Fig. 225. It will be noticed that the space A, which in Fig. 226 is in communication with the suction pipe, is now entirely cut off, and any fluid in it will, neglecting leakage, be carried round with the piston L. After a short time, the upper extremity of the major axis ceases to have contact with the casing, and the space A is put in communication with the delivery pipe. No further transference of fluid from the suction pipe takes place until the position of the pistons is as shown in Fig. 226, when the space B is put into communication with the delivery pipe. Since the space above the pistons in Fig. 225 is exactly the same as in Fig. 226, it follows that, whatever the fluctuations in volume have been in the interval, the whole of the fluid which occupied the space A has been discharged up the delivery pipe. It will thus be seen that the total volume of fluid pumped up per revolution is equal to four times the volume of the space A; or, expressed more generally, is equal to twice the difference between the area of a circle having a diameter equal to the major axis of the piston and the area of the piston itself, multiplied by the axial length of the piston.

In Fig. 224 each piston has two projections and two hollows, but the number of teeth is arbitrary. Fig. 227 shows a pump in which the pistons have six teeth. As in the previous case, the theoretical discharge is equal to the area of the two addendum circles less the area of the pistons, multiplied by the axial length of the pistons.

It will be noticed that leakage is prevented by the contact of the pistons with the casing and with each other. Sliding, and therefore wear, takes place not only between the pistons and the casing, but also between the pistons themselves, and it is a matter of difficulty to keep a fluid-tight contact. It is for this reason that, notwithstanding their great simplicity and the absence of valves, they are not often used as water-pumps. They are, however, frequently used for supplying the blast to furnaces (as in Roots blowers), and also for pumping thick pasty fluids which might interfere with the proper working of the valves.

There are two points of detail which ought to be noticed. In the first place, if toothed pistons are used, as shown in Fig. 227, one wheel can always act as driver to the second; but with the pistons shown in Fig. 224 this would be impossible in certain portions of the revolution. The shafts P_1 and P_2 almost invariably, therefore, receive the equal and opposite rotations from two equal spur wheels which gear with each other, and are keyed to the shaft on the outside of the casing—the wheels being driven, through gearing, from the engine. The object of the piston is, in fact, merely to preserve contact, and not to transmit force from one to the other. In the second place, the circular sides of the casing must be rather more than a semi-circumference in length, or otherwise communication would be opened with the delivery pipe before that with the suction pipe was closed.

Shapes of Blowers. The shapes given to the rotatory pistons is arbitrary provided they satisfy the condition that the motion transmitted by their sliding contact is exactly the same as that which would be transmitted by the rolling contact of the two pitch circles; in other words, provided the common normal at the point of contact of the pistons always passes through the pitch point. The point of contact will not always lie on the line of centers, and the velocity of sliding at any instant will be equal to the length of the common normal to the two surfaces, measured to the pitch point, multiplied by twice the angular velocity of either wheel.

It has been shown that cycloidal curves satisfy the required condition—the parts of the piston above the pitch circles being epicycloids, and the parts below hypocycloids. The size of the rolling circle—which, since the pistons are invariably of the same shape, will be the same for both the projection and the hollow—will depend on the number of teeth in the piston, but the diameter of the pitch circle must be an exact multiple of the diameter of the rolling circle. If the pistons are two-toothed wheels, as shown in Fig. 224, the diameter of the rolling circle will be one-quarter that of the pitch circle, and the points where the piston profile crosses the pitch circle will divide the latter into four equal parts (as in **Root's Blower**).

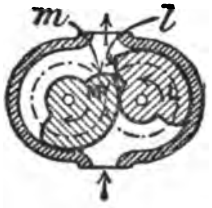


Fig. 228.

If the pistons are six-toothed wheels, as shown in Fig. 227, the diameter of the rolling circle is one-twelfth that of the pitch circle; and so on. Fig. 228 shows a pair of pistons consisting of two half-cylinders of different diameters and connected by the curves **l** and **m.** The circular portions roll without slipping, and the curves **l** and **m** must satisfy the necessary kinematic condition. If the portion below the pitch circles be a radial straight line, the portion above it must be an epicycloid formed by a rolling circle half the size of the pitch circle.

The profiles need not, however, consist of

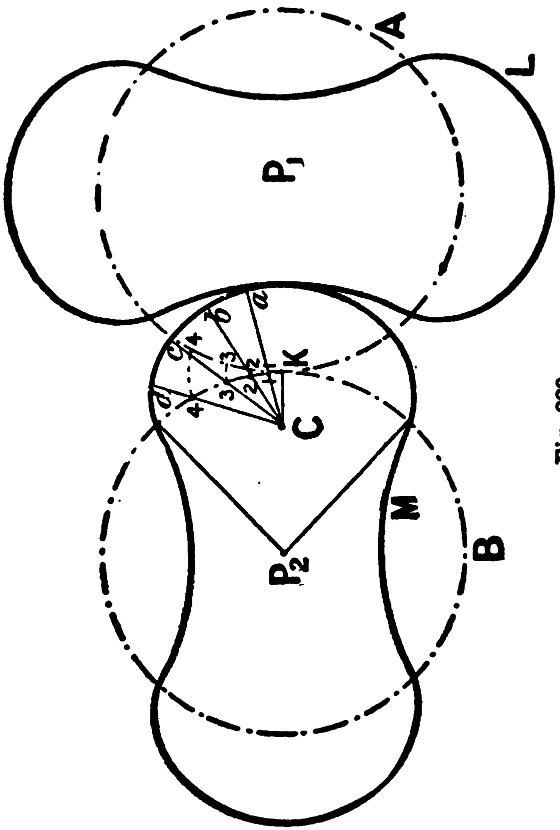


Fig. 229.

curves possessing any particular mathematical properties. If the profile of one of the pistons is given, that of the second can be found by the geometrical or mechanical method.

For example, Fig. 229 shows an illustration of the geometrical method in which the points of each piston are circular arcs subtending an angle of 90° at the center—the height of the point being taken as half the radius of the pitch circle. The center of the circle forming the point of the piston keyed to P_2 is C, and, following the method a number of normals through the points a, b, c,... are drawn to the circular arc. These all necessarily pass through the point C, and they intersect the pitch circle B of center P_2 in the points 1, 2, 3,... With K (the pitch point) as center, arcs passing through the points 1, 2, 3,... are struck to meet the pitch circle A in the points 1, 2, 3,... This construction, since the pitch circles are equal, merely makes the arcs K1, 1 2, 2 3... on each pitch circle the same. With the points on A as centers, and radii equal to 1a, 2b, 3c,... circular arcs are drawn; and the envelope of these arcs is the proper shape of the hollow of the piston on P to gear with the given point. The whole pistons are as shown. Other shaped pistons, obtained in the same way, are shown in Fig. 230.

In the mechanical method, a template of one piston would be cut out, and the two pitch circles would roll together as explained. The profile of

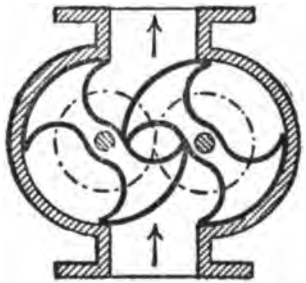


Fig. 230.

the given piston would be marked off on the sheet rotating about the second center; and the envelope of the curves so obtained would be the shape of the second piston. In Fig. 230 the shape of the second piston is governed by the path of the extreme points of the first piston.

The great value of the drop hammer is its simplicity and cheapness as a means of storing energy, which can be given out again in doing the work of raising, stamping, and forging.

The drop hammer is an example of the useful application of the principle of the falling weight. In finding the work accumulated in any moving body, such, for instance, as energy stored up in a flywheel, the work of a locomotive when ascending an incline, the work of a cannon ball, and similar questions, it is necessary to introduce the force of gravity into the calculation, since the law of gravitation necessarily has an effect upon such bodies as are dealt with in these calculations. It is therefore perhaps necessary to briefly review the action of gravity on falling bodies to enable the practical mechanic to understand what the gravity constant means.

If a body be raised 16 1/12 feet, then allowed to fall freely, it will fall through this space of 16 1/12 feet in one second, and at the end of that second it will have attained a velocity of 32 1/6 feet per second. This velocity of 32 1/6 feet per second, which is simply due to the force of gravity, is denoted by **g** and the velocity **v** attained at the end of **t** seconds will be $t \times 32\ 1/6$, or $v = t \times 32\ 1/6$. Therefore the velocity of a body which has fallen for four seconds will be at the end of that time travelling at a velocity $= 4 \times 32\ 1/6 = 128\ 2/3$ feet per second.

The mean velocity—that is, the velocity in the middle of that time—will be $2 \times 32\ 1/6 = 64\ 1/3$ feet per second, and the space described will be $4^2 \times 16\ 1/12 = 257\ 1/3$ feet.

Formula for Falling Bodies when Falling from Rest.

h = height of fall in feet.
v = velocity in feet per second.
g = force of gravity = 32.2.
t = time of fall in seconds.

$$h = \frac{g t^2}{2} = \tfrac{1}{2} g t^2 = \frac{v^2}{2g}$$

$$v = g t = \frac{2h}{t} = \sqrt{2gh}$$

$$t = \frac{v}{g} = \frac{2h}{v} = \sqrt{\frac{2h}{g}}$$

If the drop hammer be raised to a definite height, the work expended in raising it will be $W \times h$, and in doing so the force of gravity will have to be overcome. If the hammer be now supported, there will be potential energy stored up in it, and when allowed to fall it will attain a certain velocity depending upon the distance fallen. When the hammer reaches the end of its fall, the accumulated work in the hammer will be

$$\frac{W v^2}{2g} = W h$$

Example. Suppose a drop hammer of 500 pound weight be raised through a height of 579 feet. The work expended in raising this hammer will be

$$W\times h=500\times 579=289500 \text{ foot-pounds.}$$

If the hammer be now supported at this height, the potential energy which exists in, or is stored up, will be=289,500 foot-pounds. When allowed to fall the accumulated work will be equal to

$$\frac{W v^2}{2g}$$

First find v:

$$v=\sqrt{2gh}=\sqrt{2\times 32\tfrac{1}{6}\times 579}=193 \text{ feet per second,}$$

when the hammer reaches the end of its fall it will have attained a velocity equal to 193 feet per second, therefore

$$\frac{Wv^2}{2g}=\frac{500\times 193\times 193}{2\times 32\tfrac{1}{6}}=289500 \text{ foot-pounds,}$$

and this is the same result as $W\times h$.

A certain amount of energy is passed into the drop hammer in raising it up, and when it falls the energy is given out again. There is neither gain nor loss of power. It may be that a great pressure is exerted through a small space, or a less pressure through a greater space, and in both instances the work may be the same.

If a resistance is offered to a 560-pound hammer, falling from a height of 16 feet, during the last one foot of its fall the average pressure acting against the resistance will be 8,960 pounds, the pressure being much greater at the commencement, and reducing as it reaches the last inch, the accumulated energy gradually decreasing to simply that of the weight of the hammer itself as it reaches the end of its fall.

But should the hammer be brought to rest in a fraction of 1 foot, then the resistance offered must be proportionately greater.

A stamp hammer 200 pounds in weight falls 10 feet, and in stamping a piece of metal the hammer is brought to rest in the space of the last ½ inch of its fall. What resistance has been offered by the metal article?

$$W\times h=200\times 10=2000 \text{ foot-pounds,}$$

$$\tfrac{1}{2} \text{ inch} = \tfrac{1}{2} \text{ of } \tfrac{1}{12} = \tfrac{1}{24} \text{ of 1 foot,}$$

$$\text{and since } 2000=\frac{R\times 1}{25}$$

$$\text{therefore } R=\frac{2000\times 24}{1}=48000 \text{ pounds.}$$

Work done by a hand hammer. The conditions under which the hand hammer is used make it necessary that the law of gravitation shall be introduced into the calculation. Take the case of a machinist striking a blow upon the head of a chisel, or driving a nail into a piece of wood, with a 2-pound hand hammer.

As another example, consider the case of a machinist driving a key into a boss of a flywheel with a 4-pound hammer. In the first case there are two forces acting upon the hammer, namely, force of gravity and the man's muscular force. The workman raises the hammer, he then drives it home, delivering a blow upon the head of the chisel. The first portion of the distance through which the hammer moves is traversed by a movement of the whole arm from the shoulder.

This is followed up by the workman straightening his arm at the elbow, then, just as he is about to reach the head of the chisel with the hammer to strike the blow, he straightens his wrist, thereby adding impetus to the hammer, which is already rapidly falling, and in this manner a very great velocity is given, probably at the exact moment of impact the actual velocity may be 50 feet per second.

In the second example, where a blow is delivered upon the head of a steel key, by a hammer, and the hammer is driven in a horizontal line, the machinist will swing the hammer through a comparatively long distance, and will probably put the weight of the upper half of his body into the blow, thereby considerably increasing the velocity of the hammer, which may be 50 feet per second, as before. In both these cases of hand hammers the accumulated work or energy stored up in the hammer will be the same as though the hammer had fallen from a sufficient height to attain that velocity which the hammer has at the moment of impact. But here the only information we have to assist us in solving the problem is the weight of the hammer and the assumed velocity at which it is moving, say 50 feet per second. Since having no particulars as to the height from which a body must fall to attain this velocity, it is necessary to introduce the law of gravitation into the calculation to enable reliable results to be obtained.

We have for the 2-pound hammer accumulated work

$$\frac{Wv^2}{2g}=\frac{2\times50\times50}{2\times32}=78 \text{ foot-pounds.}$$

If the face of the hammer moves the head of the chisel 1/16 inch, then

$$\tfrac{1}{16}\times\tfrac{1}{12}=\tfrac{1}{192} \text{ of 1 foot,}$$

$$\text{and } R=\frac{78\times192}{1}=14976 \text{ pounds.}$$

If a nail had been driven ¼ inch,

$$\tfrac{1}{4}\times\tfrac{1}{12}=\tfrac{1}{48} \text{ of 1 foot,}$$

$$\text{and } R=\frac{78\times48}{1}=3744 \text{ pounds.}$$

In the case of the 4-pound hammer we have accumulated work

$$\frac{Wv^2}{2g}=\frac{4\times50\times50}{2\times32}=156 \text{ foot-pounds.}$$

If the key is driven ⅛ inch by the blow,

$$\tfrac{1}{8}\times\tfrac{1}{12}=\tfrac{1}{96} \text{ of 1 foot.}$$

$$\text{and } R=\frac{156\times96}{1}=14976 \text{ pounds resistance.}$$

The work done by the jack hammer, namely, 14,976 pounds, is approximately the same that would be obtained by a dead load of 14,976 pounds giving a direct pressure.

Circumference of Circles.

Diam.	Circum.	Diam.	Circum.	Diam.	Circum.	Diam.	Circum.
1/8	.3927	10	31.41	30	94.24	65	204.2
1/4	.7854	10½	32.98	31	97.38	66	207.3
3/8	1.178	11	34.55	32	100.5	67	210.4
1/2	1.570	11½	36.12	33	103.6	68	213.6
5/8	1.963	12	37.69	34	106.8	69	216.7
3/4	2.356	12½	39.27	35	109.9	70	219.9
7/8	2.748	13	40.84	36	113.0	71	223.0
1	3.141	13½	42.41	37	116.2	72	226.1
1 1/8	3.534	14	43.98	38	119.3	73	229.3
1 1/4	3.927	14½	45.55	39	122.5	74	232.4
1 3/8	4.319	15	47.12	40	125.6	75	235.6
1 1/2	4.712	15½	48.69	41	128.8	76	238.7
1 5/8	5.105	16	50.26	42	131.9	77	241.9
1 3/4	5.497	16½	51.83	43	135.0	78	245.0
1 7/8	5.890	17	53.40	44	138.2	79	248.1
2	6.283	17½	54.97	45	141.3	80	251.3
2¼	7.068	18	56.54	46	144.5	81	254.4
2½	7.854	18½	58.11	47	147.6	82	257.6
2¾	8.639	19	59.69	48	150.7	83	260.7
3	9.424	19½	61.26	49	153.9	84	263.8
3¼	10.21	20	62.83	50	157.0	85	267.0
3½	10.99	20½	64.40	51	160.2	86	270.1
3¾	11.78	21	65.97	52	163.3	87	273.3
4	12.56	21½	67.54	53	166.5	88	276.4
4½	14.13	22	69.11	54	169.6	89	279.6
5	15.70	22½	70.68	55	172.7	90	282.7
5½	17.27	23	72.25	56	175.9	91	285.8
6	18.84	23½	73.82	57	179.0	92	289.0
6½	20.42	24	75.39	58	181.2	93	292.1
7	21.99	24½	76.96	59	185.3	94	295.3
7½	23.56	25	78.54	60	188.4	95	298.4
8	25.13	26	81.68	61	191.6	96	301.5
8½	26.70	27	84.82	62	194.7	97	304.7
9	28.27	28	87.96	63	197.9	98	307.8
9½	29.84	29	91.10	64	201.0	99	311.0

Area of Circles.

Diam.	Area.	Diam.	Area.	Diam.	Area.	Diam.	Area.
1/8	0.0123	10	78.54	30	706.86	65	3318.3
1/4	0.0491	10½	86.59	31	754.76	66	3421.2
3/8	0.1104	11	95.03	32	804.24	67	3525.6
1/2	0.1963	11½	103.86	33	855.30	68	3631.6
5/8	0.3068	12	113.09	34	907.92	69	3739.2
3/4	0.4418	12½	122.71	35	962.11	70	3848.4
7/8	0.6013	13	132.73	36	1017.8	71	3959.2
1	0.7854	13½	143.13	37	1075.2	72	4071.5
1 1/8	0.9940	14	153.93	38	1134.1	73	4185.4
1 1/4	1.227	14½	165.13	39	1194.5	74	4300.8
1 3/8	1.484	15	176.71	40	1256.6	75	4417.8
1 1/2	1.767	15½	188.69	41	1320.2	76	4536.4
1 5/8	2.073	16	201.06	42	1385.4	77	4656.6
1 3/4	2.405	16½	213.82	43	1452.2	78	4778.3
1 7/8	2.761	17	226.98	44	1520.5	79	4901.6
2	3.141	17½	240.52	45	1590.4	80	5026.5
2¼	3.976	18	254.46	46	1661.9	81	5153.0
2½	4.908	18½	268.80	47	1734.9	82	5281.0
2¾	5.939	19	283.52	48	1809.5	83	5410.6
3	7.068	19½	298.64	49	1885.7	84	5541.7
3¼	8.295	20	314.16	50	1963.5	85	5674.5
3½	9.621	20½	330.06	51	2042.8	86	5808.8
3¾	11.044	21	346.36	52	2123.7	87	5944.6
4	12.566	21½	363 05	53	2206.1	88	6082.1
4½	15.904	22	380.13	54	2290.2	89	6221.1
5	19.635	22½	397.60	55	2375.8	90	6361.7
5½	23.758	23	415.47	56	2463.0	91	6503.9
6	28.274	23½	433.73	57	2551.7	92	6647.6
6½	33.183	24	452.39	58	2642.0	93	6792.9
7	38.484	24½	471.43	59	2733.9	94	6939.8
7½	44.178	25	490.87	60	2827.4	95	7088.2
8	50.265	26	530.93	61	2922.4	96	7238.2
8½	56.745	27	572.55	62	3019.0	97	7389.8
9	63.617	28	615.75	63	3117.2	98	7542.9
9½	70.882	29	660.52	64	3216.9	99	7697.7

To compute the circumference of a diameter greater than any in the above table:

Rule.—Divide the dimension by 2, 3, 4, etc., if practicable, until it is reduced to a diameter to be found in table. Take the tabular circumference of this diameter, multiply it by 2, 3, 4, etc., according as it was divided, and the product will be the circumference required.

Example.—What is the circumference of a diameter of 125? 125÷5=25. Tabular circumference of 25=78.54, 78.54×5=392.7, circumference required.

To compute the area of a diameter greater than any in the above table:

Rule.—Divide the dimension by 2, 3, 4, etc., if practicable, until it is reduced to a quotient to be found in the table, then multiply the tabular area of the quotient by the square of the factor. The product will be the area required.

Example.—What is area of diameter of 150? 150÷5=30. Tabular area of 30=706.86 which× 25=17,671.5 area required.

LOGARITHMS OF NUMBERS

Logarithms are the exponents of a series of powers and roots of numbers. The logarithm of a number is that exponent of some other number, which renders the power of the other number, which is denoted by the exponent, equal to the former. In other words the logarithm of a number is the exponent of the power to which the number must be raised to give a given base.

When the logarithms of numbers form a series in arithmetical progression, their corresponding natural numbers form a series in geometrical progression, thus:

Common logarithms	0	1	2	3	4
Natural numbers	1	10	100	1,000	10,000

Natural logarithms were the invention of Lord Napier. Common logarithms, the kind in general use, were invented by Prof. Briggs of Oxford, England. Logarithms are extremely useful in shortening the labor of mathematical calculations.

The addition and subtraction of common logarithms correspond to the multiplication and division of their natural numbers.

In a like manner, involution is performed by multiplying the common logarithm of any number by the number denoting the required power, and evolution by dividing the common logarithm of the number denoting the required root.

The common logarithm of a number consists of two parts, an integral part or whole number, which is called the characteristic, and a decimal called the mantissa.

To find the common logarithm of a given number from the Table proceed as follows:

The first two figures of the number will be found in the vertical column to the extreme left in the table, and the third figure of the number in the horizontal row at either the top or bottom of the table. Having found the first two figures of the number, always neglecting the decimal, pass along the line opposite these figures until the column headed by the third figure of the number is reached. The number thus found will be the mantissa or decimal fraction of the logarithm. The characteristic will depend upon the number of integers or whole numbers, less one, in the number, counting from the left of the decimal point. If the decimal point be entirely to the left of the number, the characteristic is obtained by counting the number of cyphers before the first number, to the right and adjacent to the decimal point.

Example: Find the common logarithm of 5.06 from the Table.

Answer: In the row of figures opposite 50 and in the column under 6, the mantissa of the logarithm is .7042. Counting from the decimal place of the number to the left, the characteristic will be one less than the number of figures to the right of the decimal point, which is, in this case, 1, and 1 minus 1 equals zero, which is the characteristic of the mantissa .7042, the complete logarithm of 5.06 will then be 0.7042.

The logarithm of 0.506 is—1.7042
The logarithm of 5.06 is 0.7042
The logarithm of 50.6 is 1.7042
The logarithm of 506 is 2.7042

To find the number corresponding to a given logarithm: As the mantissa of the given logarithm is not usually found in the table, select the four figures corresponding nearest to the given mantissa. The first two figures of the number will be found in the column marked "No." at the left of the row in which is the mantissa elected, and the third or last figure of the number at the top or bottom of the vertical row of figures.

Example: Find the number from the Table corresponding to logarithm 1.0334.

Answer: The first two figures of the number corresponding to the mantissa .0334 are 10, and at the top of the vertical column the third figures given as 8, making the three figures 108. As the characteristic is 1 therefore the actual number is 10.8.

The number corresponding to—1.0334 is .108
The number corresponding to 0.0334 is 1.08
The number corresponding to 1.0334 is 10.8
The number corresponding to 2.0334 is 108

To multiply one or more numbers together, add the common logarithms of the numbers together, the sum will be the logarithm of the required number.

To divide a number by one or more numbers, subtract the sum of the common logarithms of the numbers from the logarithms of the number to be divided.

The mantissa of the common logarithm of 6 is the same as the mantissa of 60 or 600, the characteristic only being changed thus:

Common logarithm of .600=—1.7782
Common logarithm of 6.00= 0.7782
Common logarithm of 60.0= 1.7782
Common logarithm of 600 = 2.7782

The table gives the common logarithms of numbers from 100 to 999.

Note. A decimal point must always be prefixed to the mantissa of a logarithm obtained from the table, before affixing the characteristic.

LOGARITHMS OF NUMBERS FROM 100 TO 999.

No.	0	1	2	3	4	5	6	7	8	9	Diff.
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	40
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	37
12	0792	0828	0865	0899	0934	0969	1004	1038	1072	1106	33
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	31
14	1561	1492	1523	1553	1548	1614	1644	1673	1703	1732	29
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	27
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	25
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	24
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	23
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	22
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	21
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	20
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	19
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	18
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	17
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	17
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	16
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	16
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	15
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	14
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	14
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	13
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	13
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	13
No.	0	1	2	3	4	5	6	7	8	9	Diff.

LOGARITHMS OF NUMBERS FROM 100 TO 999.—(CONT.)

No.	0	1	2	3	4	5	6	7	8	9	Diff.
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	13
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	12
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	12
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	12
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	12
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	12
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	11
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	10
42	6232	6242	6253	6263	6274	6284	6294	6304	6314	6325	10
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	10
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	10
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	10
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	9
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	9
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	9
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	9
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	9
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	8
52	7160	7186	7177	7185	7193	7202	7210	7218	7226	7235	8
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	8
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	8
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	8
56	7482	7490	7497	7505	7512	7520	7528	7536	7543	7551	8
No.	0	1	2	3	4	5	6	7	8	9	Diff.

LOGARITHMS OF NUMBERS FROM 100 TO 999.—(CONT.)

No.	0	1	2	3	4	5	6	7	8	9	Diff.
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	8
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	8
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	7
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	7
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	7
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	7
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	8
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	7
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	6
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	6
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	6
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	6
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	6
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	6
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	6
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	6
No.	0	1	2	3	4	5	6	7	8	9	Diff.

LOGARITHMS OF NUMBERS FROM 100 TO 999.—(CONT.)

No.	0	1	2	3	4	5	6	7	8	9	Diff.
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	6
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	5
86	9345	9350	9355	9360	9365	9369	9374	9379	9384	9389	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	5
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	5
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	5
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	5
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9724	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	4
95	9777	9782	9786	9790	9795	9800	9805	9809	9814	9818	5
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	5
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	4
No.	0	1	2	3	4	5	6	7	8	9	Diff.

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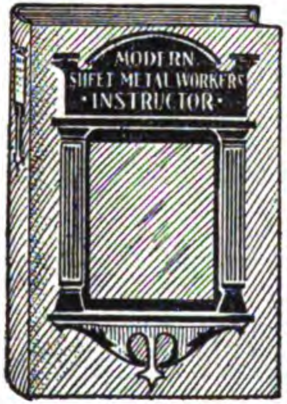

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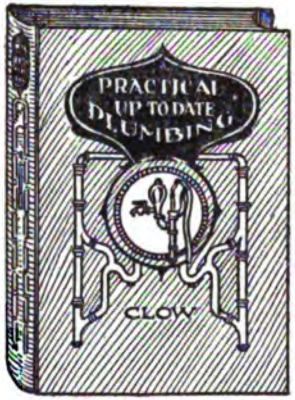

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