"The dexterous hand and the thoughtful mind find their strength in union alone"

ROGERS'

Drawing and Design

AN EDUCATIONAL TREATISE

RELATING TO

LINEAR DRAWING; MACHINE DESIGN; WORKING DRAWINGS; TRANSMISSION METHODS; STEAM, ELECTRICAL AND METAL WORKING MACHINES AND PARTS; LATHES; BOILER AND PARTS; INSTRUMENTS AND THEIR USE; TABLES, Etc.

THEO. AUDEL & CO., 72 FIFTH AVENUE, NEW YORK

PUBLISHERS

"One peculiar feature of the draftsman's opportunity is that it takes hold of all the mechanical occupations, and of one almost as much as of the other. It is not in the least monopolized by the machinist, and it is not the necessity of his shop more than of the others. The pattern maker certainly has quite as much to do with working drawings, and why not also the molder, the blacksmith, the boiler maker, the carpenter, the coppersmith and all the rest? It will be to the immense advantage of the workers in any of these lines, and to the young man a most presumptive means of advancement, to be not only able to read drawings, but to make them."—*American Machinist.*

PREFACE.

In a report to the Bridge Commissioners, as to the progress being made in the construction of the steel cables designed to support the immense weight of the (N. Y.) East River Suspension Bridge, Chas. G. Roebling, C. E., used these impressive words, quoted, as printed in *The Sun*:

> "Further, Mr. Roebling said the work of placing four cables nineteen inches in diameter across the river, WAS ONE THAT REQUIRED A CERTAIN DELIBERATION. NO ERROR OF ANY KIND MUST BE MADE. Although all the men that could be utilized in the work have been employed, yet the progress made appears to be slow. Laymen might, from this, infer that the work is lagging, but the Commissioners should know that this was not the case. The work will proceed, Mr. Roebling says, and be finished to the perfect satisfaction of the Commissioners."

These emphasized words have been frequently in the mind of the author of this work, relating to drawing and design. During the long months required by its preparation the greatest of care has been taken to avoid error of any sort, and the utmost deliberation has been given to the careful presentation of each subject.

This has been called "the age of illustration;" the truth of the saying is evident on every side from the daily illustrated newspaper to the blue print in the hand of the iron worker. In illustrations of whatever nature we come back to the L. B. & T. elements—length, breadth and thickness—and to linear drawing as the foundation of all drawing whether industrial or artistic; for linear drawing has for its object the accurate delineation of surfaces and the construction of figures obtained by the studied combination of lines. We must come back to first principles in all knowledge, as the ball comes back to the hand of the skillful thrower, so that on the next attempt it may be projected still further upward.

PREFACE.

The ability to draw is *like an added sense* whose value could be somewhat determined, if those engineers and others who are skilled in the art, would name the sum of money for which they would part with its knowledge—for—

"A chance sketch—the jotted memoranda of a contemplative brain often forms the nucleus of a splendid invention. An idea thus preserved at the moment of its birth may become of incalculable value when rescued from the desultory train of fancy and treated as the sober offspring of reason." This quotation is from the one who wrote also the noble sentence—"Thou hast not lost an hour whereof there is a record; a written thought at midnight will redeem the livelong day."

From its inception to its closing page the main idea of the author has been to instruct, to impart knowledge of drawing and design with special reference to a considerable degree of method and completeness; his aim has been to educate, or to draw out, and develop harmoniously the mental powers—to train to a certain result the various processes described and to nurture an abiding interest in the student's mind of a noble and ancient art. "First, the blade, then the ears, then the ripened corn appears" expresses what has been the attempted order of instruction.

The power *to draw* is akin to that, and, to the engineer and mechanic, second only to the power to *read;* one needs not only to read the printed page but also to read a blueprint or a rightly drawn and porportioned sketch; there should be many thousand good draughtsmen scattered about and around before there is one professor or regular instructor in the art; for to the average man drawing should be looked upon as a help in his daily avocation rather than as a staff to lean upon for life-long employment.

PREFACE.

There is a current saying, "one never sees an old draughtsman." This is more true in the United States—the home of Opportunity—than in older countries; its meaning is that the position in the draughting room is but a stage in the development of the Engineer, the Superintendent, the Manager in engineering works.

A good knowledge of draughting is a round on the ladder of preferment; a second round is a fair working knowledge of *the mathematics and theory of mechanism*, for the foundation of all accurate attainment in drawing and design are laid in these two fundamental sciences. It may be well always to remember that

> "Education does not consist merely in storing the head with materials; that makes a lumber room of it; but in learning how to turn those materials into useful products; that makes a factory of it: and no man is educated unless his brain is a factory, with storeroom, machinery and material complete."

To this may be added that the helpful value of a teacher or instructor cannot be overestimated; man was not created to do his appointed work alone, he needs all assistance and aid possible—to help and be helped—is the universal law of progress, and especially is this true in the first beginnings in the art of drawing; afterwards the student may be supposed to have acquired a real interest in his stimulating and useful endeavors.

It is an odd thing that the preface, which is always understood as something *going before*, is often written last, hence these few long paragraphs are prepared to close the long and rather pleasant task of the author of the book ere it is delivered *in toto* to the Printer, Binder and to the management of its most excellent and reliable Publishers for its introduction to those for whom it is designed.

With these views and to further such ends this book has been prepared, and with such aims more or less successfully attained, the volume is now committed to the kind favor of its patrons.

TABLE OF CONTENTS.

THE SCOPE AND PLAN OF THE WORK.

The special mission of this book can almost be gathered from its title page and the preface. It is intended to furnish gradually developed lessons in linear drawing applied to the various branches of the mechanic arts.

The work is comprised within some twelve divisions or general subjects; the first of which consists of Abbreviations and Conventional Signs, Useful Terms and Definitions with illustrations.

The second section relates to the Drawing Board, T-square and Triangles and their use, lettering, shade and section lining, etc.

The third division is devoted to Geometrical Drawing; the subject is preceded by many valuable definitions, axioms and examples of postulates and followed by many illustrations, largely based upon the problems solved by Euclid more than twenty-two centuries ago.

The fourth division relates to the Development of Surfaces and Isometric, Cabinet and Orthographic projections. The fifth section relates to Working Drawings embracing Tracing, Blue Printing, Dimensioning, Reading of Drawings, etc.

The foregoing portions comprise "PART ONE" of the work and relate almost exclusively to Drawing and Definitions. "PART TWO" is devoted to Machine Design, Transmission Methods, Metal Working Machinery, Engines and Boilers, Electrical Machines, etc., which embrace the sub-divisions six to ten.

Each one of these sections is preceded by explanatory matter, and accompanied by illustrations of the different machines, with working directions for proportioning and designing.

"PART THREE," in addition to Drawing Instruments and their Use and the Index, contains tables, of the utmost value, for use in connection with the preceding sections, especially so, as the basis of the work is planned to be largely mathematical.

The making of a book of any considerable scope and value is either—as in olden times—the life work of a single author, or as, at the present, the combined efforts of several individuals, whose united efforts produce it in a much shorter time, and it must be hoped, in greater perfection.

Although no more than a year has elapsed from the opening subject of "Abbreviations and Conventional Signs" to the closing reference—Index—pages, in no sense should the work be considered as being hasty or superficial, for the outcome of the combined efforts of those named below, is worthy of praise for having produced a thoroughly scientific and helpful book.

First of all, to Mr. John Weichsel, M. E., instructor in drawing and design in one of the foremost technical institutes of New York City, is due the credit of furnishing most of the drawings and diagrams used throughout the work, with the text accompanying each ; the book itself is the highest testimonial to the admirable and thoroughly technical character of Prof. Weichsel's work.

Mr. Henry E. Raabe, M. E., has been the technical editor throughout the period of the preparation of the text and the arrangement of the illustrations in their appropriate places. Many of the drawings, explanatory notes, and "cuts" are also his own production.

Messrs. Sutherland & Graham, Engravers, and George Byron Kirkham, Artist, are entitled to thanks for many designs and illustrations, as well as for professional advice and suggestions in several details of the "lay-out" of the volume. Mr. P. Hetto, of the U. S. Navy, an accomplished draughtsman and scholar, has read the "proof" of each separate page with critical care, and to him should be accorded praise for the almost perfect freedom from errors of any kind which marks the completed volume.

Mr. H. Harrison, of the L. Middleditch Press, has used his wide experience in the typographical arrangement of the work; in this he has been aided by Mr. Henry J. Harms in overseeing the final issue and printing of the book; the excellence of their work is evident on every printed page.

It may be added that the kind and experienced editor-in-chief has combined and added to, and in some cases, taken from, the "matter" submitted by the foregoing named persons and others and the result of the whole, is now offered with confidence to the patronage of the Mechanical World, by

THE PUBLISHERS.

ABBREVIATIONS AND CONVENTIONAL SIGNS.

In order to simplify the language or expression of arithmetical and geometrical operations the following conventional signs are used:

The sign + signifies *plus* or *more* and is placed between two or more terms to indicate addition. EXAMPLE: $4 + 3$, is 4 *plus* 3, that is, 4 added to 3, or 7.

The sign — signifies *minus* or *less* and indicates subtraction.
EXAMPLE: $4 - 3$, is 4 *minus*, that is, 3 taken from 4, or 1.

The sign × signifies *multiplied by* and placed between two terms, indicates multiplication.
EXAMPLE: 5×3, is 5 multiplied by 3, or 15.

When quantities are expressed by letters, the sign may be suppressed, thus we write indifferently, $a \times b$ or ab.

The sign : or (as it is more commonly used) ÷ signifies *divided by*, and, placed between two quantities, indicates division.
EXAMPLE: $12 : 4$, or $12 \div 4$ or $\frac{1}{4}$ is 12 divided by 4.

The sign = signifies *equals* or *equal to*, and is placed between two expressions to indicate their equality. EXAMPLE: $6 + 2 = 8$, meaning that 6 plus 2 is equal to 8.

The union of these signs : :: : indicates geometrical proportion.

EXAMPLE: $2 : 3 :: 4 : 6$, meaning that 2 is to 3 as 4 is to 6.

The sign $\sqrt{}$ indicates the extraction of a root ; as,

$\sqrt{9} = 3$, meaning that the square root of 9 is equal to 3.

The interposition of a numeral between the opening of this sign, $\sqrt{}$, indicates the degree of the root. Thus: $\sqrt[3]{27} = 3$, expresses that the cube root of 27 is equal to 3.

The signs < and > indicate respectively, *smaller than* and *greater than*.

EXAMPLE: $3 < 4$ = 3 smaller than 4 and, reciprocally, $4 > 3$ = 4 greater than 3.

Fig. signifies figure ; and pl., plate.

USEFUL TERMS AND DEFINITIONS.

Lines, Angles, Surfaces and Solids constitute the different kinds of quantity called *geometrical* magnitudes.

LINES AND ANGLES.

A ***surface*** is that which has extension in length and breadth only.

A ***solid*** is that which has extension in length, breadth and thickness.

An ***angle*** is the difference in the direction of two lines proceeding from the same point.

A ***point*** is said to have position without magnitude; it is generally represented to the eye by a small dot.

A ***line*** is considered as length without breadth or thickness; it denotes the direction between two points. Lines are principally of three kinds: (1) *right lines*, (2) *curved lines*, (3) *mixed lines*.

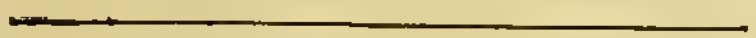


Fig. 1.

A ***right line,*** or as it is more commonly called, a *straight line* is the shortest line that can be drawn between two given points, as above in Fig. 1.

A ***curved line*** is one of which no portion, however small, is straight; it is therefore longer than a straight line connecting the same points; a straight line is often called simply a line, and a curved line a curve, a *regular curved line*, as Fig. 2, is a portion

Fig. 2.

of the circumference of a circle, the degree of curvature being the same throughout its entire length; an *irregular curved line* has not the same degree of curvature throughout, but varies at different points.

A ***waved line,*** shown in Fig. 3, may be either

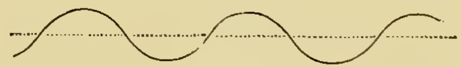


Fig. 3.

regular or irregular; the illustration shows the former, the inflections on either side of the dotted line being equal.

Note.—There are other lines used in common drawing-room definitions, viz.: *Broken*, etc.

Broken—One composed of different successive straight lines. *Center*—A line used to indicate the center of an object. *Construction*—A working line used to obtain required lines. *Dotted*—A line composed of short dashes. *Dash*—A line composed of long dashes. *Dot and Dash*—A line composed of dots and dashes alternating. *Dimension*—A line upon which a dimension is placed. *Full*—An unbroken line, usually representing a visible edge. *Shade*—A line about twice as wide as the ordinary full line.

Mixed lines are composed of straight and curved lines, as Fig. 4.

FIG. 4.

Parallel lines are those which have no inclination to each other—Figs. 5 and 6 being everywhere equidistant; consequently they never meet though produced to infinity. If the parallel lines shown in Fig. 6 were produced they would form two circles having a common center.

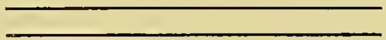


FIG. 5.

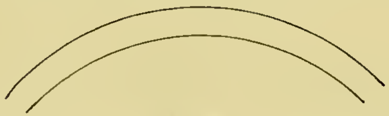


FIG. 6.

Horizontal lines are lines parallel with the horizon, as in Fig. 7.

Vertical lines are often called *plumb lines* as they are parallel to a plumb line suspended freely in a still atmosphere. A *horizontal line* in a drawing is shown by a line drawn from left to right across the paper; a *vertical line* in a drawing is represented by a line drawn up and down the paper or at right angles to a horizontal line, as in Fig. 7.

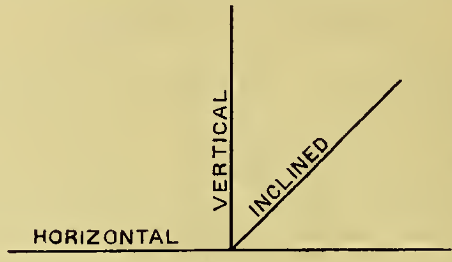


FIG. 7.

Inclined or oblique lines occupy an intermediate between horizontal and vertical lines as shown in Fig. 7; two lines which converge towards each other and which, if produced, would meet or intersect are said to incline towards each other.

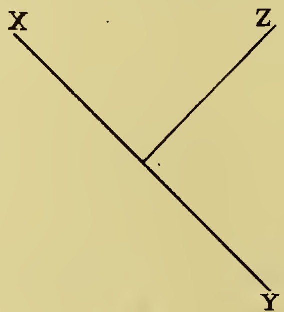


FIG. 8.

Perpendicular lines. Lines are perpendicular to each other when the angles on either side of the point of meeting are equal.

Vertical and horizontal lines are always perpendicular to each other, but perpendicular lines are not always vertical and horizontal; they may be at any inclination to the horizon, provided that the angles on either side of the point of intersection are equal, as X Y and Z in Fig. 8.

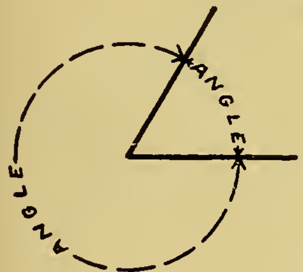


Fig. 9.

Fig. 10.

Angles. Two straight lines drawn from the same point, diverging from each other form an angle, as shown in Fig. 9: the angle is the difference in the direction of two lines proceeding from the same point.

Note.—Mechanics' squares, if true, are always right-angled.

A ***right angle*** is formed when two straight lines intersect so that all angles formed are equal, as shown in Fig. 10.

An ***obtuse angle*** is greater than a right angle, Fig. 11.

Fig. 11.

An ***acute angle*** is smaller than a right angle, Fig. 12.

Obtuse and acute angles are also called *oblique angles;* and lines which are neither parallel nor perpendicular to each other are called *oblique lines.*

The ***vertex or apex of an angle*** is the point in which the including lines meet.

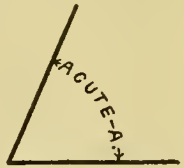


Fig. 12.

An angle is commonly designated by three letters and the letter designating the point of divergence is always placed in the middle.

The magnitude of an angle does not depend upon the length of the sides but upon their divergence from each other.

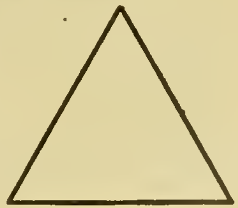


Fig. 13.

STRAIGHT SIDED FIGURES.

A ***surface*** is a magnitude that has length and breadth without thickness; as a plane surface, or, the imaginary envelope of a body.

A ***plane*** is a surface such that if any two of its points be joined by a straight line, such line will be wholly in the surface. Every surface which is not a plane, or composed of plane surfaces, is a *curved surface.*

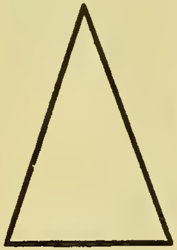


FIG. 14.

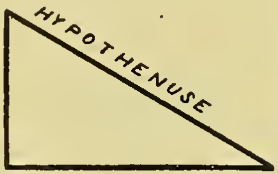


FIG. 15.

FIG. 16.

A ***plane figure*** is a portion of a plane terminated on all sides by lines either straight or curved.

A ***rectilinear figure*** is a surface bounded by straight lines.

Polygon is the general name applied to all rectilinear figures but is commonly applied to those having more than four sides. A *regular polygon* is one in which the sides are equal.

A ***triangle*** is shown in Fig. 13. When surfaces are bounded by three straight lines they are called triangles.

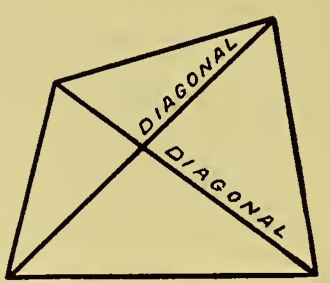


FIG. 17.

An ***equilateral triangle*** has all its sides of equal length, and all its angles equal, as appears in the illustration, Fig. 13.

FIG. 18.

An ***isosceles triangle*** has two of its sides and two of its angles equal, as illustrated in Fig. 14.

A ***right-angled triangle*** has one right angle, Fig. 15: the side opposite the right angle is called the *hypothenuse;* the other sides are called respectively the *base* and *perpendicular.*

The ***altitude of a triangle*** is the length of a perpendicular let fall from its vertex to its base.

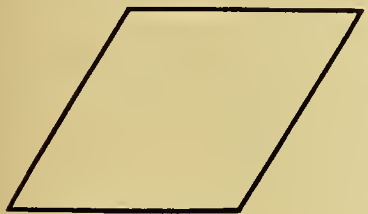


FIG. 19.

FIG. 20.

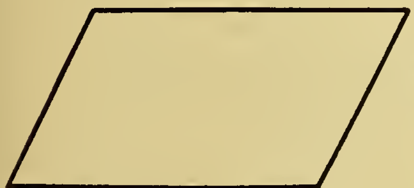


FIG. 21.

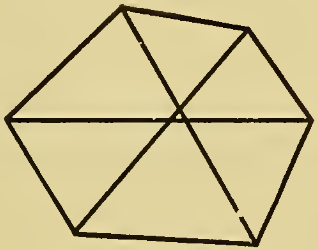


FIG. 22.

A ***quadrilateral*** is a figure bounded by four straight lines. If the opposite sides of a quadrilateral are paralleled it is called a *parallelogram.*

NOTE.—The *superficial contents* of a triangle may be obtained by multiplying the altitude by one half the base.

A *parallelogram*, in which the four sides are equal, and form right angles with each other, is called a *square*, Fig. 16.

There are three kinds of quadrilaterals: The trapezium, the trapezoid, and the parallelogram—as above.

The ***trapezium*** has no two of its sides parallel, Fig. 17.

The ***trapezoid*** has only two of its sides parallel, Fig. 18.

There are four varieties of parallelograms: The rhomboid, the rhombus, the rectangle and the square.

The ***square*** is an equilateral rectangle, Fig. 16.

A ***rhombus*** is a parallelogram as shown in Fig. 19, one in which the four sides are equal, but none of the angles are right angles.

A ***rectangle*** is a parallelogram which has its opposite sides parallel, and all its angles right angles, Fig. 20.

A ***rhomboid*** is a parallelogram in which the adjacent sides are unequal, and none of the angles are right angles, Fig. 21.

A ***diagonal*** is a straight line, which joins two opposite angles of a polygon, Figs. 17, 22.

A ***pentagon*** is a polygon bounded by five straight lines, Fig. 23. If the sides and angles formed by them are equal the figure is called a *regular pentagon*, Fig. 24.

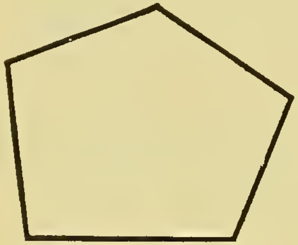


FIG. 23.

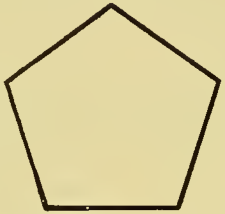


FIG. 24.

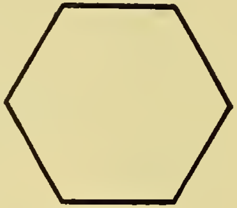


FIG. 25.

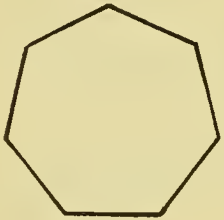


FIG. 26.

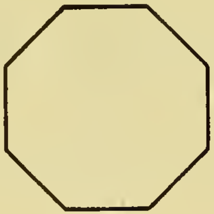


FIG. 27.

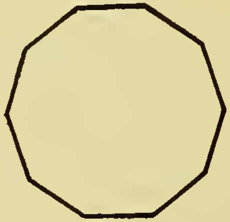


FIG. 28.

A ***hexagon*** is a polygon bounded by six straight lines. Fig. 25 illustrates a *regular hexagon.*

A ***heptagon*** is a polygon bounded by seven straight lines. Fig. 26 illustrates a *regular heptagon.*

An ***octagon*** is a a polygon bounded by eight straight lines. In Fig. 27 is shown a *regular octagon.*

A ***decagon*** is a polygon bounded by ten straight lines. Fig. 28 illustrates a *regular decagon.*

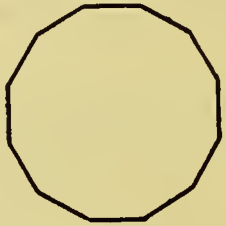


FIG. 29.

A ***dodecagon*** is a polygon bounded by twelve straight lines. In Fig. 29 is shown a *regular dodecagon.*

NOTE.—Polygons of more than eight sides are rarely used in mechanical drawing. Their most frequent application occurs in laying out of the hubs of large sectional wheels.

A ***convex surface*** is one that when viewed from without is curved outward by rising or swelling into a rounded form, Fig. 30.

Fig. 30.

A *double convex surface* is regularly protuberant or bulging on both sides.

Fig. 31.

Concave means hollow or curved inward; said of an interior of an arched surface or curved line in opposition to convex, Fig. 31.

CIRCLES AND THEIR PROPERTIES.

A ***circle*** is a plane figure bounded by one uniformly curved line, all of the points in which are at the same distance from a certain point within, called the *center;* the *circumference* of a circle is the curved line that bounds it; the *diameter* of a circle is a line passing through its center, and terminating at both ends in the circumference; the *radius* of a circle is a line extending from its center to any point in the circumference; it is one-half of the diameter; all the diameters of a circle are equal, as are also all the radii; an *arc* of a circle is any portion of the circumference; the fixed point about which the circle is drawn is called the *center of the circle;* any straight line, drawn within the circle, connecting any two points in the circumference without passing through the center, is called a *chord.*

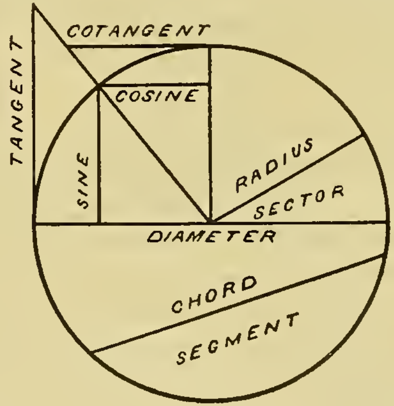


Fig. 32.

A ***semicircle*** is the half of a circle and is bounded by half the circumference and a diameter; a *segment of a circle* is any part of its surface cut off by a straight line; a *sector of a circle* is a space included between two radii and the arc they intersect. See Fig. 32.

Note.—*Radius* is derived from the Latin word *ray*, meaning a divergent line, the plural in Latin is *radii;* the English word for the plural term is *radiuses.*

A ***quadrant*** is a sector equal to one-fourth of the circle; the two radii bounding a quadrant are at right angles.

A ***tangent*** to a circle or other curve is a straight line which touches it at only one point. *Every tangent to a circle is perpendicular to the radius drawn to the point of tangency.*

A ***degree.*** The circumference of a circle is supposed to be divided into 360 equal parts called *degrees* and marked (°). Each degree is divided into 60 minutes, or 60′; and for the sake of still further minuteness of measurement, each minute is divided into 60 seconds, or 60″. In a whole circle there are, therefore, $360 \times 60 \times 60 = 1{,}296{,}000$ seconds. The annexed diagram, Fig. 32, exemplifies the relative positions of the

Sine, Tangent,
Co-Sine, and Co-Tangent

of an angle; the co- in co-sine and co-tangent is simply an abbreviation of the word, *complement.* The circumferences of all circles contain the same number of degrees, but the greater the radius the greater is the absolute measures of a degree, and every circumference is the measure of precisely the same angle.

Thus if the circle be large or small, the number of the division is always the same, a degree being equal to $\frac{1}{360}$th part of a circle; the semicircle is equal to 180° and the quadrant to 90°.

The ***sine*** of an arc is a straight line drawn from one extremity perpendicular to a radius drawn to the other extremity of the arc, Fig. 32; the *co-sine* of an arc is the sine of the complement of that arc, as shown in the same figure.

The ***tangent of an arc*** is a line which touches the arc at one extremity and is terminated by a line passing from the center of the circle through the other extremity of the arc, Fig. 32; the *co-tangent* of an arc is the tangent of the complement.

For the sake of brevity, these technical terms are contracted thus: for sine, we write *sin.*; for co-sine, we write *cos.*; for tangent, we write *tan.*, etc.

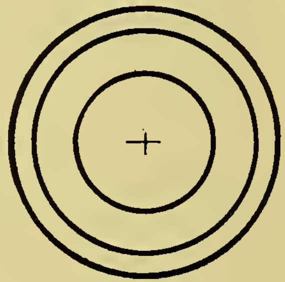


FIG. 33.

Concentric circles are those which are described about the same center, Fig. 33.

Eccentric circles are those which are described about different centers, Fig. 34.

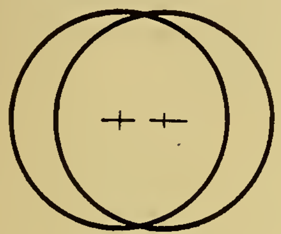


FIG. 34.

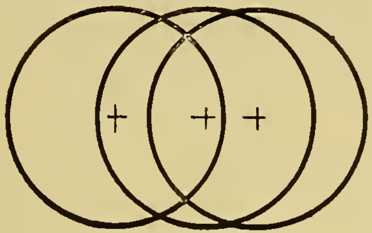


FIG. 35.

Eccentric circles are two or more circles whose centers lay within the circumference of one or more of these circles, but do not form a common center about which they could all be described. Figs. 34, 35, 36.

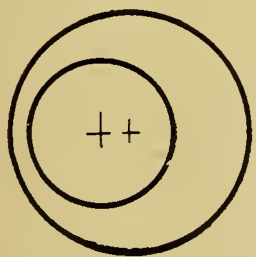


FIG. 36.

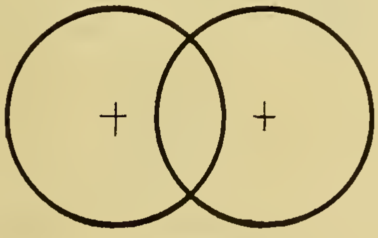


FIG. 37.

The centers of eccentric circles may also lay outside of each other's circumference, as in Fig. 37, or the center of one circle may lay outside of the other's circumference, while the former circle may be either wholly or partly within the circumference of the latter, as in Figs. 38 and 39.

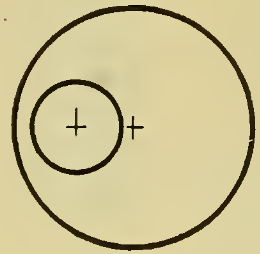


FIG. 38.

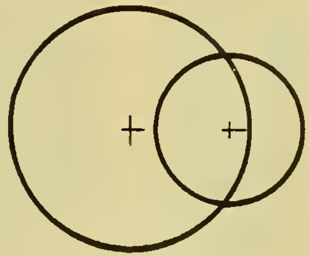


FIG. 39.

In another instance the center of one circle may lay on the circumference of the other, as in Fig. 40.

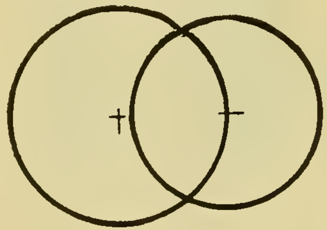


FIG. 40.

The distance between the centers of eccentric circles is called the *radius of eccentricity*.

If two circles lay in a position as indicated in Fig. 41, they are not regarded as eccentric circles, but are treated as two independent figures.

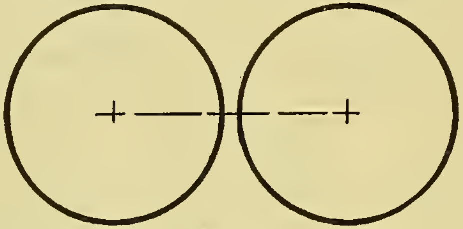


Fig. 41.

A ***Parabola*** is a curve, described by a point, moving so, that its distances from a straight line, and a fixed point are always equal, Fig. 42; the straight line is called the *Directrix*, and the fixed point is called the *Focus* of the parabola; a straight line drawn at right angles to the directrix, and passing through the focus, is called the *Axis*.

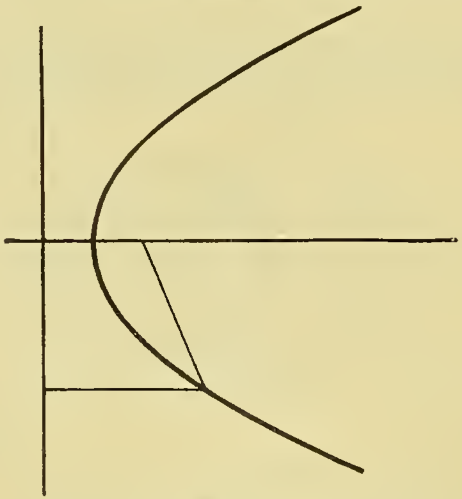


Fig. 42.

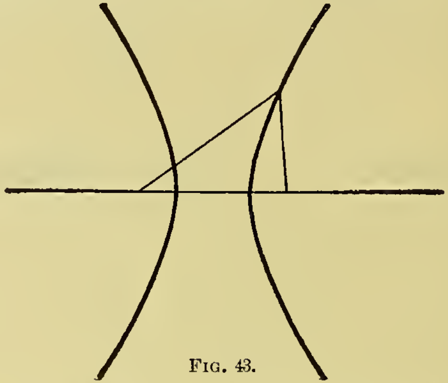


Fig. 43.

A ***Hyperbola*** is a curve from any point of which, if two straight lines be drawn to two fixed points, their difference shall always be the same. See Fig. 43.

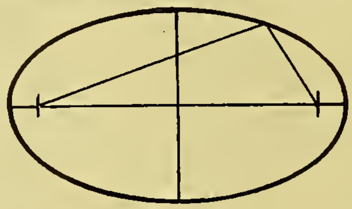


Fig. 44.

An ***Ellipse*** is a curve, described by a point, moving so, that the sum of its distances from two fixed points is always constant; the two fixed points are called the *Foci*, Fig. 44.

SOLIDS.

A ***solid*** has the parts constituting its substance so compact or firmly adhering as to resist the impression or penetration of other bodies; it has a fixed form, is hard, firm and unlike a fluid or liquid; it is not hollow, hence sometimes heavy.

A ***conic section*** is a curved line formed by the intersection of a cone and a plane.

Intersection of solids is a term used to describe the condition of solids which are so joined and fitted to each other as to appear as though one passes through the other

By the envelope of a solid is meant the surface which encases or surrounds it.

A ***prism*** is a solid body whose ends or bases are equal and parallel plane figures, and whose sides are parallelograms. The shape of a prism is always expressed by the form of its bases.

A ***triangular prism*** is a prism with the triangular bases, as shown in Fig. 45.

A ***quadrangular prism*** is a prism with quadrangular bases, Fig. 46.

A ***pentagonal prism*** is a prism with pentagonal bases, Fig. 47.

A ***hexagonal prism*** is a prism with hexagonal bases, Fig. 48.

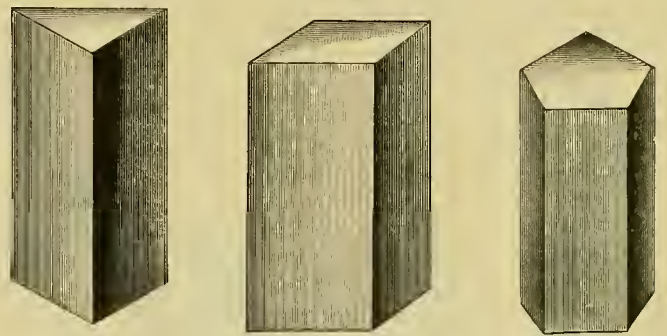


FIG. 45. FIG. 46. FIG. 47.

A ***cube*** is a quadrangular prism whose bases and sides are all equal and form perfect squares, Fig. 49.

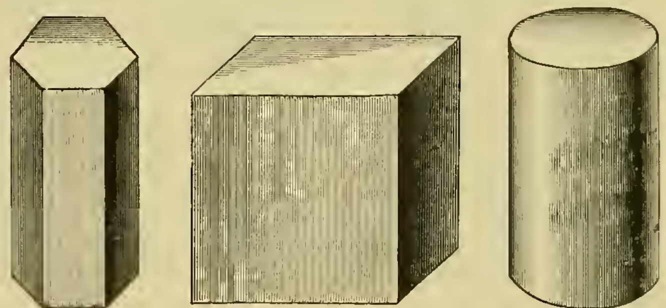


FIG. 48. FIG. 49. FIG. 50.

A ***cylinder*** is a solid, bounded by two equal circular surfaces or bases, and one continuous curved surface, Fig. 50. All cross sections of a cylinder are equal to the bases.

A ***cone*** is a solid bounded by a circular base, and one curved surface, extending from the circular base to a point opposite it, Fig. 51.

Fig. 51.

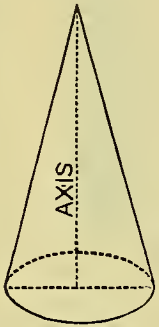


Fig. 52.

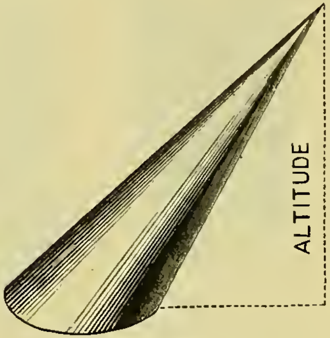


Fig. 53.

A ***right cone.*** If a perpendicular, dropped from the apex of the cone to its base, meets the center of the base circle, the cone is called a right cone, Fig. 52. The perpendicular in this case is called the *Axis* of the cone.

An ***oblique cone.*** If the perpendicular falls alongside the center of the base circle, or entirely outside of its circumference, the cone is called an *oblique cone*, Fig. 53.

A ***truncated cone.*** A cone, cut off in the manner shown in Fig. 54, is called a *truncated cone*, If an oblique cone is cut in the above manner, it is called an *oblique truncated cone*, Fig. 55.

If a cone is cut by a plane, parallel to the outline of its surface, vertically opposite the center line of the cutting plane, as shown in Fig. 56, the outline of the section is a *parabola*, Fig. 57.

Fig. 54.

Fig. 55.

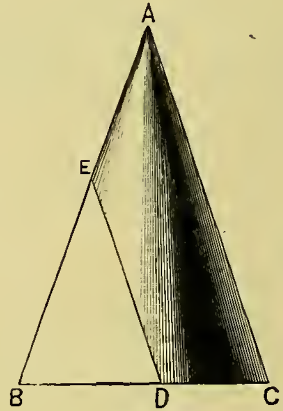


Fig. 56.

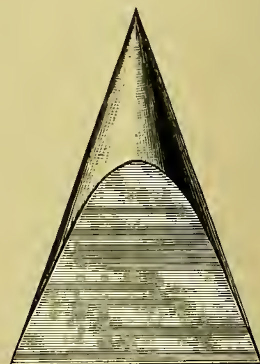


Fig. 57.

If the cutting plane forms a smaller angle than the parabola, with the outline of the side on which

FIG. 58.

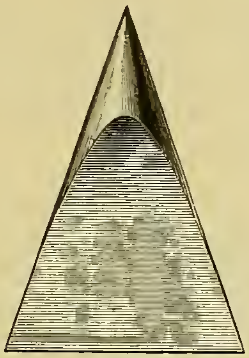


FIG. 59.

it is cut, as shown in Fig. 58, the section is a *hyper-*

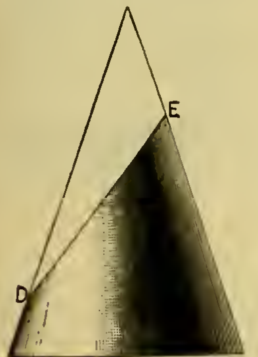


FIG. 60.

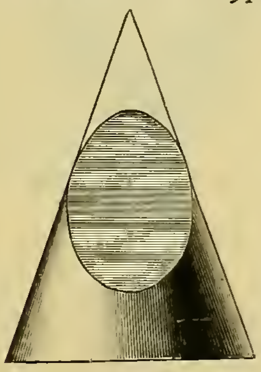


FIG. 61.

bola, Fig. 59. If the cutting plane forms a greater angle than the parabola, with the surface, so that the cone is cut in the manner shown in Fig. 60, the section is an *ellipse*, Fig. 61.

A ***pyramid*** is a solid, whose base is a polygon, and whose sides are formed by triangles.

The point in which all the lines of the triangular sides meet, is called the *apex* of the pyramid.

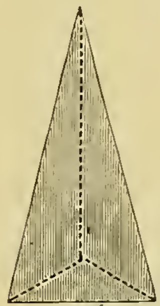


FIG. 62.


FIG. 63.

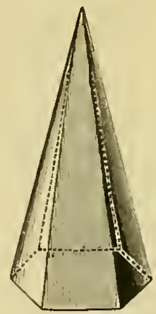


FIG. 64.

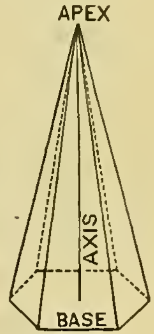


FIG. 65.

Pyramids are classified as triangular, quadrangular, pentagonal, hexagonal, etc., pyramids, depending upon the shape of their base, Figs. 62, 63, 64.

If the base of a pyramid forms a regular polygon, and a perpendicular dropped from the apex, to the base, passes through the center of the base, it is called a *right pyramid*, Fig. 65.

The ***altitude*** of a pyramid or a cone, is the perpendicular distance from the apex to the base, Figs. 66, 67. The altitude of a prism or a cylinder is the perpendicular distance between the bases, Figs. 68, 69.

A ***truncated pyramid*** is the part remaining, after the apex is cut away, Figs. 54 and 70. A truncated cone or pyramid is also called the *frustrum* of the cone or pyramid.

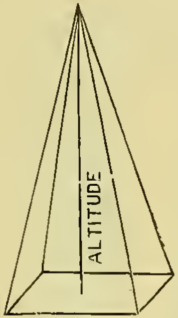


Fig. 66.

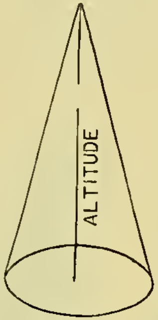


Fig. 67

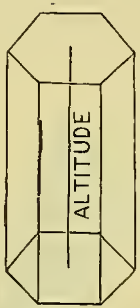


Fig. 68.

Fig. 69.

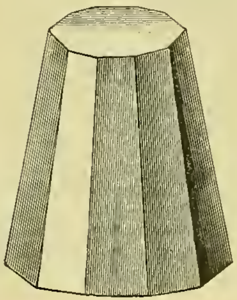


Fig. 70.

Fig. 71.

A ***sphere*** is a solid, bounded by a uniformly curved surface, any point of which is equidistant from the center, Fig. 71.

A ***polyhedron*** is a solid, bounded by polygons. There are five regular polyhedrons—as follows:

A ***tetrahedron*** is a solid, bounded by four equilateral triangles, Fig. 72.

A ***hexahedron*** is a solid, bounded by six squares; the common name for this solid is cube, Fig. 49.

An ***octahedron*** is a solid, bounded by eight equilateral triangles, Fig. 73.

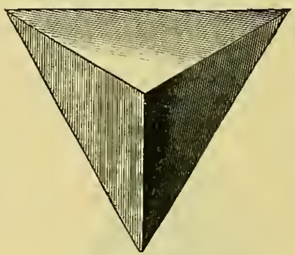


Fig. 72.

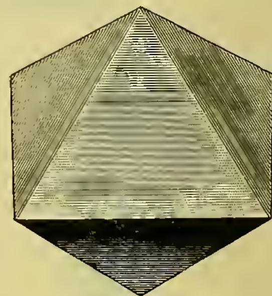


Fig. 73.

A ***dodecahedron*** is a solid, bounded by twelve regular pentagons.

An ***icosahedron*** is a solid, bounded by twenty equilateral triangles.

DRAWING BOARD, T-SQUARE AND TRIANGLES.

The problems explained in the following paragraphs are but a small part of the great number of problems that may be executed with the aid of the tee-square and triangles.

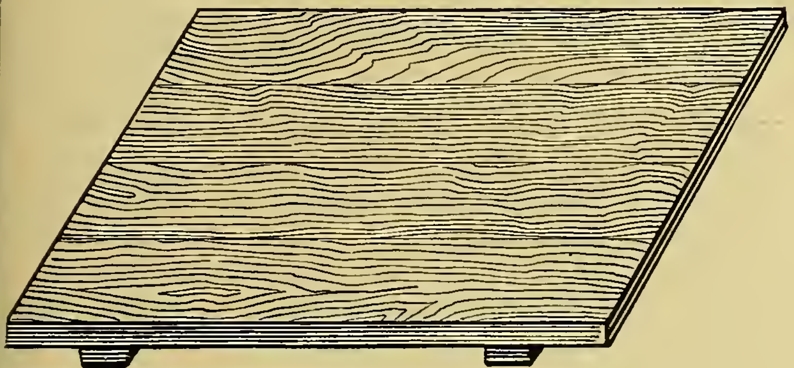


FIG. 74.

In fact, all drawings, embracing straight lines only, may be drawn with the aid of the above instruments, provided the nature of the drawing does not call for greater accuracy or for lines other than straight ones. In the latter case, the mathematical instruments described hereafter need to be employed.

The paper on which it is intended to make a drawing, is generally fastened, by means of thumbtacks, to a specially made board called a drawing board, Fig. 74.

The drawing board should be made about 2 inches longer and 2 inches wider than the paper. It should be made of well-seasoned, straight-grained pine, free from all knots; the grain should run lengthwise of the board.

The edges of the board should be square to each other and perfectly smooth in order to provide a good working edge for the head of the tee-square to slide against.

A pair of hard-wood cleats is screwed to the back of the board. The board should be about three-quarter inch in thickness. The cleats, fitted at the back of the board, at right angles to its longest side, may be about two inches wide and one inch thick. Such cleats will keep the board from warping through changes of temperature and moisture.

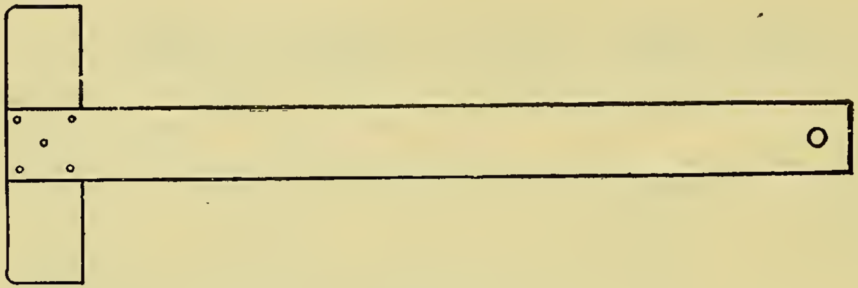


FIG. 75.

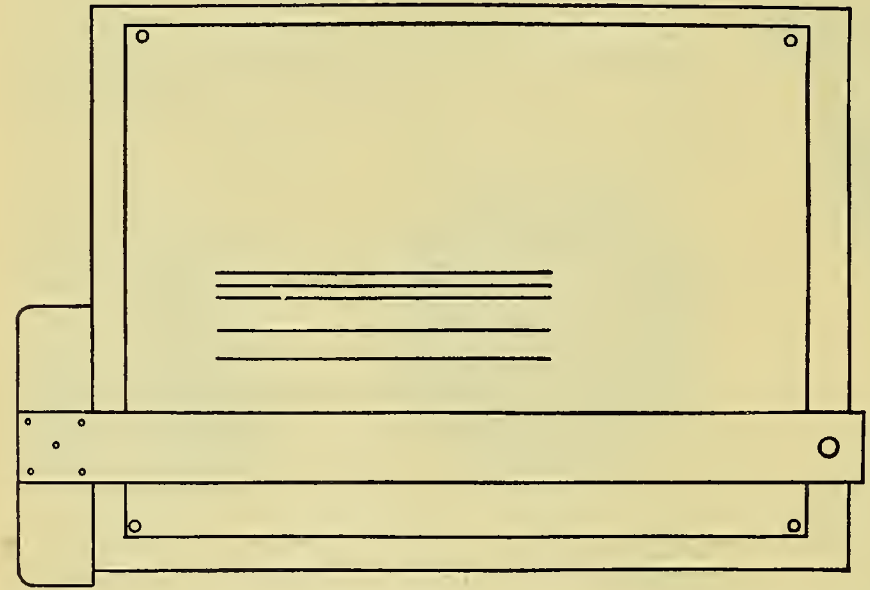


FIG. 76.

All lines parallel to the longer edges of the board are called horizontal lines. For drawing such lines an instrument is used, called a tee-square, Fig. 75. A tee-square consists of two parts, the head and the blade, which should be square to each other.

The blade should be as long as the drawing board. It should be made of well-seasoned, fine-grained hard wood, and as light as its proper use will permit. The head may be made of any kind of well-seasoned wood. The blade should be laid on the face of the head and there fastened to it with four or five screws. The tee-square should be used with its head held firmly against the left hand edge of the board. Any number of horizontal lines may be drawn by sliding the tee-square up or down, Fig. 76.

Another kind of a tee-square is shown in Fig. 77. The blade of this tee-square is fastened to the head by means of a square-necked bolt and a fly-nut. The blade may be so adjusted as to form any desired angle with the head. This tee-square is called the adjustable tee-square.

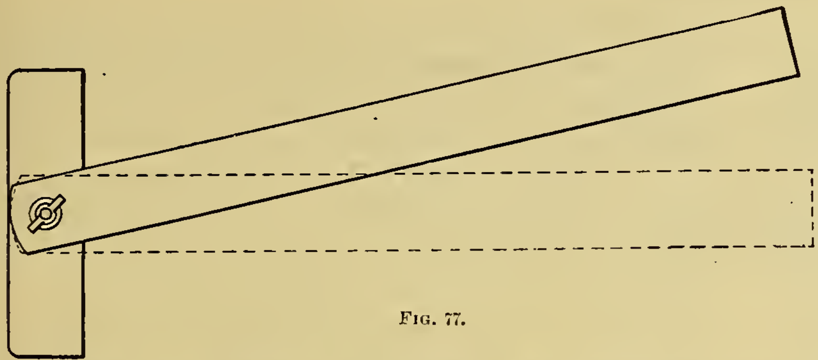


FIG. 77.

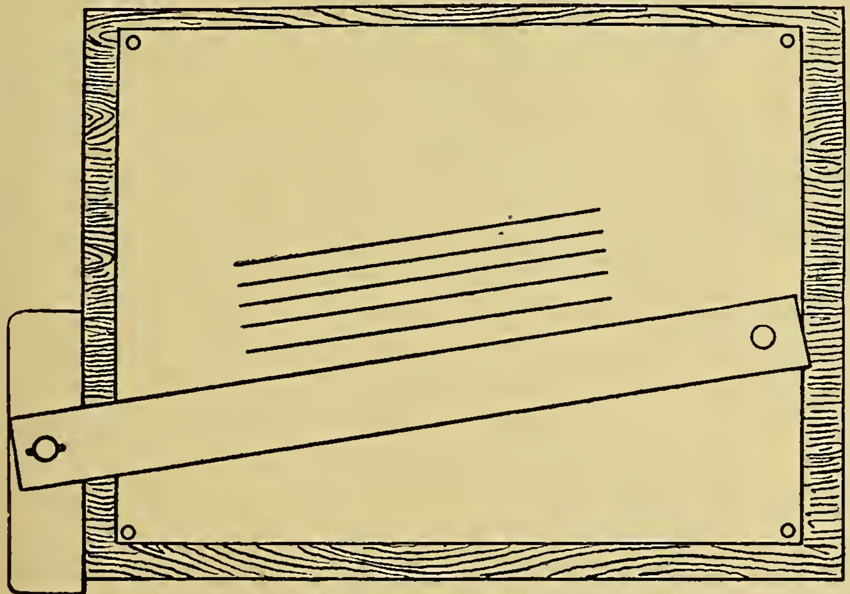


FIG. 78.

After setting the blade at the desired angle to the head, we can draw any number of parallel lines at that angle, by sliding the tee-square up or down, Fig. 78.

For drawing lines other than horizontal ones, set squares or triangles are used. They are made in various styles, some being cut out of a single piece of wood, while others are framed together of three or more pieces.

Two triangles will be required for ordinary purposes. One should have one angle of 90 degrees, that is a square angle or a right angle, and two angles of 45 degrees each, that is equal to one-half of a right

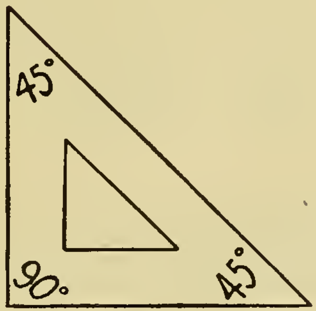


FIG. 79.

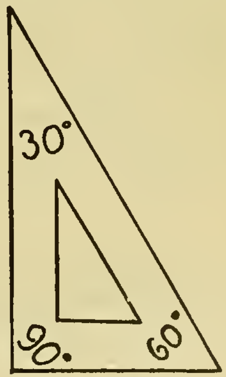


FIG. 80.

angle; the two short sides of the triangle are of equal length, Fig. 79.

The other triangle should contain one angle of 90 degrees, one angle of 30 degrees (that is equal to one-third of a right angle) and one angle of 60 degrees (that is equal to two-thirds of a right angle.) In this triangle the shortest side is equal to just one half the longest side, Fig. 80.

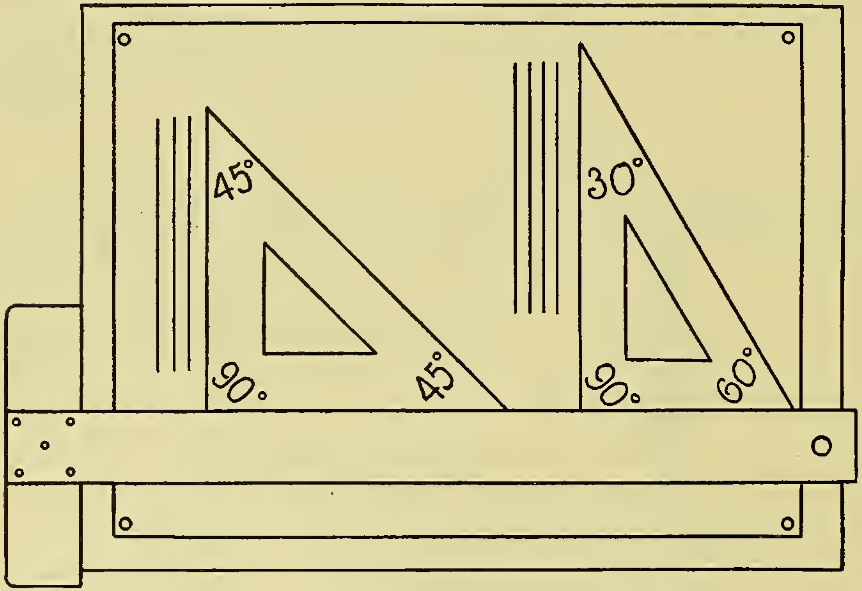


Fig. 81.

The first triangle is called the 45-degree triangle, the second, the 30-degree triangle or the 60 degree triangle. These triangles may be made of wood, hard rubber, or celluloid, of which materials it is also preferable to make the tee-square for many reasons. Triangles made of straight-grained well-seasoned hard wood will be found most satisfactory.

By placing the tee-square in position on the drawing board, with its head against the left-hand edge of the board, and placing either triangle with its short side to the edge of the tee-square, we may draw lines parallel to the short side of the drawing board, which we will call vertical lines, Fig. 81. Any number of vertical lines may be drawn by sliding the triangle in this position along the edge of the tee-square.

The manner in which the head of a tee-square is united to the blade determines its adaptability or otherwise to the use made of it; in some the head of a tee-square is rectangular in section, and the blade mortised into it; in others the blade is dovetailed and let into the head of a tee-square for the whole of its thickness; the method spoken of on page 42 is, however, the most approved.

Keeping the tee-square in position and placing against its blade one edge of the 45-degree angle, we may draw a line making an angle of 45 degrees with a horizontal line, Fig. 82. Such a line is called

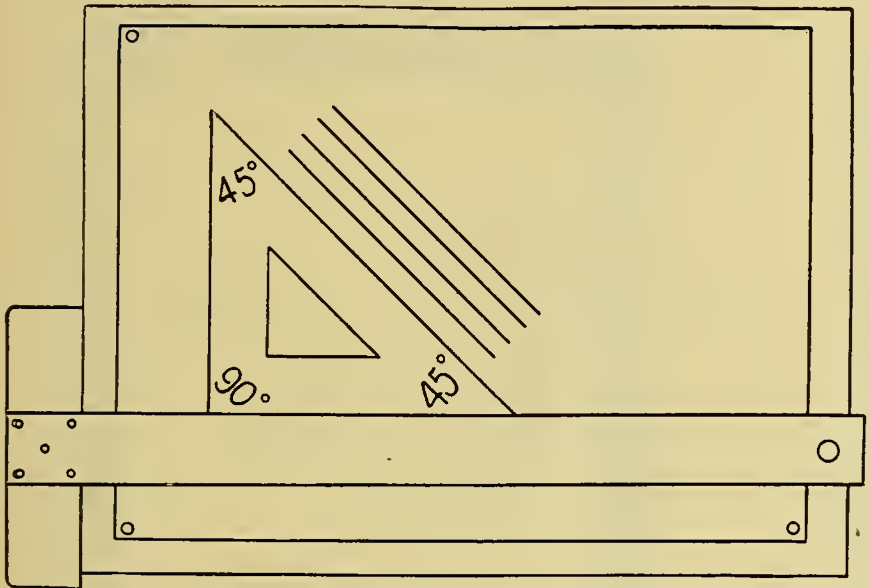


FIG. 82.

a 45-degree line, or we may write it 45° line, the small circle at the top, placed after the number meaning degree.

By placing one edge of the 30-degree angle against the blade of the tee-square, held in position on the board, a line making an angle of 30 degrees with a horizontal line, or simply a 30-degree line, Fig. 83, may be drawn; in a similar manner a 60-degree line may be drawn with the 60-degree angle of the triangle.

By combining the two triangles as in Figs. 84, 85, a 15-degree line and a 75-degree line may be drawn.

We may draw a line or lines parallel to any given line in our drawing, by the use of the two triangles in the following manner:

Place one of the triangles with one of its edges exactly on the given line; place the longest edge of the second triangle against the longer one of the two remaining edges of the first triangle; then hold the second triangle in place and slide upon it the first triangle, Fig. 86.

Using the triangles in a similar manner we may draw a line or lines at a right angle to any given line, thus—

Place one edge of either triangle exactly on the given line; place the longest edge of the second triangle exactly to the longest edge of the first triangle. Hold the second triangle in place and turn the first triangle so that one edge will form a right angle with the given line, as in Fig. 87. By placing one edge of the right angle of either triangle on the given line, as the first operation, the first triangle will not have to be turned.

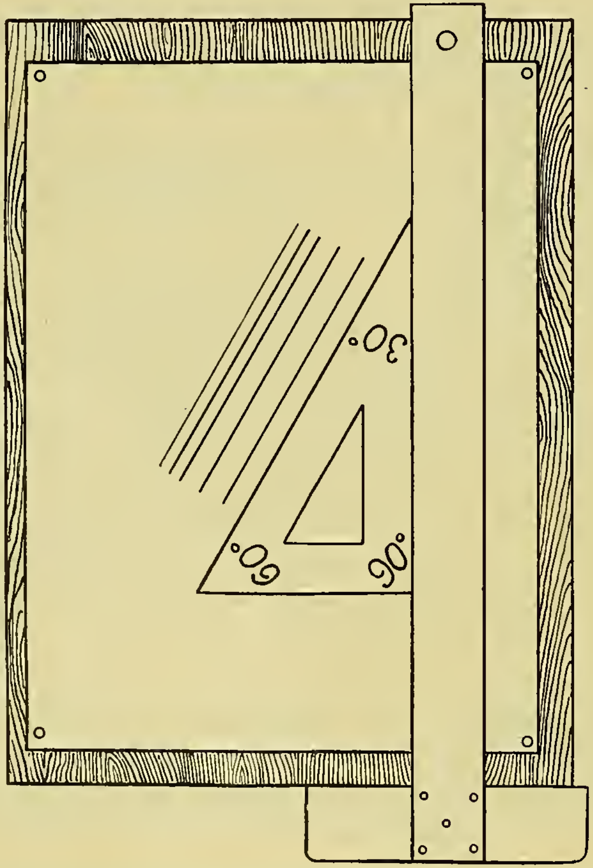


FIG. 83.

By sliding the first triangle upon the second one, any number of lines may be drawn which will be at right angles to the given line.

With a knowledge of the preceding rules a great

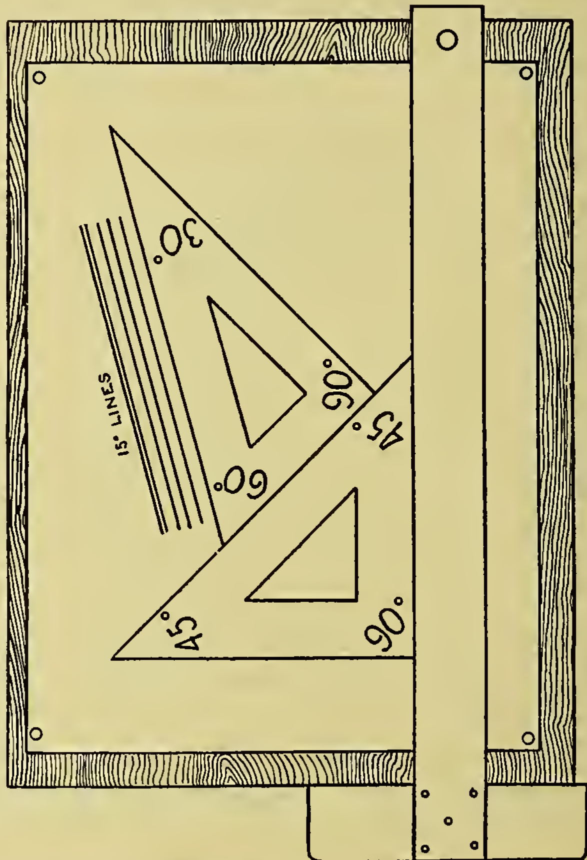


FIG. 84.

variety of figures may be drawn. In the following we will show how a square, an equilateral triangle, a hexagon and an octagon may be drawn by these simple means.

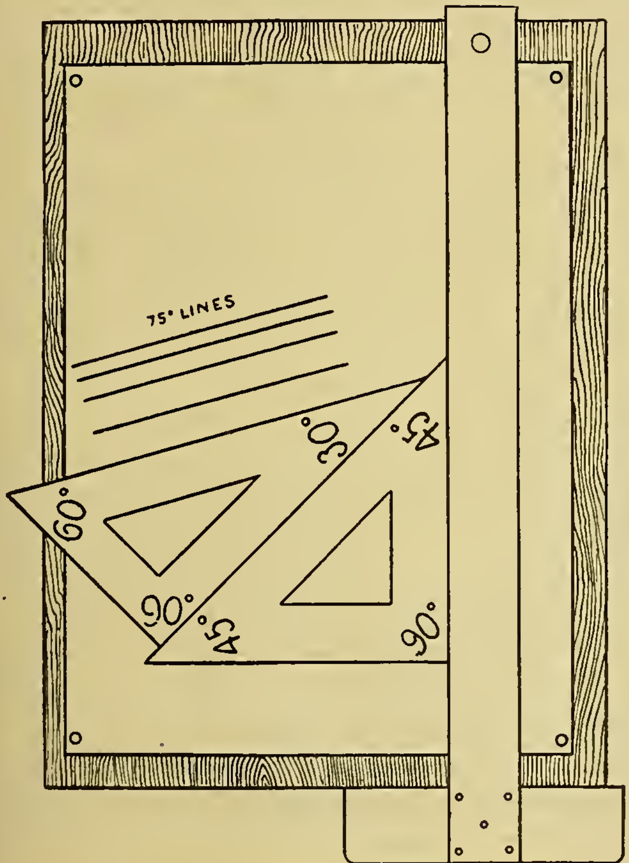


Fig. 85.

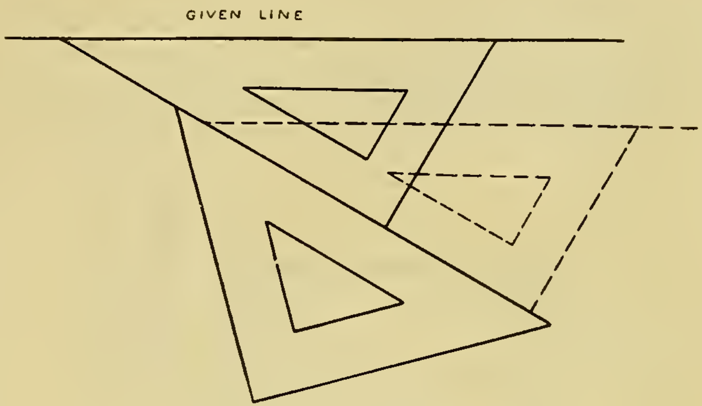


Fig. 86.

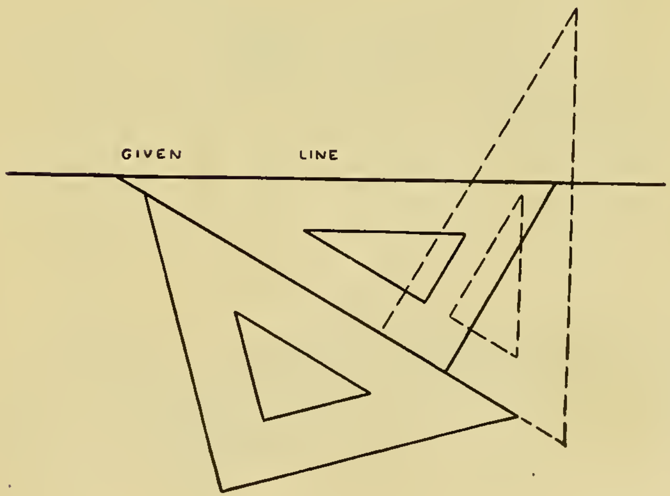


Fig. 87.

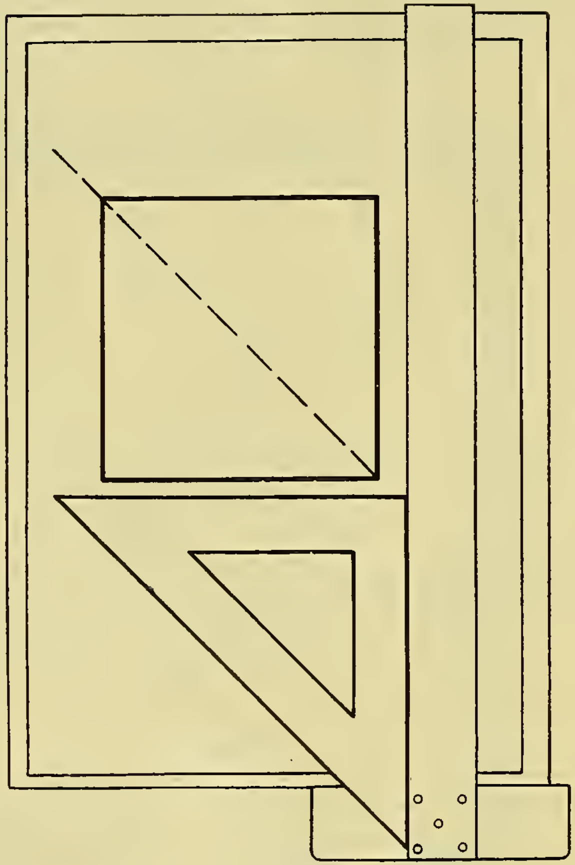


Fig. 88.

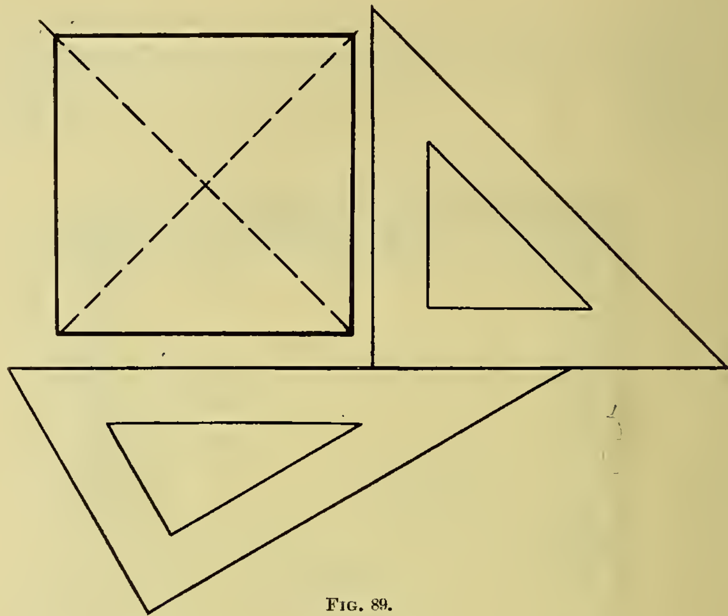


Fig. 89.

Let it be required to draw a four-sided plane figure, all sides of which are equal and all its angles right angles. Such a figure is called a square.

If the sides of the required square should be parallel to the edges of the drawing board, we then draw a horizontal line by means of the tee-square, Fig. 88. On this line we mark two points, the distance between them being equal to the side of the required square. By means of either triangle draw vertical lines through the two points on the first line; make one of the vertical lines equal to the first line, that is equal to a side of the square, by drawing a 45-degree line from the foot of one of the vertical lines, to meet the other vertical line, and move the tee-square to the point of intersection of these two lines, where a horizontal line is drawn, meeting the other vertical line and forming the concluding side of the required square.

If a square is to be drawn on any given line, which is neither horizontal nor vertical (such lines are called oblique lines) we will proceed as follows: Fig. 89, on the given line mark two points, the distance between them being equal to a side of the required square. Through these two points draw lines at right angles to the first line. Make one of these sides equal to a side of the required square and draw through the end of it a line parallel to the first line. This line will form the concluding line of the square.

Let it be required to draw a square, when the length of its diagonal only is given, Fig. 90.

Place the longest edge of the 45-degree triangle exactly on the given diagonal. Place the tee-square with an edge of its blade against one of the short sides of the triangle. By sliding the triangle upon the tee-square held in place, draw two lines through the ends of the given diagonal with the other short edge of the triangle. These will form two sides of the square. Bring the triangle back to its first position upon the diagonal, hold it in place and remove the tee-square, placing it now against the other short edge of the triangle. Sliding the triangle upon the tee-square, draw the two remaining sides of the square, as before.

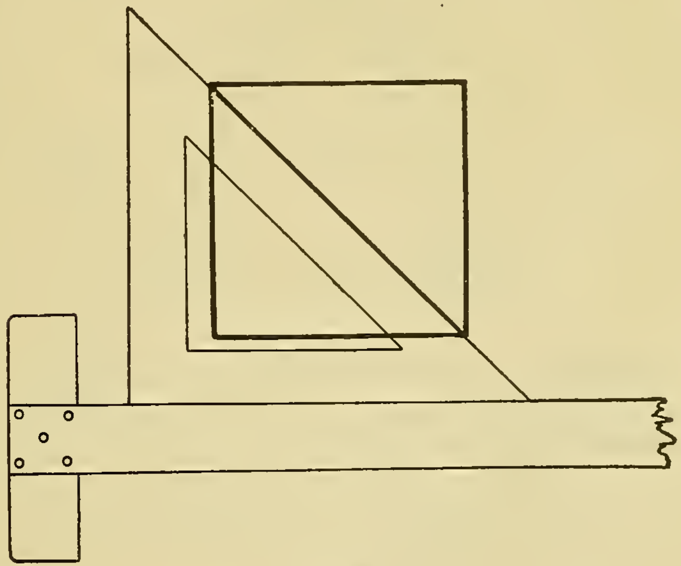


FIG. 90.

To draw an equilateral triangle upon a given line. The angles in an equilateral triangle are 60-degree angles, Fig. 91.

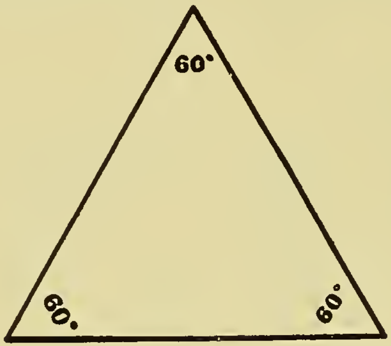


Fig. 91.

Place the edge of the blade of the tee-square exactly on the given line. Place one edge of 60-degree angle of the 60-degree triangle to the edge of the tee-square, and draw lines making an angle of 60 degrees with the tee-square, through both ends of the given line. These lines, with the given line, will form the required triangle.

To draw a regular hexagon :

Draw a line, AB, Fig. 92; set off from any point, O, on the line AB, two distances, AO and OB, each equal to a side of the required hexagon. Through the points A, O and B draw six

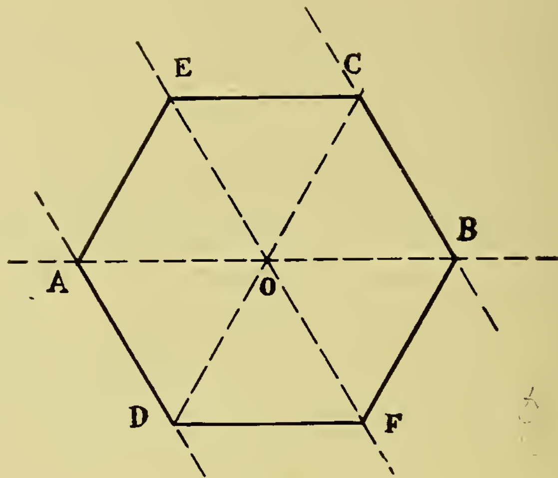


Fig. 92.

parallel lines making angles of 60 degrees with the line AB; three lines, AE, DOC and FB in one direction, and the other three, CB, EF and AD in the other direction. Join the points E and C and D and F. A E C B F D is the hexagon required.

To draw a hexagon on a given line. Let AB be the given line, Fig. 93. Draw the lines AC and BE at an angle of 60 degrees to the given line, in one direction, and the lines AF and BD, at the same angle, in the other direction. At the points A and B on the given line, draw two lines at right angles to this line, these lines cutting the lines, EB and AF, at the points E and F. Join E and F and through the points E and F draw the lines EC and FD at 60-degree angles to the given line, EC cutting the line AC at C and FD cutting the line BD at D. Then A C E F D B is the required hexagon.

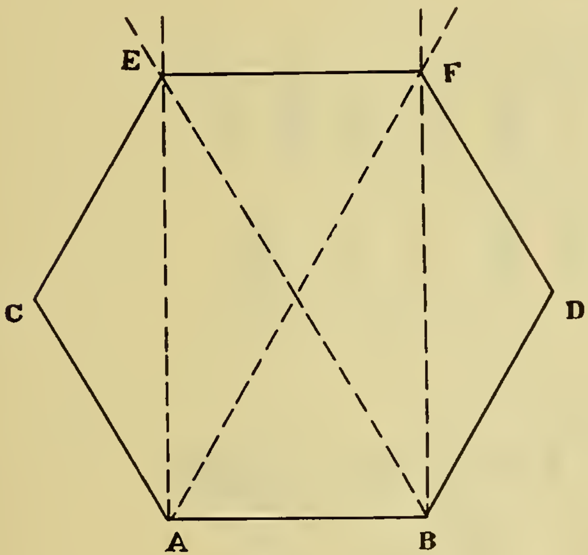


Fig. 93.

To draw an octagon on a given line :

Let AB be the given line, Fig. 94. At the points A and B draw lines at angles of 45 degrees to the given line, AC, in one direction, and BH in the other direction. Make AC and BH each equal to the line AB. Through C draw the line CF parallel to BH and through H the line EH parallel to AC. Draw lines through C and through H at right angles to the given line ; the line CD cutting the line BD

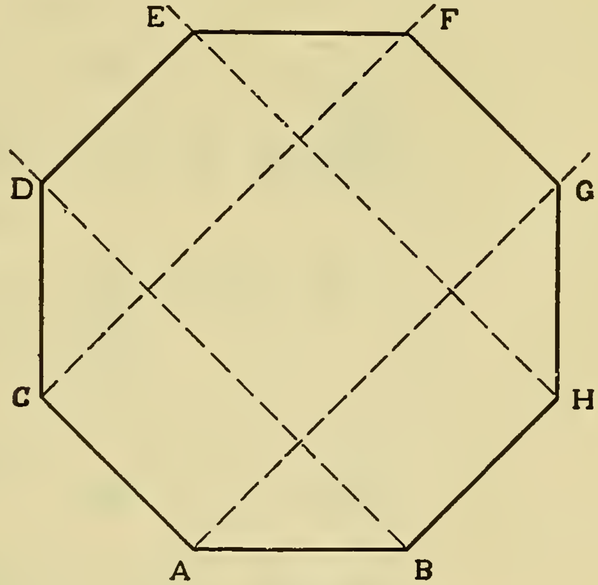


Fig. 94.

at D and the line HG cutting the line AG at G. Through D draw the line DE parallel to CF and cutting EH at E ; then draw through G the line GF parallel to EH and cutting CF at F. Join EF and A C D E F G H B is the required octagon.

FIG. 95.

LETTERING.

Let it be said that lettering is intended to convey to the mind of the observer a simple but attractive impression of what the drawing is to express.

When the information necessary to the reading of a drawing cannot be expressed by lines and scale dimensions, it must be indicated in the form of printed explanations, remarks, etc., as explained and illustrated in the following pages.

Whole volumes have been published upon this most fascinating subject. When writing was the universal mode of expression, that is, before the invention of printing—the art of lettering was one of the fine arts. Many manuscripts are now extant whose titles are made upon vellum in inks of gold, scarlet, blue and other gaudy colors; these have added vastly to the value of the books and aided in their preservation through the long centuries. The illustration upon the opposite page is given as a specimen of one of these ancient ("*antique*") alphabets.

To do good lettering is not an easy task, and unless the student is already experienced he should devote much time to practicing the art, working slowly and bearing in mind that much time is required to make well-finished letters.

Lettering of various styles are in use, some quite simple and others difficult, especially in cases where an ornamental heading is required, but it must be remembered that a drawing is primarily made to convey an idea, and not for an ornament.

The character and size of the letters on all working drawings should be in harmony with the drawing on which they appear. It is desirable to have all lettering on a drawing made in the same style, only differing in size or finish of details.

Capital letters should always be sketched in pencil, especially by the beginner, and inked in afterwards; the lettering used on mechanical drawings is usually of the simplest character, the letters being composed of heavy and light strokes only; for headings, titles of large drawings, where comparatively large lettering is required, it will be most appropriate to use large letters.

The title should be conspicuous, but not too much so; sub-titles should be made smaller than the main-title.

The "Scale" and general remarks placed in the margin of the drawing or near the title should come next in size. All explanations and remarks on the views should not be larger than one-eighth inch.

The examples of lettering given as illustrations are briefly explained on page 63.

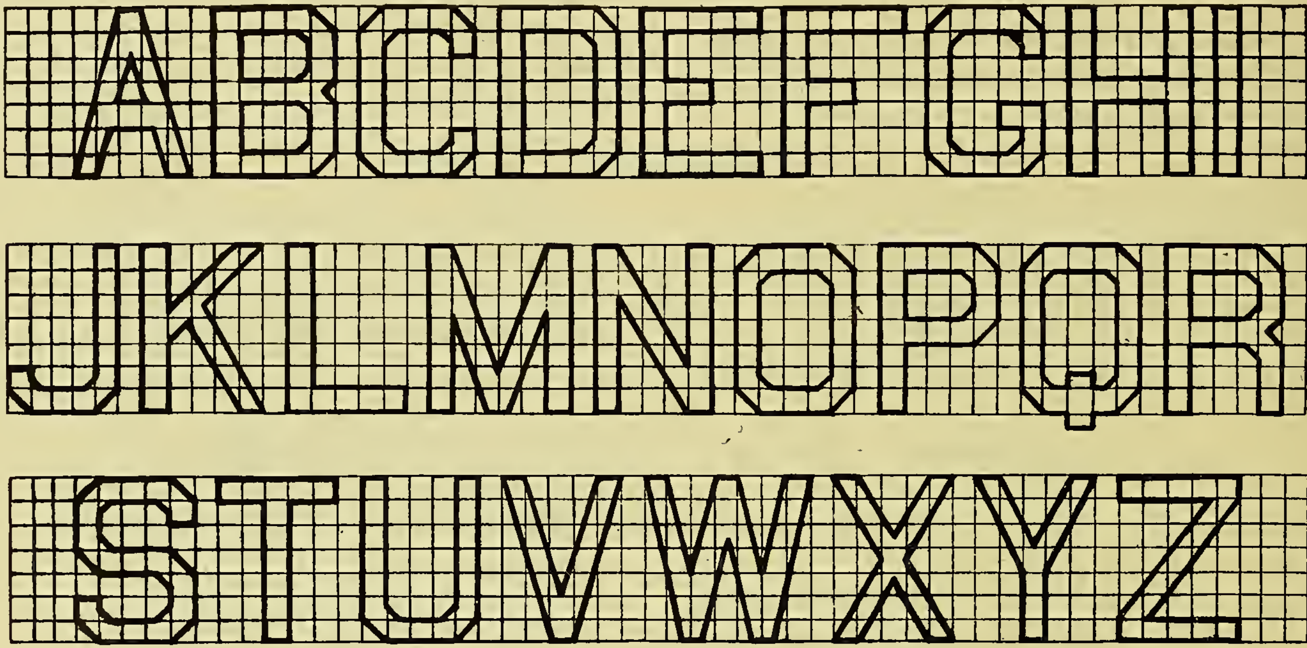


FIG. 96.

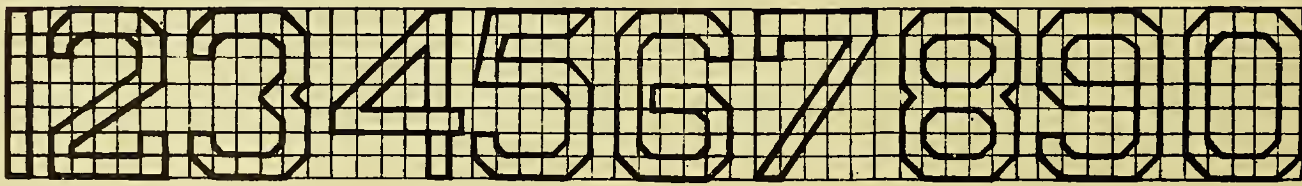


FIG. 97.

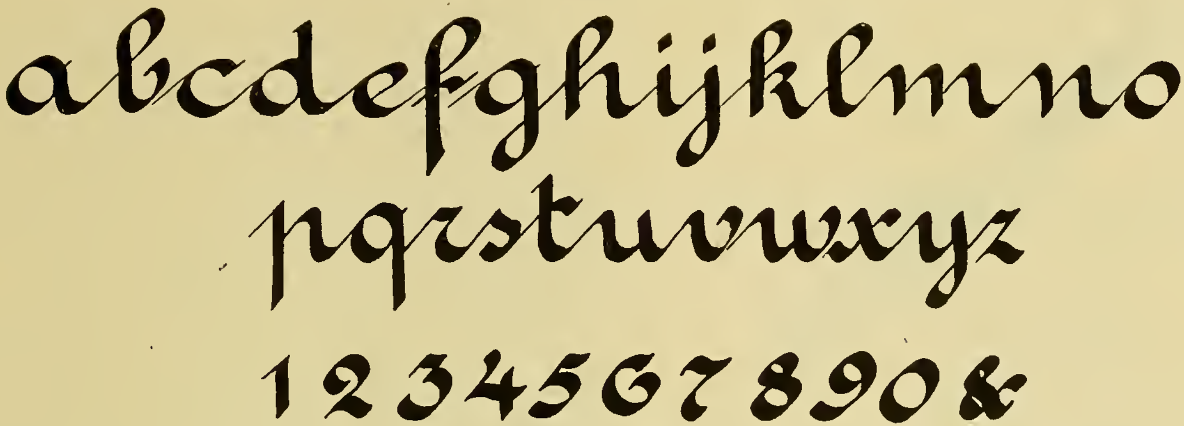


FIG. 98. (See page 63.)

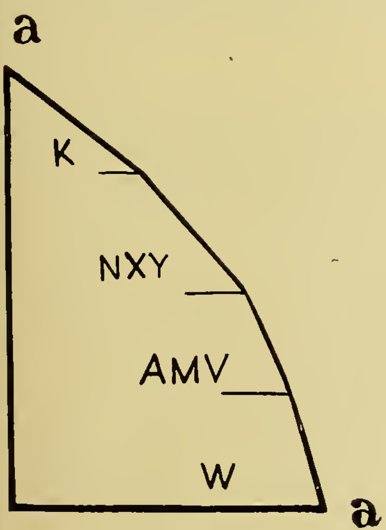


FIG. 99.

Fig. 99 shows one of the devices in use for facilitating the laying out of letters; this instrument is known as the lettering triangle and may be made of metal, hard rubber, celluloid, etc.

The broken line a a contains lines of different inclinations by which the slanting parts of those letters, shown on the triangle, may be laid out.

The highest inclined line may be used for the slanting strokes of the letter K; the inclined line, situated next to the highest is intended to be used for the letters N, X and Y; the next inclined line is to be used for the drawing of the letters A, M and V and the lowest inclined line is used for the letter W.

Other triangles and templates have been made for laying out lettering of different character, of which the example given is one of several in common use.

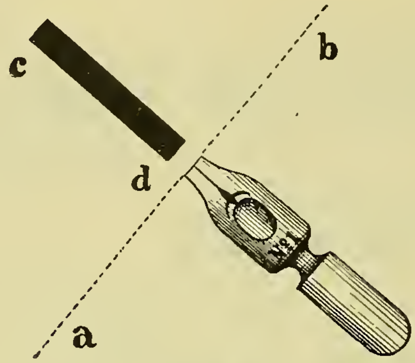


FIG. 100.

The above figure, 100, shows a pen made specially for round writing upon drawings; while nearly all lettering is executed by a common writing pen this device deserves a description.

The "nibs" of the pen are cut off, leaving a short, straight line at the point; the width of this point is equal to the greatest thickness of a line which may be desired for the letters; these pens are manufactured in various widths and numbers; No. 1 is made for a stroke of about 1/8" in thickness; the highest numbers are made with a point nearly like the ordinary writing pen point.

The No. 1 pen may be used for capital letters, about one inch high and for small letters about 1/2" high; the pen is always held parallel to the line *ab* at 45°, Fig. 100.

A motion of the pen in the direction of the line a b produces a fine line; all strokes, light or heavy, are made by means of the whole width and not by only one edge of the pen; heavy strokes are made with the pen moving in the direction c d, Fig. 100, with the whole width of the pen. The pen should move smoothly over the paper without any special pressure being brought to bear on it.

Vertical strokes produced by a downward motion of the pen will not be quite so wide as the line c d.

All strokes should be executed with an unaltered position of the pen "nibs," which must remain parallel to the direction of the line *ab* and inclined about 45°.

Letters containing circular curves are made with the pen in the same position; a circle should not be made by one continuous motion of the pen; it should be formed of two semicircles, taking care to smoothly join the two semicircles.

It is well for the beginner to lay out a number of squares in pencil and to practice the circular strokes within the squares; the completed circle should be contained within the square. The light strokes will be parallel to the diagonal of the square, the vertical stroke should be parallel to the vertical sides of the square. The attractive appearance of the lettering will entirely depend upon the correctness of connecting the semicircles and straight lines of which the letters are composed.

The size and thickness of the writing depend on the width of the pens and cannot be arbitrarily executed by means of the same pen, without distorting the regular form of the characters.

The pen must at all times be kept clean, as otherwise no clean-cut line can be obtained. The ink should be kept only on the outside or upper side of the pen, and its bottom side should be kept perfectly dry. As soon as the draughtsman notices that the bottom of the pen becomes wet he should cease writing with it, as it will produce an uneven line.

The letters should be made with plain, even, clear-cut lines, well proportioned in all parts and especially well spaced. A special device, called an "inkholder," is used in order to keep a sufficient quantity of ink on the upper side of the pen.

Free hand lettering should only be taken up after the student is proficient in mechanical lettering; pencil guide-lines for letters and words should be drawn; larger letters may first be penciled in very lightly, and an ordinary writing pen may be used for inking them in.

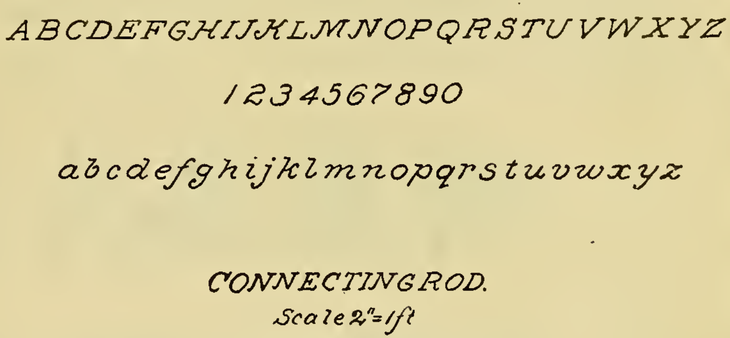


Fig. 101. (See page 63.)

Letters should be so placed as not to interfere with the lines of the drawing and should clearly point out the part intended to be described. When single letters are used, they should be inked in before the shade or section lines are drawn; it is a good plan to start with the middle letter of the inscription and work in both directions.

The use of both the writing and drawing pen enables the lettering to be done in a much shorter time; when the ruling pen is employed it is in connection with the tee-square and the set square.

The appearance of a drawing will often be helped by a border put on in connection with the lettering.

The four principal styles of letters used in mechanical drawing are Block, Roman, Old English and Script, each of which will be found illustrated under this section of the work; it will be found upon investigation that most letters in use to-day are founded upon one of these four styles; the modern tendency is in the direction of simply designed letters, legibility being considered of vital importance.

A B C D E F G H I J K L M N
O P Q R S T U V W X Y Z &

A B C D E F G H I J K L M
N O P Q R S T U V W X Y Z
a b c d e f g h i j k l m n o p q r s t
u v w x y z
1 2 3 4 5 6 7 8 9 0 ½ 1 2 3 4 5 6 7 8 9 0 ½

FIG. 102. (*See page 63.*)

It will familiarize the student with the standard alphabets in Roman, Block, Old English and Script to copy the several specimens given.

The space between the nearest parts of all letters should be exactly alike; this rule also applies to the space between each word; between the words, of course, should be wider than the letter spaces.

A reasonable space (never less than one-third the height of the letters used), should be left between lines of words.

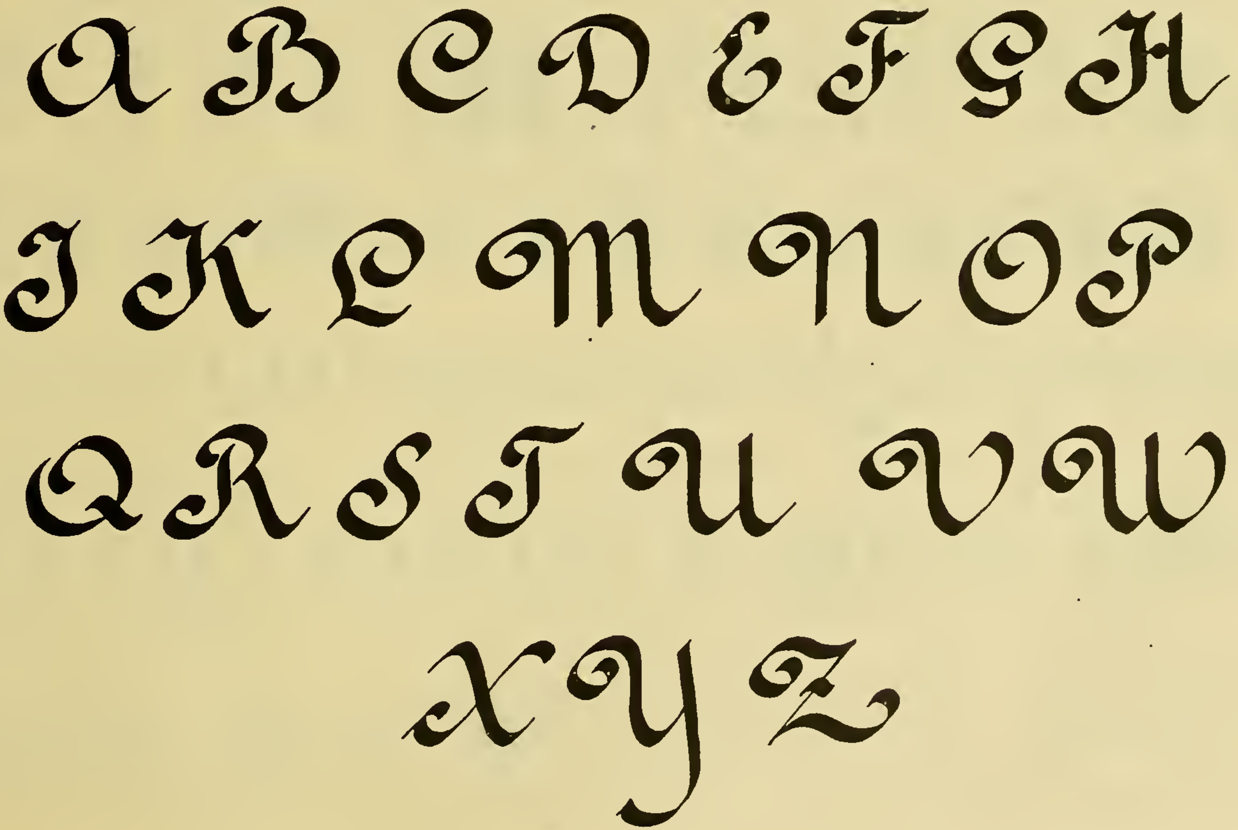


Fig. 103. (*See page 63.*)

Mathematical accuracy should be aimed at as a rule in all lettering executed for mechanical drawings. A knowledge of punctuation, spelling, capitalization and paragraphing is essential in this work; if unfamiliar with these subjects the student should acquire a thorough knowledge of them.

Perfectly horizontal ruled lines should first be drawn, one for the top of a line of letters, another for the bottom and then the letters should be sketched with the utmost care; the outlines may be ruled with a ruling pen, if desired, and the curved lines drawn with a compass ruling pen.

The heavy or shaded stems of letters should all be of the same width; after the outlines have been carefully penned in, the unfilled spaces may be "brushed" in with either liquid India ink or very black water color.

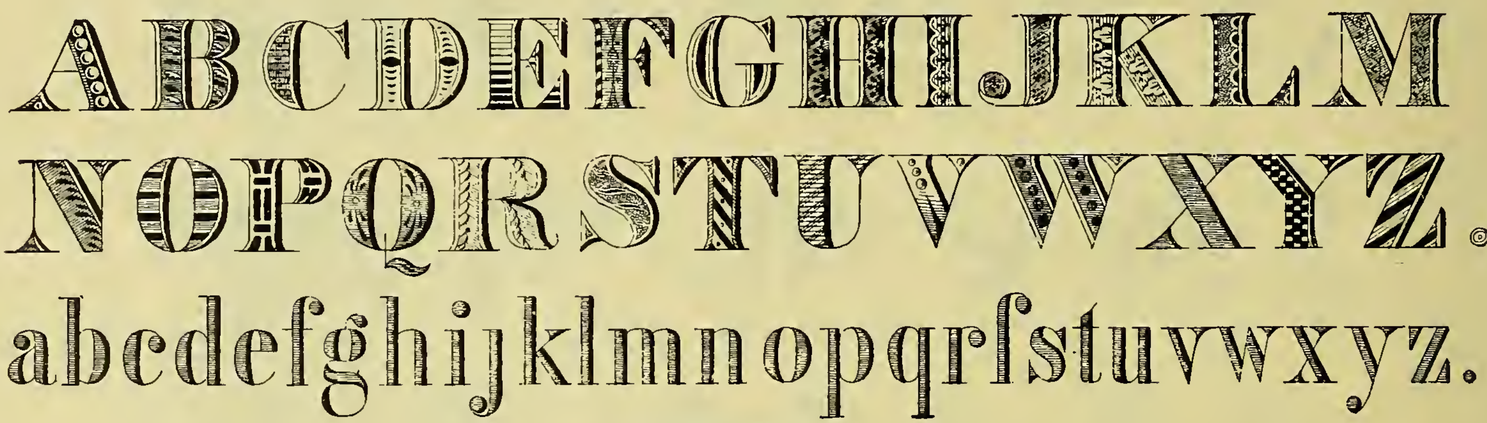


FIG. 104. (See page 63.)

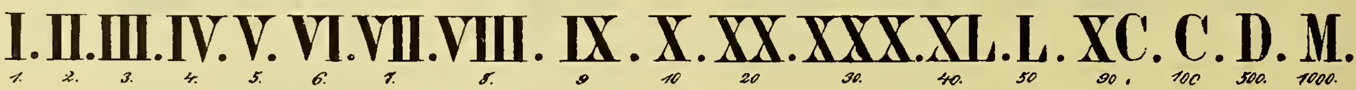


FIG. 105.

1 6

2 ABCDEFGHIJKLMNOPQRSTUV 7

3 WXYZ&. 8

4 9

5 abcdefghijklmnopqrſstuvwxyz. 0

Fig. 106.

ABCDEFGHIJK

LMNOPQRST

12345 UVWXYZ 67890

Fig. 107.

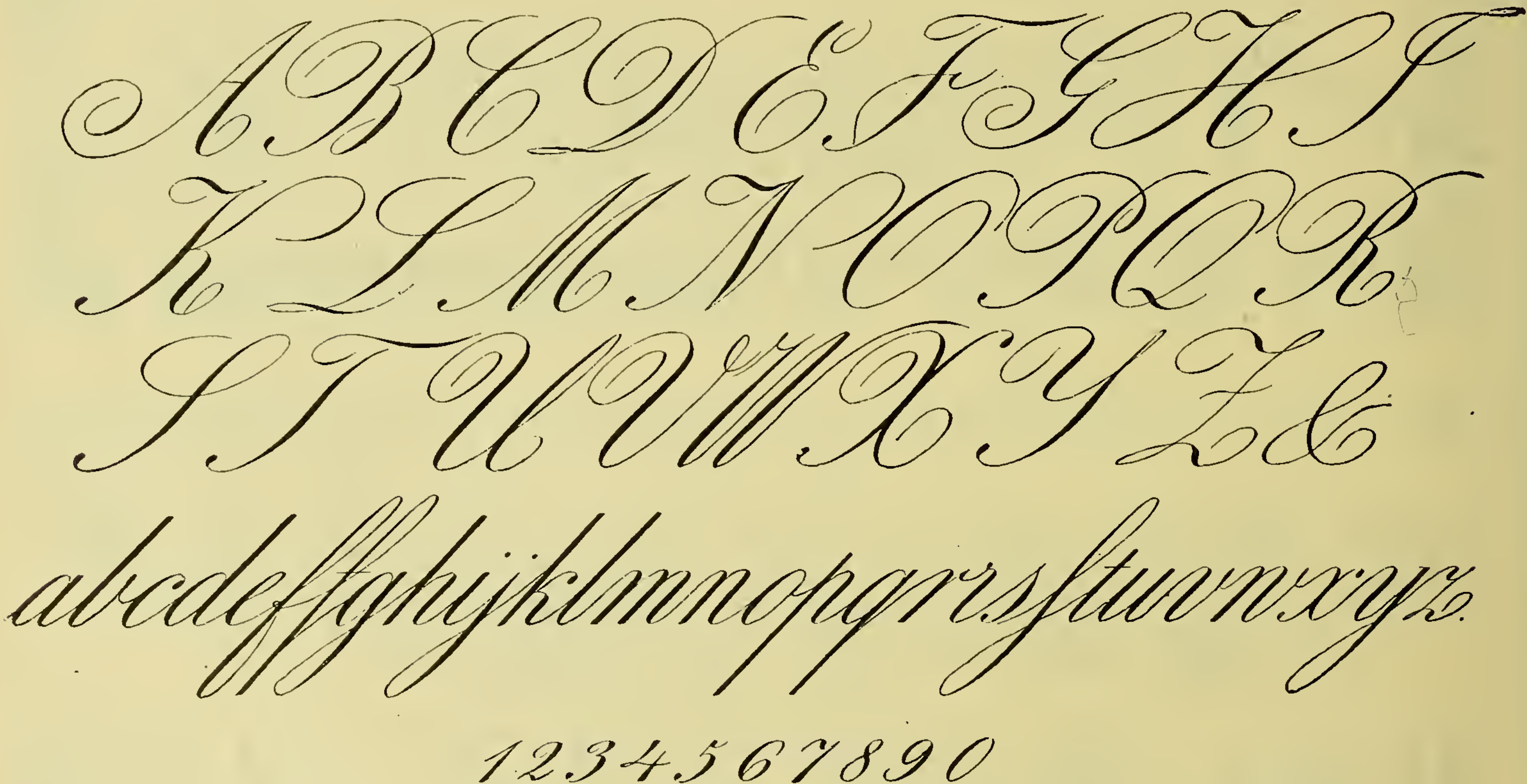

A B C D E F G H I
K L M N O P Q R
S T U V W X Y Z &
abcdefghijklmnopqrstuvwxyz.
1 2 3 4 5 6 7 8 9 0

Fig. 108

In Figures 96 and 97 are examples of block letters and numerals.

The squares are laid off in fine pencil lines and the desired letters may be sketched on the drawing in pencil and then inked in with pen and triangle; when the inking is completed all the pencil lines are erased. This is a rudimentary form of letter that can be made with the aid of cross section paper.

In Figs. 98 and 103 are shown two styles of free-hand lettering. The vertical letters are more difficult to draw than the slanting ones. When making these letters two fine pencil lines should always be drawn, one at the top and one at the bottom of the letters and sometimes it is very convenient to rule a third guide line midway between the two others.

These examples exhibit a form of lettering known as *round writing;* the easy way to master it and its artistic appearance, combined with the rapidity with which it can be written, are its principal merits.

In the upper part of Fig. 102, page 58, is shown another example of the block letter; this is very distinct and readily executed by the aid of the drawing pen. In the lower part of the figure (102) are shown Italic letters and numerals; the proper angle for their slant is 23°.

In Fig. 104 are shown ornamental letters based upon the Roman; in the Roman letters the square is taken as the basis of construction; W takes the whole square, its height and width being equal; I is one-quarter as wide; A five-sixths, etc.

In Fig. 105 are shown the form and proportions of the Roman numerals and their value in the Arabic method of expressing numbers.

In Fig. 106 is given another example of Italic letters and numerals.

In Figs. 107 and 108 are given illustrations of script letters and Figs. 109 and 110 will suggest to the student still other forms.

The letters shown in Fig. 101 are constructed in a simple form convenient for remarks, etc., needed to be placed in the margin of the drawing.

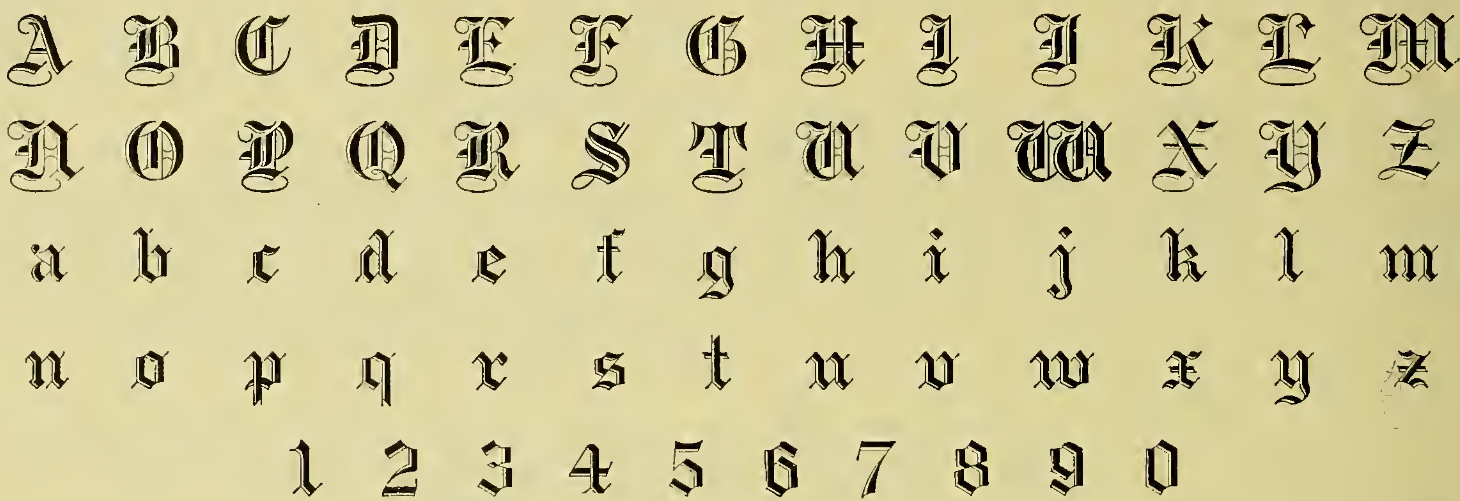


FIG. 109.

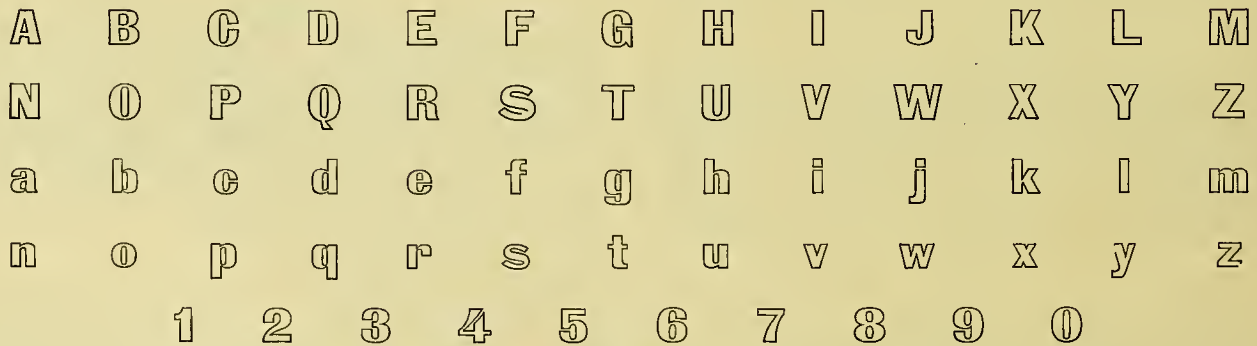


FIG. 110.

SHADE LINES.

In instrumental drawings shade lines are used for the purpose of making the reading of a drawing easier than if all lines were of the same thickness.

By means of these, the draughtsman knows without referring to any other view of the object whether the part looked at is above or below the plane of the surface; for instance, the rectangles in Fig. 111 represent square projecting pieces, whereas the

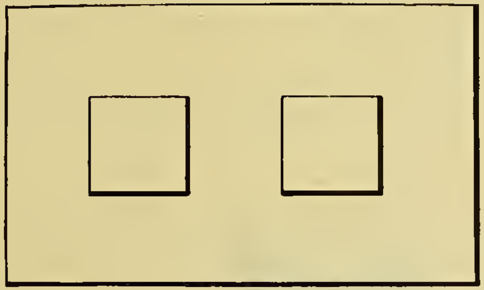


FIG. 111.

rectangles in Fig. 112 represent square holes; the difference being made apparent by the shade lines.

In order that the shading on drawings may be uniform, and to avoid confusion the rays of light are assumed to come in a single invariable direction, in such a way as to make an angle of 45 degrees with the plane of the paper, and also with all vertical and horizontal lines of the drawing, and to come from the upper left-hand corner of the drawing; the direction of the light being indicated by the slanting edge of the 45° triangle as shown in Fig. 113.

All the rays of light are not supposed to be emanating from one and the same point, but from a large and distant source of light and are thrown in parallel lines.

The shade lines are the edges of such surfaces as intercept the light. They produce the effect of

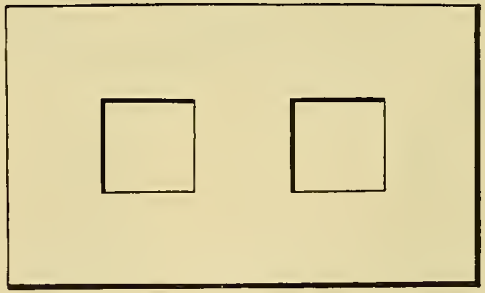


FIG. 112.

"relief" and aid the reader or the student in understanding the true character of the object with greater facility than could be done on drawings with all lines of one and the same thickness.

The following rules should be strictly adhered to by the student in shading drawings:

(*a*). The rays of light are assumed to make an angle of 45 degrees with the plane of the paper and to come from the upper left-hand corner, at an angle of 45° with all horizontal and vertical lines as previously mentioned.

(*b*). Each view of the subject should be considered as a top view for the purpose of shading; its top part will thus be exposed to the light.

(*c*). Lines representing edges which cast shadows are to be drawn in heavy lines.

(*d*). All the edges formed by the intersection of a light and dark surface or two dark surfaces, are to be shaded.

Figs. 114 and 115 show two views of a square block or rectangular prism. In the top view, a b c d, the rays of light fall upon the rear side of the object, b c, upon the top, a b c d, and upon the left side, a b; the light does not reach the front and right sides, a d, and, d c; hence they are dark surfaces; the edges a d and d c, separating the light surface, a b c d, from the dark surfaces are therefore shade lines.

The explanations given in regard to the top view can also be applied to the other view of the same object and the lines e h and h g will thus be obtained as shade lines.

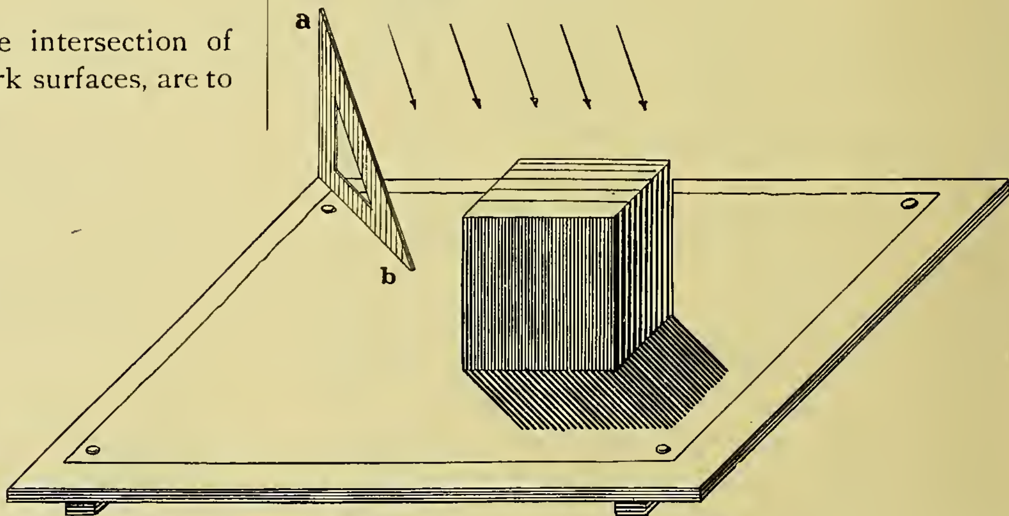


Fig. 113.

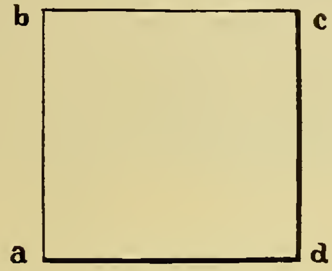


FIG. 114.

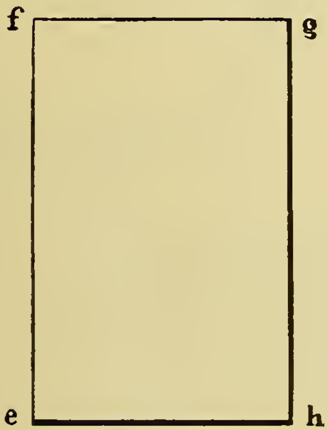


FIG. 115.

Figs. 116 and 117 represent a hollow square-prism; its top view shows the shade lines a d and d c, that is, the right and bottom sides of the view upon which the rays of light do not fall; the lines

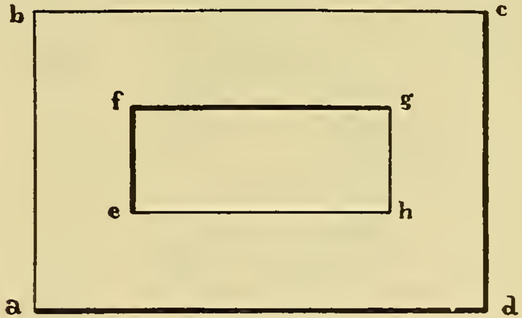


FIG. 116.

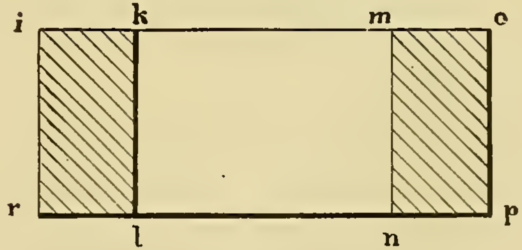


FIG. 117.

e f and f g are also shade lines for the same reason; the vertical section r i o p shows the right side o p and bottom r p, also the vertical line k l, as shade lines.

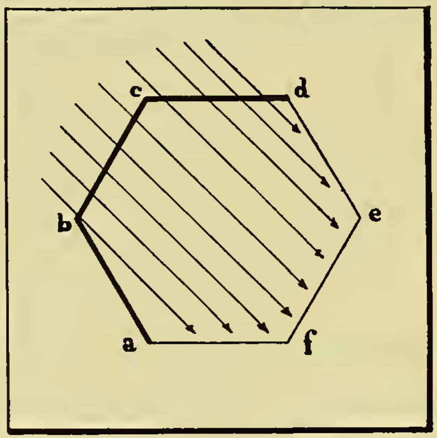


FIG. 118.

FIG. 119.

Another example of shade lines is given in Figs. 118 and 119; in this case the top view shows a hexagonal hole, offering a good opportunity to consider the shading of objects with inclined planes. It will be plainly seen that the lines c d and b c must be shade lines and the lines a f and f e, situated directly in the way of the rays of light, are light lines.

The two remaining sides b a and d e of the hexagonal hole cannot readily be put down as shade or light lines. In order to find out their nature draw a number of 45° parallel lines over the figure in question and those faces of the hexagonal hole reached by the rays of light, represented by the 45° lines.

It will be seen that the edge b a intersects the arrows of light; the face a b will therefore be a dark surface, and consequently must be shaded. It will also be noticed that the rays of light fall directly upon the face, an edge of which is the line e d, thus making this latter a light line.

In order to illustrate more clearly the shading of lines belonging to planes, which are inclined in various degrees to the direction of the light, the top view of a cube placed in three different positions is shown in Figs. 120, 121 and 122. In Fig. 120 the edge a b makes an angle of more than 45° with a horizontal line; parallel lines drawn at an angle of 45° representing the rays of the light will strike the side of which a b is an edge; this side must therefore be a light surface and the line will be a light one.

In Fig. 121 the line a b forms an angle of 45 degrees with a horizontal line showing that the side of the cube of which a b is an edge is placed in a position parallel to the direction of the light; for this reason said side is considered a light surface and the line a b is a light line. This is done in every case in which the line in question forms an angle of 45 degrees with a horizontal line. The same is true for the line c d, which is parallel to a b.

In Fig. 122 the edge a b forms an angle of less than 45 degrees with a horizontal line. It will be observed that the side of which a b is an edge cannot receive any direct light, as the rays are broken by the edge of which b is the highest point; hence the edge b a is a shade line.

In Fig. 123 are shown the front and bottom views of a cylinder; the shade lines on the front are easily determined, in a similar manner to foregoing cases where a drawing has been made of a rectangle. Many draughtsmen, however, will only shade the plane sides of the cylinder, claiming that shade lines are intended to represent edges only; according to this view the bottom line of the elevation of the cylinder should only be shaded.

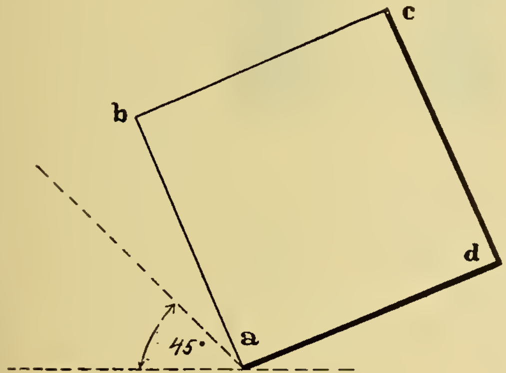


FIG. 120.

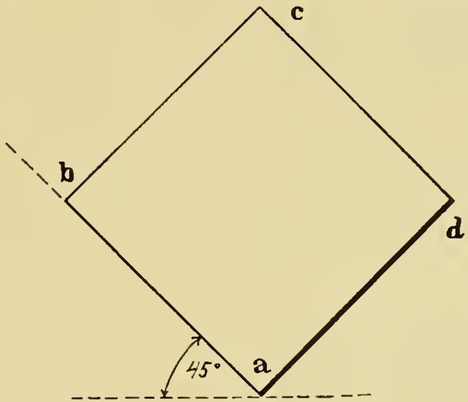


FIG. 121.

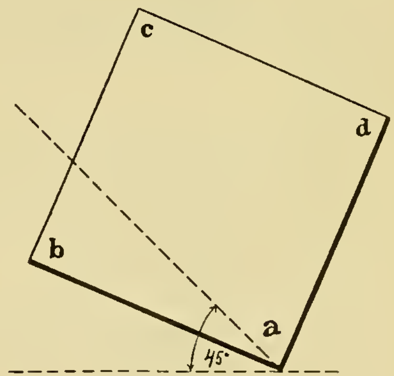


FIG. 122.

At times a tendency has been noticed to give the shade lines a more general application. As shade lines are always found on all right and bottom sides of those parts situated in front of the surrounding surface, it is very easy to recognize this condition in every similar case, whether the part in question be bounded by plane or by cylindrical surfaces.

It is therefore recommended that shade lines be drawn in each case, independently of the character of surface, with very few exceptions, when a rigid adherence to this rule will tend to produce a bad effect.

The shaded portion in the bottom view of the cylinder, Fig. 123, shows the manner in which circles are to be shaded when they represent projections of cylinders or circular holes.

Fig. 124 shows that the circle is shaded between the points of tangency of the two 45-degree lines a b and f g; the heaviest part of the shaded circle is near the 45-degree line c d e, passing through the center of the circle. The thickness of the lines should gradually decrease from e toward b and toward g; to obtain the best result with neatness is to shift the center point of the compasses along the line c e, a distance equal to the thickness of the desired line. With the same radius used to describe the original circle describe now part of another circle, being careful not to run over the first one and to stop when the two lines coincide.

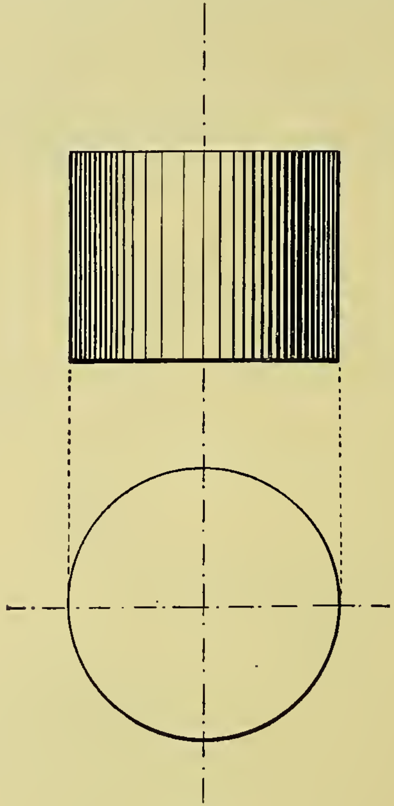


Fig. 123.

The shade line made in this way must not be drawn too heavy; to assure the success of this operation it is necessary to have a very sharp needle point in the compass in order not to cause too large a hole in the center of the original circle. The shifting of the center may be avoided when drawing the shade line in the following manner: When the original circle is drawn keep the center-

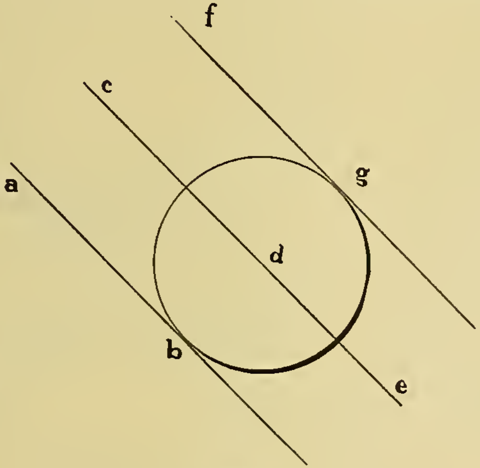
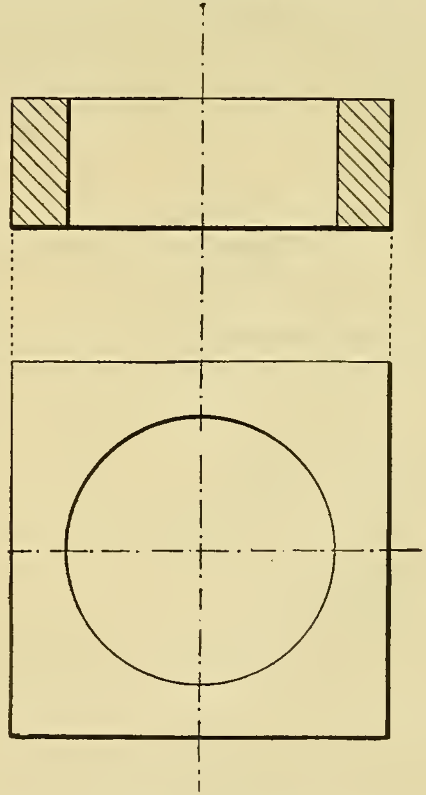


FIG. 124.

point in the center and without changing the radius put the pen point in motion in the direction of the part of the circumference to be shaded. The pressure upon the pen is gradually increased as it approaches the heaviest part of the shade line and then gradually diminished.

Figs. 125 and 126 show the manner of shading a circular hole. The directions for this operation are the same as for shading the projections of a cylinder base, except that the opposite half of the circle is



FIGS. 125 AND 126.

shaded, which is done by shifting the center in the opposite direction.

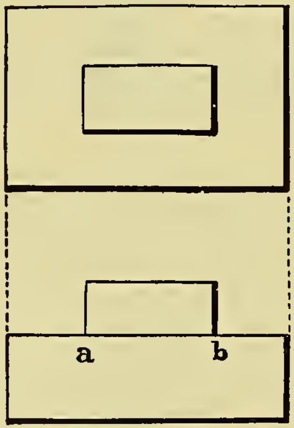
In order to make the conventional way of putting in shade lines more easily understood, a few illustrations are added for the benefit of the student.

In Fig. 127, the position of the shade lines in the top view is quite plain; in the front view, Fig. 128, the bottom line a b of the smaller block placed in the middle of the top face of the larger block is a light line.

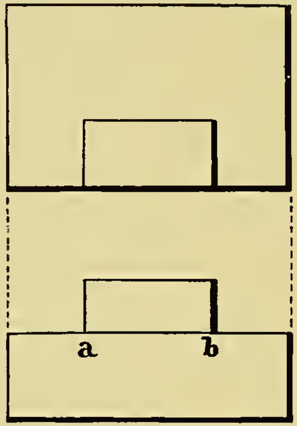
In Figs. 129 and 130, the small block placed on top of the larger one so that the front faces of both are in one plane shows a light line a b.

In Figs. 131 and 132, the smaller block is moved forward so that its lower face a b is the front edge, throws a shadow upon the corresponding part of the front face of the larger block and the line a b is therefore a shade line. Similar cases are given in Figs. 133 to 138.

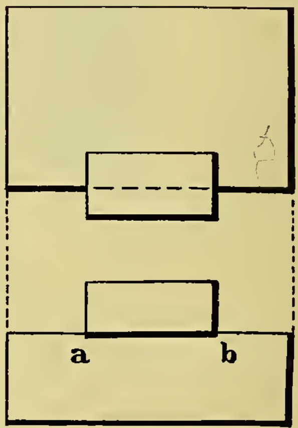
In the front view, Fig. 136, a portion a c of the bottom line a b is shaded and in Fig. 138 the whole of the bottom line a b is a shade line.



FIGS. 127 AND 128.

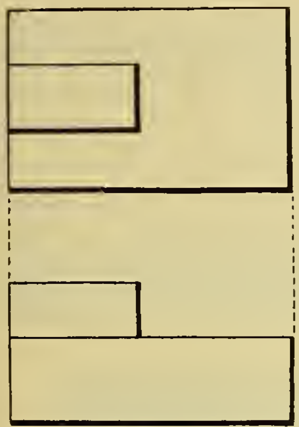


FIGS. 129 AND 130.

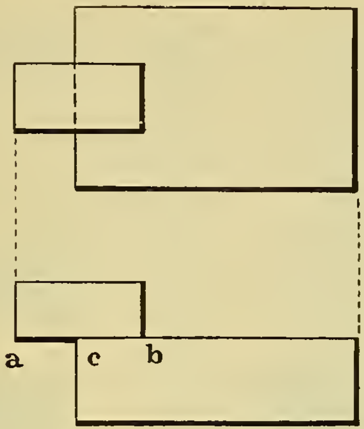


FIGS. 131 AND 132.

Fig. 139 shows the front and top views of a prism. The shading of the top view does not present any new points. In the front view the face e b c f is dark; the edge e b separating the light face d a b c from the dark one and consequently e b must be a shade line; e f is also a shade line for reasons ex-

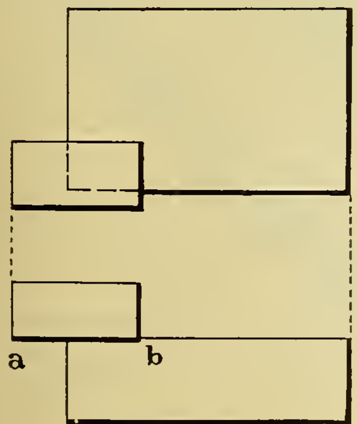


FIGS. 133 AND 134.



FIGS. 135 AND 136.

plained previously. The line b c of the upper base a c should also be shaded ; this would make part of the straight line a c heavy and the greater part light, which would produce a very odd effect and therefore the whole line, in similar cases, is drawn light. The line c f is made heavy by many draughtsmen, as the surrounding of dark surfaces by heavy lines



FIGS. 137 AND 138.

brings out such surfaces much stronger. From the various examples given above it will be seen that no special rules can be given for shading, that is, rules that would cover all cases likely to arise.

The conventional practice introduces a great variety of exceptions to any rules designed for this

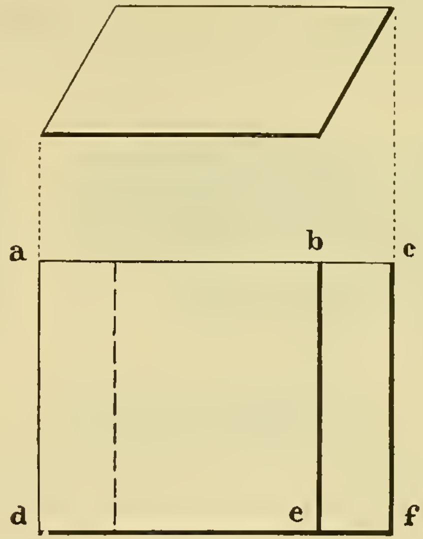


FIG. 139.

purpose. The draughtsman has to keep in mind the true purpose of putting in shade lines and place such lines where and whenever, in his opinion, they will serve as an aid to the understanding of the drawing.

PARALLEL LINE SHADING.

Plane surfaces are shaded by a number of parallel lines running parallel to the length of the plane which is to be shaded. If the plane is to be represented very light, it may be left blank or covered with very fine parallel lines, as shown in Fig. 140. A dark plane is shaded by a number of heavy parallel lines, Fig. 141.

If the plane is parallel to the plane of the paper, the shading lines should be drawn with equal spaces between them throughout the full width of the plane. If the shaded plane is inclined to the plane of the paper it is shaded by a number of lines, with the spaces between these lines gradually increasing, while the thickness of the lines gradually decreases as may be seen in Fig. 142.

A cylinder is shaded by a number of parallel lines, which are heaviest near to the side of the cylinder which does not receive any direct light. The heavy lines become lighter gradually and are drawn very fine near the midd'e of the cylinder; after this the lines are again drawn slightly heavier up to the side of the cylinder, which is nearest to the source of the light. The shading lines near the lighter side of the cylinder should never be as heavy as the heaviest lines on the dark side of the cylinder; this is illustrated in Figs. 143, 144 and 145. The surface near the middle of the cylinder is often left blank, as it is difficult to produce the effect of a light tint which is desirable at that place.

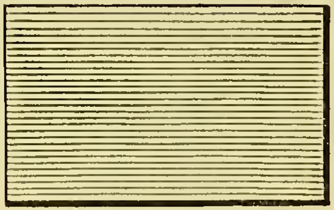


Fig. 140.

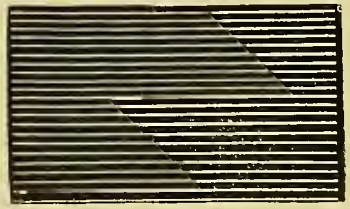


Fig. 141.

Fig. 142.

A hollow cylinder or a concave surface is shaded similar to a cylinder, as shown in Fig. 146.

The view of the sleeve nut shown in Fig. 147 illustrates the manner in which conical surfaces are shaded. Some draughtsmen do this by drawing the shading lines parallel to the outside elements of the cone. A somewhat better result is produced, how-

FIG. 143.

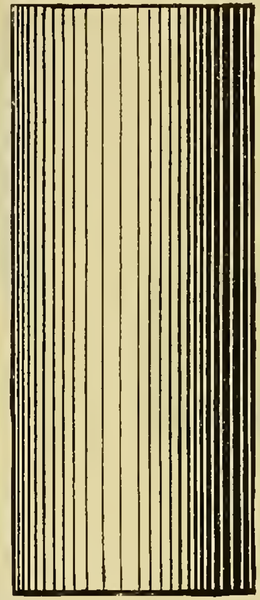


FIG. 145.

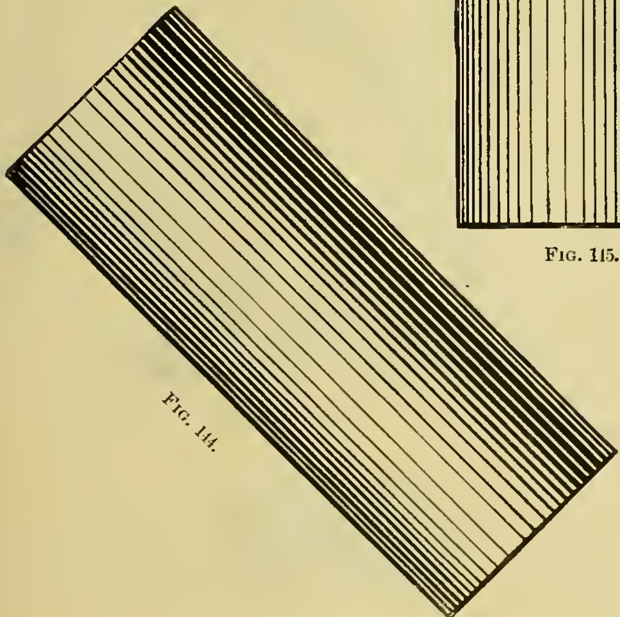


FIG. 144.

ever, by drawing the lines slanting and tapering to the vertex of the cone, which is to be shaded. Wherever possible an ordinary pin may be put into the board exactly in the vertex of the cone. The

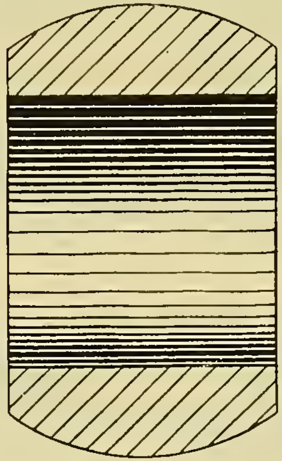


FIG. 146.

ruling edge of the triangle is thus easily kept against the pin, securing the proper direction for the tapering shading lines.

In Fig. 148 at a b is shown a cylinder placed in a horizontal position, which is slightly rounded at the end, so as not to have any sharp edge. This is also indicated by shading lines drawn at right angles to the shading lines of the cylinder.

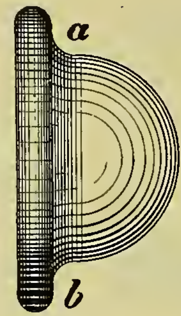


Fig. 149.

Fig. 147.

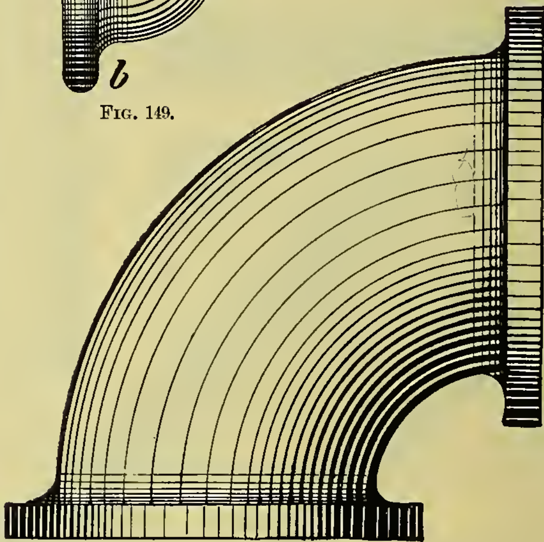


Fig. 150.

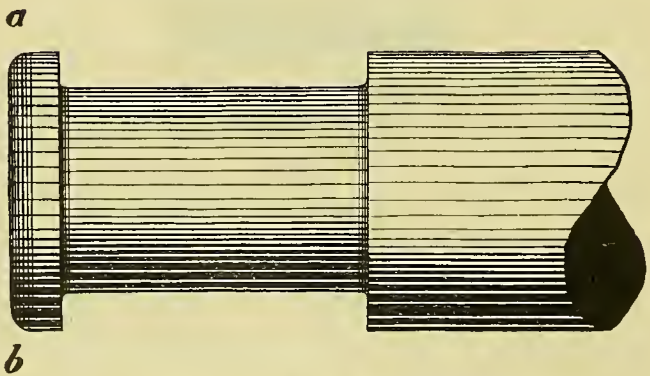


Fig. 148.

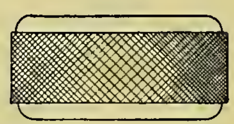


Fig. 151.

Fig. 149 shows how this may be done by the aid of curved lines; however the time required for this method does not recommend it for ordinary working drawings; the same figure includes a spherical surface and shows how such surface may be shaded.

Fig. 150 shows the shading of a curved cylinder.

Fig. 151 shows a method of representation of knurled surfaces. The spacing of the inclined lines varies, being closer near the sides of the figure.

In conclusion let it be noted that the best effects are, as a rule, produced by the fewest lines; drawings executed to small scale will look best with a shading that does not include any very heavy lines; larger scale drawings require the use of very heavy shading lines.

In ordinary working drawings shading is, as a rule, but very little employed; it is, however, sometimes done to shade the surface of shafts and even bolts as well as other cylindrical parts of small diameter by a few conveniently placed lines.

SECTION LINING.

It is sometimes necessary to make use of a section in order that certain details, which would otherwise be hidden, may be shown in a plain,

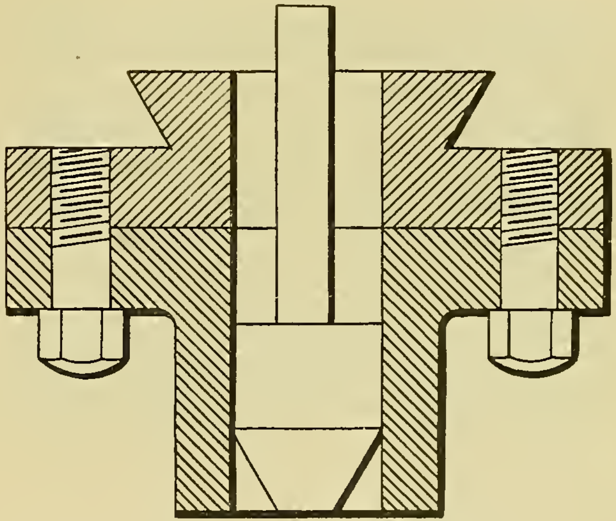


Fig. 152.

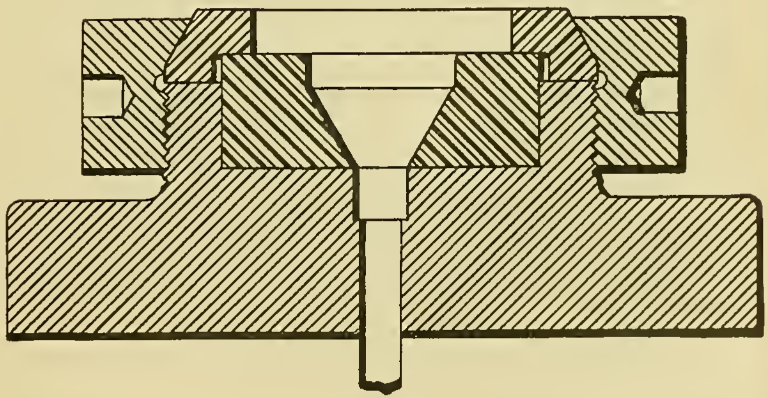


Fig. 153.

concise manner. The method used in shops, and the best for most purposes, consists of drawing parallel lines within the section, which lines are usually inclined 45 degrees. By changing the direction of these lines a clear distinction may be made between different pieces in the same view, which may be in contact.

A difference in material is shown by a variation of the character of the sectioning, see Figs. 152 and 153. The section lines are best drawn from left to right or from right to left, usually inclined 45 degrees and about one-sixteenth inch apart. For large drawings the spaces between them may be as much as one-eighth inch.

Placing the lines too near together makes the work of sectioning much harder; the lines should not be drawn first in pencil, but only in ink, as the neat appearance of the drawing depends largely upon the uniformity of the lines in the section and these lines are to be spaced by the eye only. The process consists simply in ruling one line after another, sliding the triangle along the edge of the tee-square for an equal distance after drawing each section line.

Figs. 154–162 inclusive, are examples of section lining quite generally used.

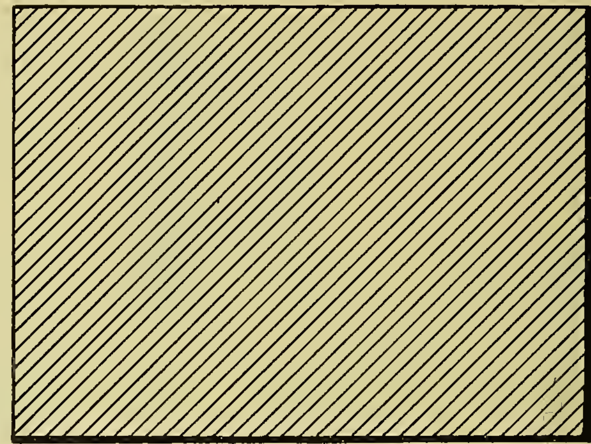


FIG. 154.

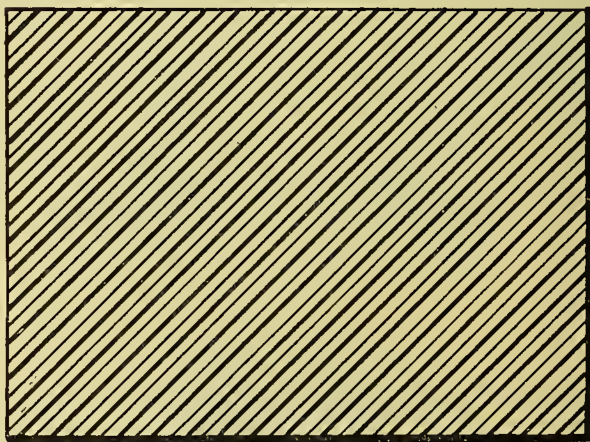


FIG. 155.

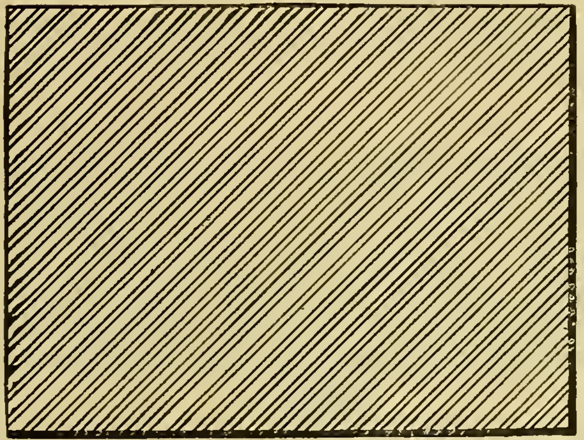


FIG. 156.

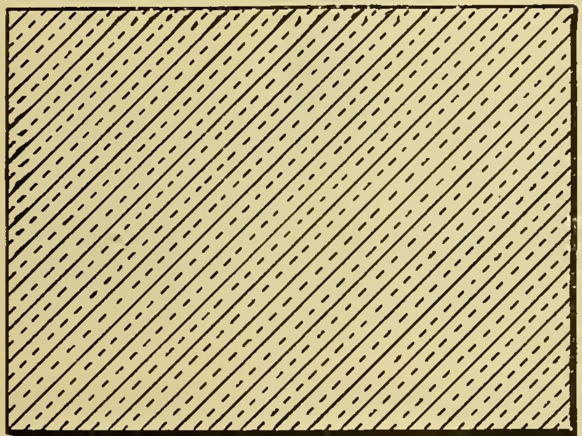


FIG. 157.

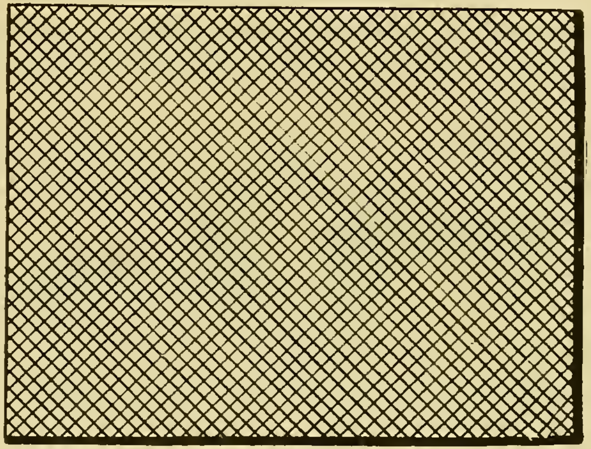


FIG. 158.

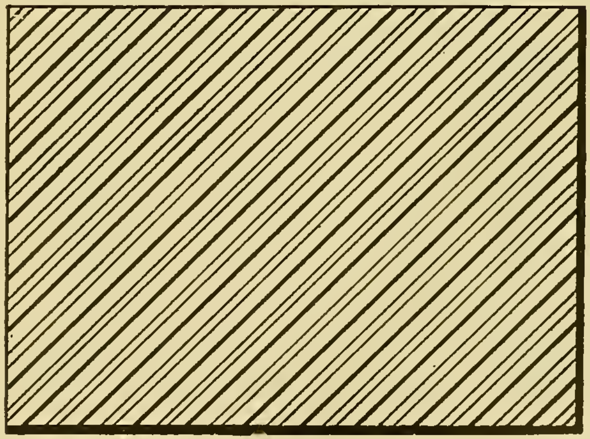


FIG. 159.

Cast iron is indicated by a series of parallel lines of medium thickness, equally distant apart as shown in Fig. 154.

Wrought iron is sectioned in the same manner as cast iron except that every alternate line is a heavy line, Fig. 155.

Cast steel is sectioned by drawing two lines, of medium thickness close together, and the third line about one and one-half times as far from the second as the second is from the first and so on as shown in Fig. 156.

Brass is sectioned by parallel lines similar to cast iron, except that every other line is broken; see Fig. 157.

Babbit is sectioned like cast iron in both directions, forming little squares, Fig. 158.

Wrought steel is sectioned by two light lines and one single heavy line. The light lines should be drawn similarly to those in Fig. 156 for cast steel, and the heavy line should be about one and one-half times as far from the light lines as the distance between them, as shown in Fig. 159.

Wooden beams are sectioned by a series of rings and radiating lines in imitation of the natural appearance of a cross section of an oak tree, Fig. 160.

A ***beam or board*** is represented by lines running similarly to those of the grain in an oak board, Fig. 160.

Brick and stone are represented as shown in Figs. 161 and 162.

Thin strips of metal like the section of boiler plates may be sectioned in the ordinary way by the usual section lines; but as this requires considerable work and produces an ill effect in the drawing, it is often better to fill in the whole sectional area with solid black.

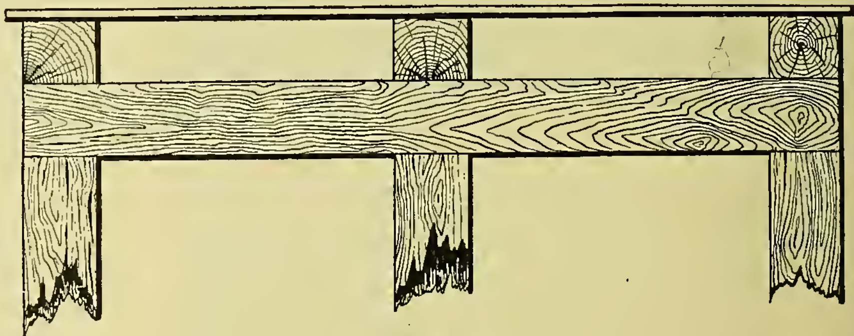


Fig. 160.

In this case a white line must be left between the adjoining pieces; this method is recommended only for small sections, see Figs. 163 and 164.

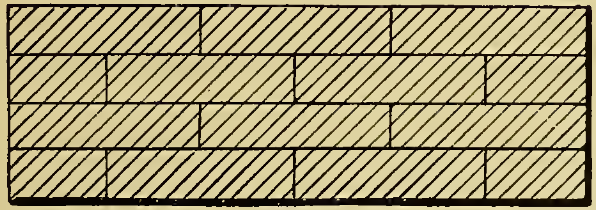


FIG. 161.

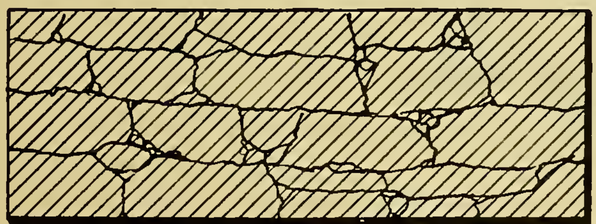


FIG. 162.

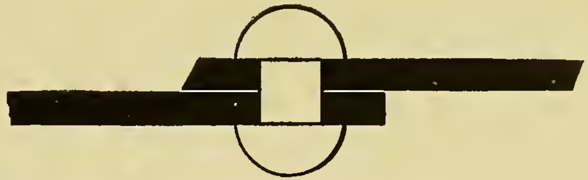


FIG. 163.

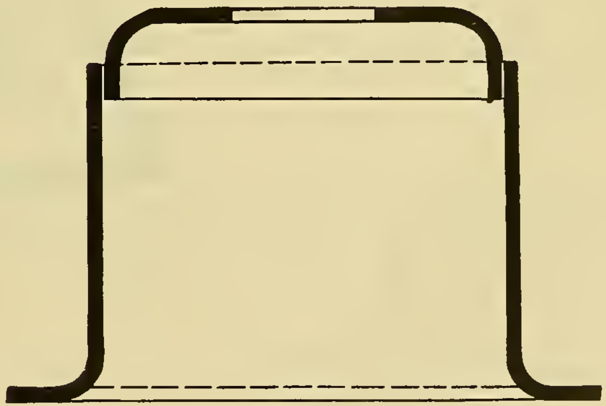


FIG. 164.

GEOMETRICAL DRAWING.

Geometry is the science of measurement; it is *the root* from which all mechanical drawings issue; the principles involved in the following problems, make up the fundamental bases of all instrumental drawing, as well as all "laying out" of work in the shop, where great accuracy is required.

The elementary conceptions of geometry relate to the simple properties of straight lines, circles, plain surfaces, solids bounded by plain surfaces, the sphere, the cylinder and the right cone.

Higher geometry is that part of the science which treats of the relations of these to lines, circles, surfaces, etc. Some geometrical terms have already been described, to these are now added a few relating to the more advanced parts of this oldest and simplest of sciences.

An ***axiom*** is a self-evident truth, not only too simple to require, *but too simple to admit of demonstration*

A ***proposition*** is something which is either proposed to be done, or to be demonstrated, and is either a problem or a theorem.

A ***problem*** is something proposed to be done.

A ***theorem*** is something proposed to be demonstrated.

A ***hypothesis*** is a supposition made with a view to draw from it some consequence which establishes the truth or falsehood of a proposition, or solves a problem.

A ***lemma*** is something which is premised, or demonstrated, in order to render what follows more easy.

A ***corollary*** is a consequent truth derived immediately from some preceding truth or demonstration.

A ***scholium*** is a remark or observation made upon something going before it.

A ***postulate*** is a problem, the solution of which is self-evident.

EXAMPLES OF POSTULATES.

Let it be granted—

I. That a straight line can be drawn from any one point to any other point;
II. That a straight line can be produced to any distance, or terminated at any point;
III. That the circumference of a circle can be described about any center, at any distance from that center.

AXIOMS.

I. Things which are equal to the same thing are equal to each other.
II. When equals are added to equals the two or more wholes are equal.
III. When equals are taken from equals the remainders are equal.
IV. When equals are added to unequals the wholes are unequal.
V. When equals are taken from unequals the remainders are unequal.
VI. Things which are double of the same thing, or equal things are equal to each other.
VII. Things which are halves of the same thing, or of equal things, are equal to each other.
VIII. The whole is greater than any of its parts.
IX. Every whole is equal to all its parts taken together.
X. Things which coincide, or fill the same space, are identical, or mutually equal in all their parts.
XI. All right angles are equal to one another.
XII. A straight line is the shortest distance between two points.
XIII. Two straight lines cannot enclose a space.

The tools used in geometrical drawing are the compass, with pencil and pen points, the ruling pen, straight edge and scales; in the following pages will be found a series of exercises which have been selected with a view to their importance in their application in problems of accurate drawing.

EXERCISES IN GEOMETRICAL DRAWING.

To bisect a given straight line; that is, to divide it into two equal parts.

Let AB be the given line, Fig. 165.

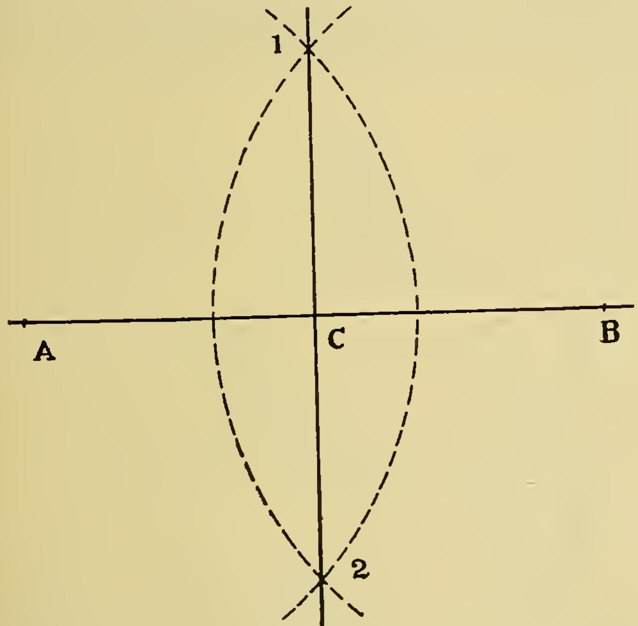


FIG. 165.

From A as a center with a radius greater than one-half of the given line AB, describe the arc 1 2. From B as a center, and with the same radius, describe an arc, cutting the former at 1 and 2; then through the points of intersection draw the line 1C2 and it will divide the line AB into two equal parts at the point C.

To bisect a given angle; that is, to divide a given angle into two equal angles.

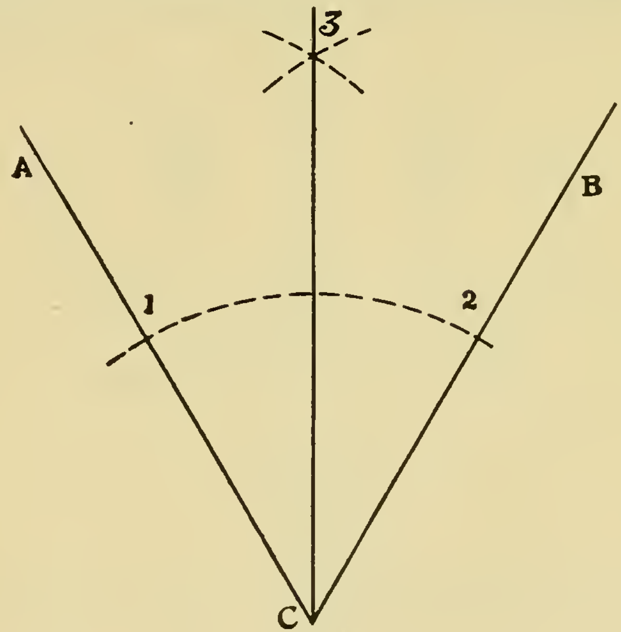


FIG. 166.

Let ACB be the given angle, Fig. 166.

With the vertex C as a center, and any radius, describe an arc cutting both sides of the given angle at 1 and 2. From 1 and 2 as centers, with any radius, describe arcs cutting each other at 3.

Through this point of intersection draw the line 3C and it will bisect the angle as required.

To divide a given angle into four equal parts.

Let ACB be the given angle, Fig. 167. Bisect

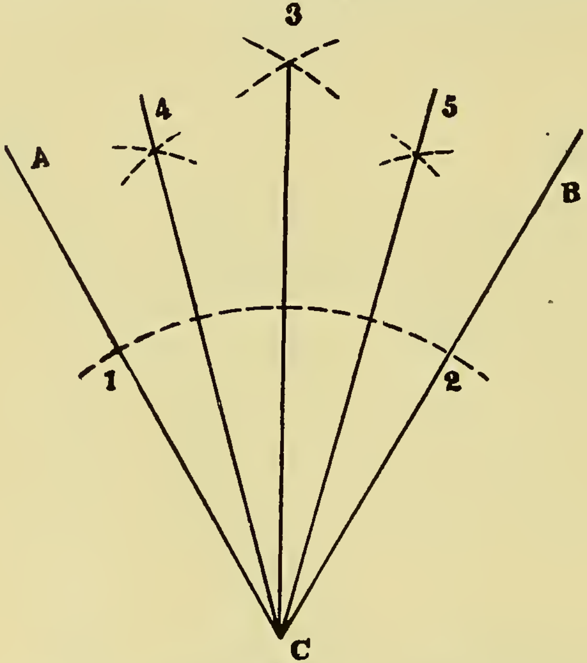


FIG. 167.

the given angle as described in Problem 2 by the line 3C. Bisect the angles 3CB and 3CA by the lines C4 and C5 and these lines divide the angle into four equal angles as required.

To trisect a right angle; that is, to divide it into three equal parts.

Let ABC be a right angle, Fig. 168, that is, an angle with the sides perpendicular to each other. From B as a center with any radius, describe an arc cutting the sides of the angle at 1 and 4.

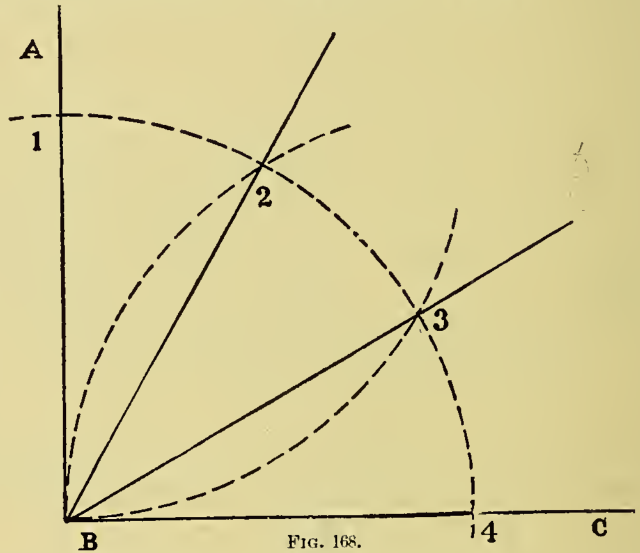


FIG. 168.

With the same radius and with 4 as a center, describe an arc cutting the former at 2. From 1 as a center with the same radius, cut the arc at 3.

Through the points 2 and 3 draw the lines 2B and 3B and they will divide the angle into three equal parts as required.

To draw a line perpendicular to a given straight line from a given point in that line; that is, to erect a perpendicular to the given line at a given point in that line.

Let AB be the given line and C the given point in that line, Fig. 169.

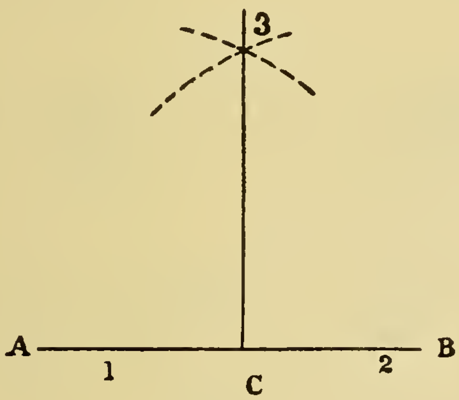


FIG. 169.

With any radius set off on each side of the point C, equal distances, as C1 and C2. From the points 1 and 2 as centers, with any radius greater than C1 or C2, describe arcs cutting each other at 3. Through the point of intersection draw the line 3C, which will be perpendicular to the line AB.

To draw a perpendicular line to a straight line, from a given point without that line; that is, to drop a perpendicular to a given line from a point without it.

Let AB be the given line and C the given point, Fig. 170.

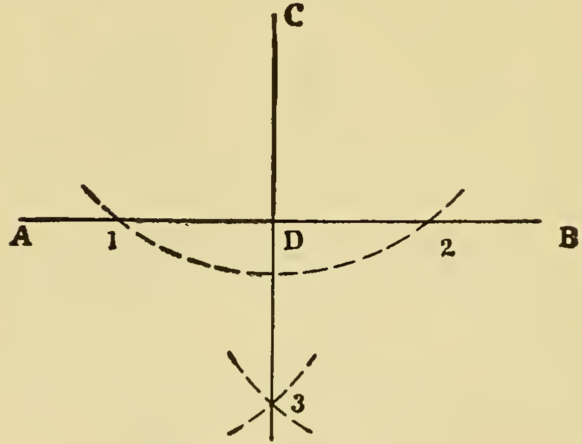


FIG. 170.

From C as a center with any radius extending below the line AB describe an arc 1 2, cutting AB at 1 and 2. From 1 and 2 as centers, with the same or any other equal radii, describe arcs cutting each other at 3. Through the point C and the point of intersection 3 draw the line 3DC; then the line CD will be perpendicular to AB.

To drop a perpendicular to a given line from a point which is nearly over the end of the line, Fig. 171.

Let AB be the given line and C the given point. From any point 1 on the line AB as a center, with the radius 1C describe the arc CE.

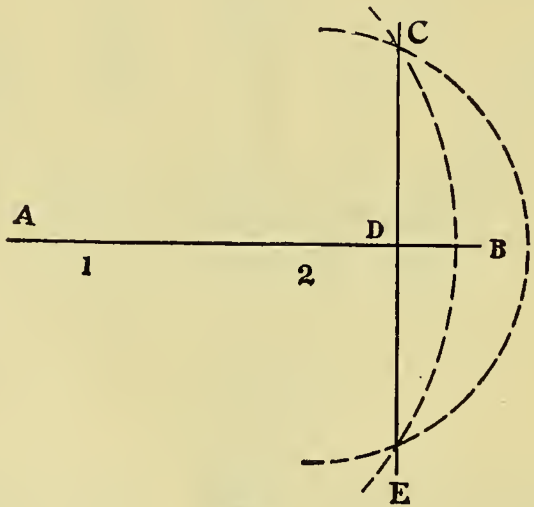


FIG. 171.

From any other point 2 on the line AB as a center, describe arcs cutting the former arc at C and E. Draw a line through the points C and E and the line CE will be the perpendicular required.

Through a given point to draw a straight line parallel to a given straight line.

Let AB be the given line and C the given point, Fig. 172.

From C as a center with any radius describe the arc 1, 2, cutting the line AB at 2.

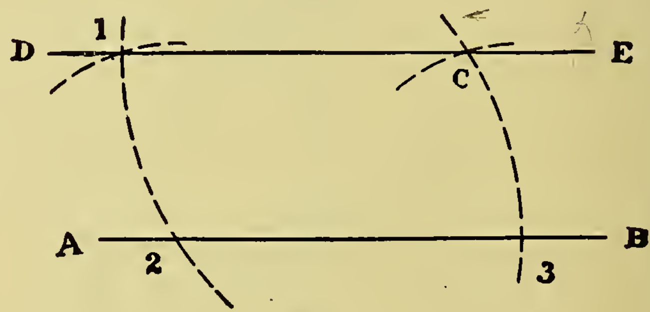


FIG. 172.

With the same radius and 2 as a center, describe the arc C3. On the arc 2, 1, set off from 2 the chord of the arc 3C, cutting it at 1. Through the points C and 1 draw a straight line D1CE and it will be parallel to AB.

To divide a straight line into any required number of equal parts (say 7 equal parts).

Let AB be the given line, Fig. 173.

From A draw a straight line AC forming any angle with AB and being of any length. Set the dividers to any convenient distance and set off seven equal divisions on the line AC beginning at A up to the point 7.

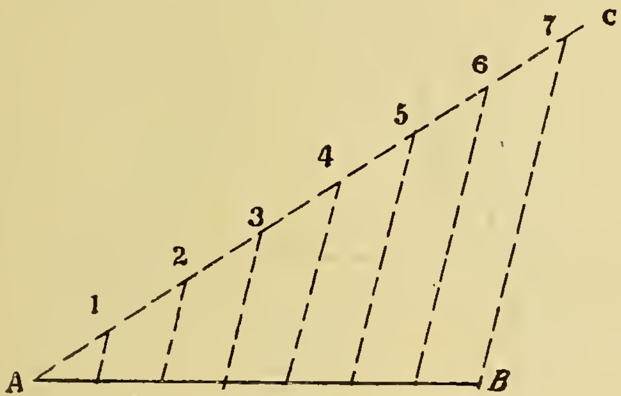


FIG. 173.

Join the points 7 and B by a straight line and draw parallels to it through the points 1, 2, 3, 4, 5, 6, and these lines will divide the given line AB into the required number of parts.

To divide a given line AB into three and a half equal parts.

Let AB be the given line, Fig. 174.

Draw a line AC forming any angle with the given line AB. Upon AC set off 7 equal parts, beginning at A up to the point 7.

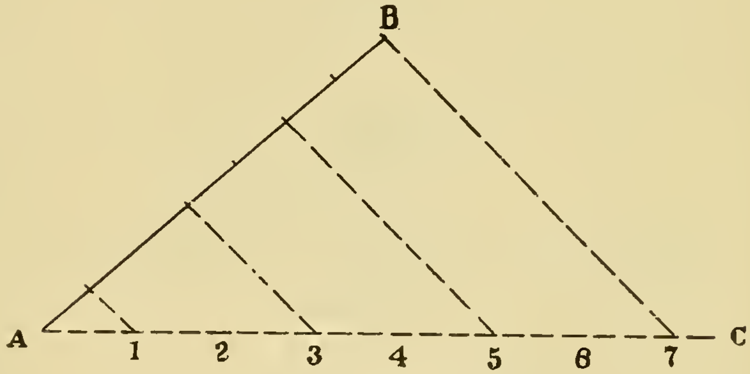


FIG. 174.

Join the points 7 and B and through the alternate points, 5, 3, 1, draw lines parallel to 7B. These lines will divide the given line AB into 3½ equal parts, as required.

To draw upon a straight line an angle which shall be equal to a given angle.

Let 1E2 be the given angle and AB the line upon which we intend to draw an angle equal to the given one, Fig. 175.

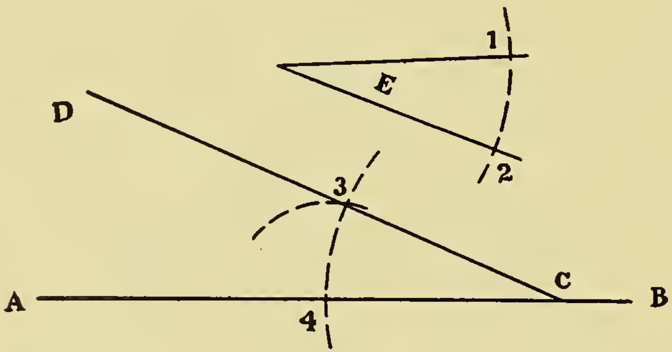


FIG. 175.

From E as a center describe an arc 1, 2, with any convenient radius. From any point on the line AB, say from C, as a center, and with the same radius describe the arc 3, 4. From 4 as a center, with a radius equal to 1, 2, intersect the arc 4, 3, at 3. A line drawn through the points 3 and C will form with the line AB the required angle.

To construct an equilateral triangle, the length of a side being given.

Let the straight line AB be the given side, Fig. 176.

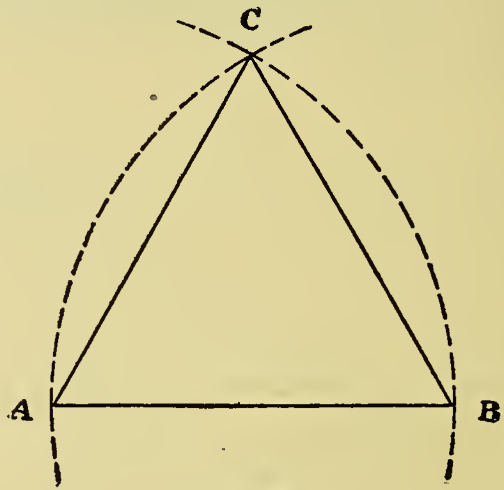


FIG. 176.

From the points A and B with a radius equal to AB describe arcs cutting each other at C. Draw the lines AC and BC; then will the triangle ABC be the required equilateral triangle.

To construct an equilateral triangle, the vertical height or altitude being given.

Let AB be the given vertical height, Fig. 177.

Through the point B draw a straight line CD perpendicular to AB.

Through the point A draw another straight line, EF, parallel to CD. From B as center with any

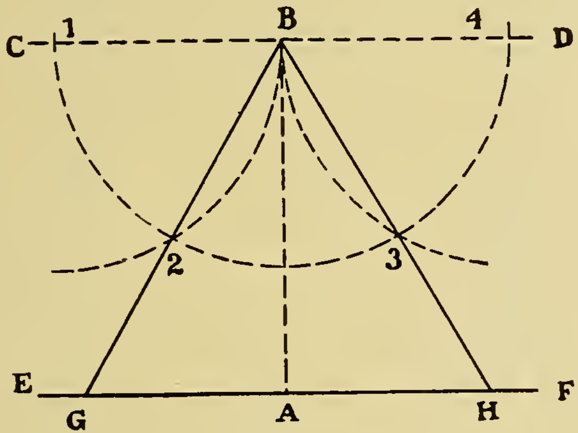


FIG. 177.

convenient radius describe a semicircle cutting CD at 1 and 4. From 1 and 4 as centers, with the same radius, cut the semicircle at 2 and 3. From B and through the points 2 and 3 draw the lines BG and BH; then GBH will be the required triangle.

To construct an isosceles triangle, with a base equal to a given straight line, and each of the two angles at the base equal to a given angle.

Let D be the given line and E the given angle, Fig. 178.

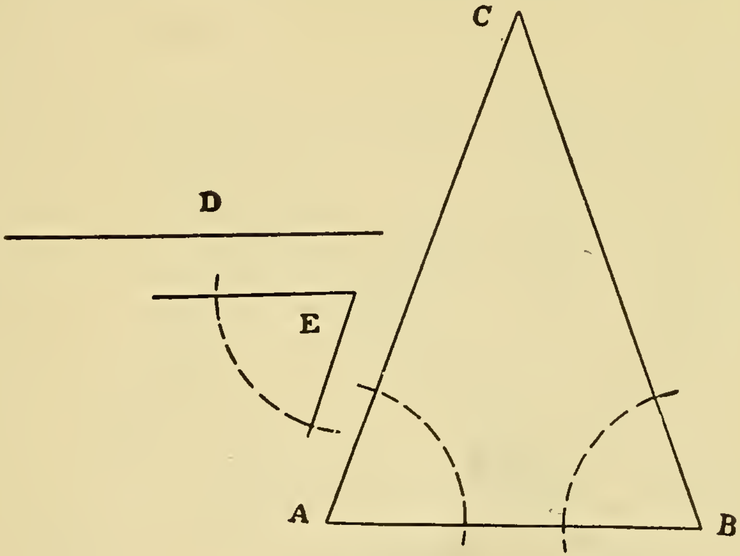


FIG. 178.

Draw a line, AB, equal to the given line D. At the points A and B construct angles equal to the given angle E. Continue the sides of the angles until they meet at C; then ABC will be the required triangle.

Two sides and the angle between them being given to construct the triangle.

Let D and E be the two given lines equal respectively to two sides of the required triangle, and F the given angle, Fig. 179.

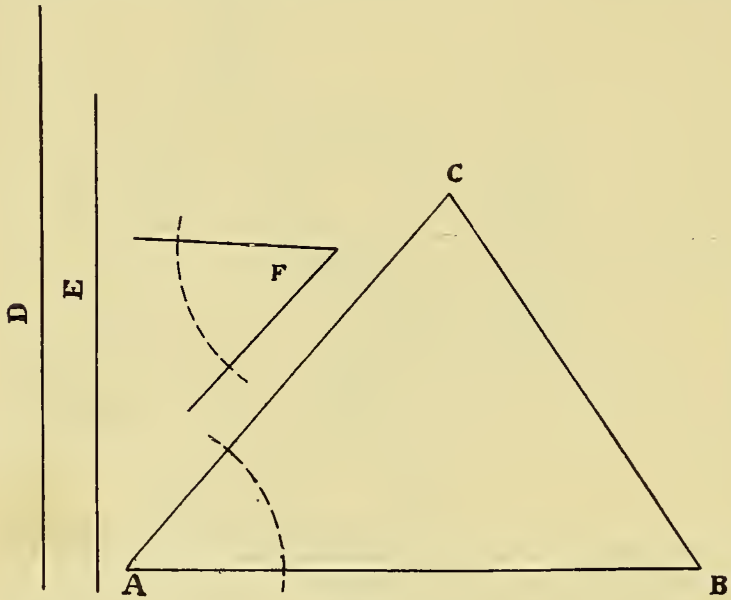


FIG. 179.

Draw a line, AB, equal to D, and at the point A construct an angle equal to F and make AC equal to E. Join the points C and B by a straight line, and ABC will then be the required triangle.

Two sides and the angle opposite one of them being given to construct a required triangle.

Let D and E be the two given sides and let E be the side opposite which the angle is to be formed equal to F, Fig. 180.

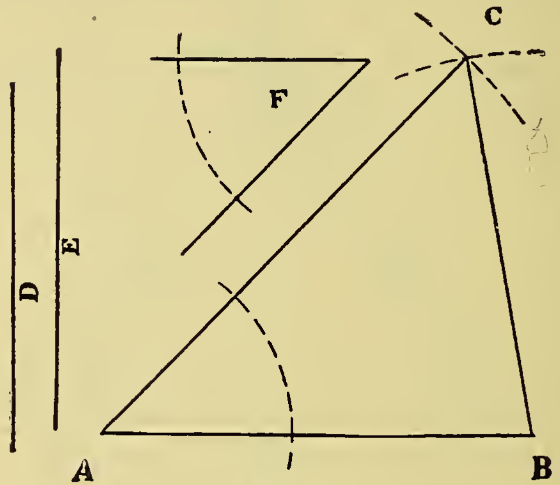


FIG. 180.

Draw a line, AB, equal to D. At the point A form an angle equal to F. With the point B as a center and a radius equal to the given line E describe an arc cutting AC at C. Join the points C and B. ABC is the required triangle.

To construct a square, the sides of which shall be equal to a given line. (See definition, page 31.)

Let AB be the given line, Fig. 181.

At the point A erect a perpendicular AD (see page 89) equal in length to AB.

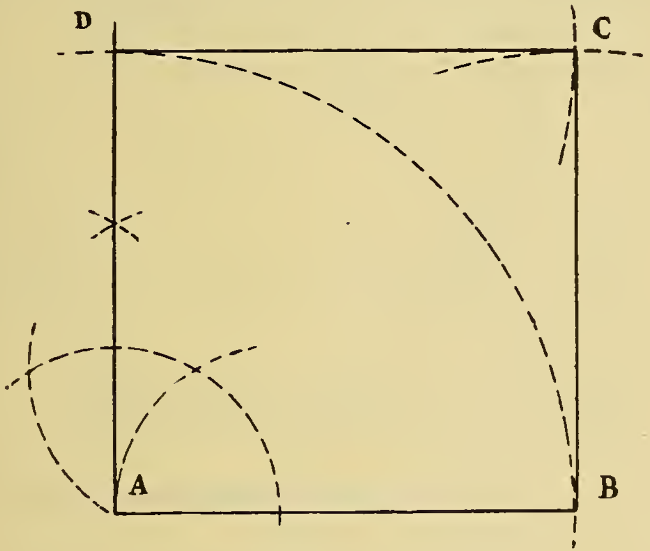


FIG. 181.

From the points B and D as centers, with a radius equal to AB, describe two arcs cutting each other at C. Connect D and C by a straight line and B and C by a straight line, and ABCD is the required square.

To construct a square its diagonal being given.

Let BD be the given length of a diagonal, Fig. 182.

Bisect the diagonal BD at the point P by the straight line AC.

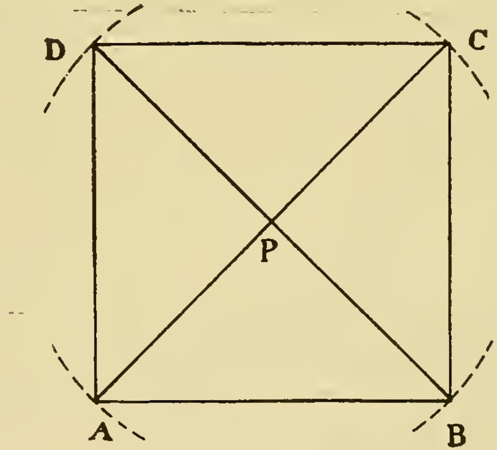


FIG. 182.

From P as a center with a radius equal to PB, or PD, cut the line AC at the points A and C. Join the points AB, BC, CD and DA, and ABCD will be the required square.

To construct a rectangle whose sides shall be equal to two given lines. (See definition, page 31.)

Let AB and CD be the given lines, Fig. 183.

Draw a straight line EF equal to AB, from E draw EH penpendicular to EF and equal to CD.

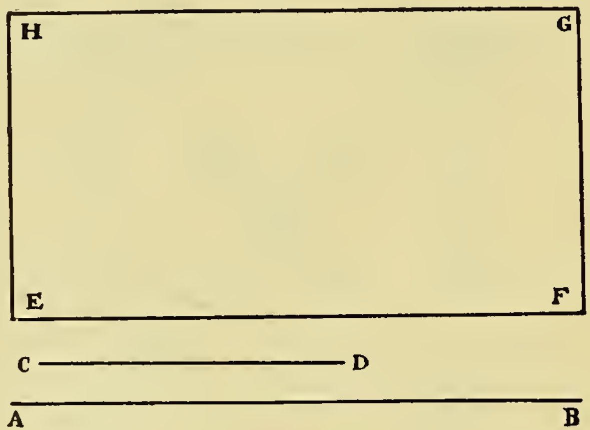


Fig. 183.

From H and F as centers with radii equal to AB and CD describe arcs intersecting at G. Join the points FG and HG; then EFGH is the required rectangle.

To construct a parallelogram when the sides and one of the angles are given. (See definition, page 31.)

Let AB and CD be the given sides and O the given angle, Fig. 184.

Draw a straight line, EF, equal to AB. At E draw an angle equal to the given angle O. Make the side, HE, of this angle equal in length to CD.

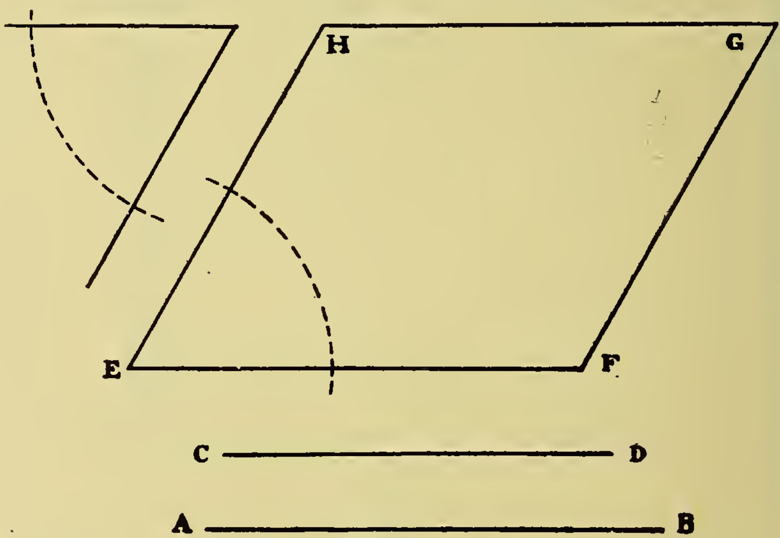


Fig. 184.

From the point F with a radius equal to CD and from H with AB as a radius describe arcs intersecting at G. Join HG and FG. EFGH is the required parallelogram.

To construct a parallelogram when the sides and one of the diagonals are given. Fig. 185.

Let CD be the given diagonal and AB and EF the lengths of the two sides.

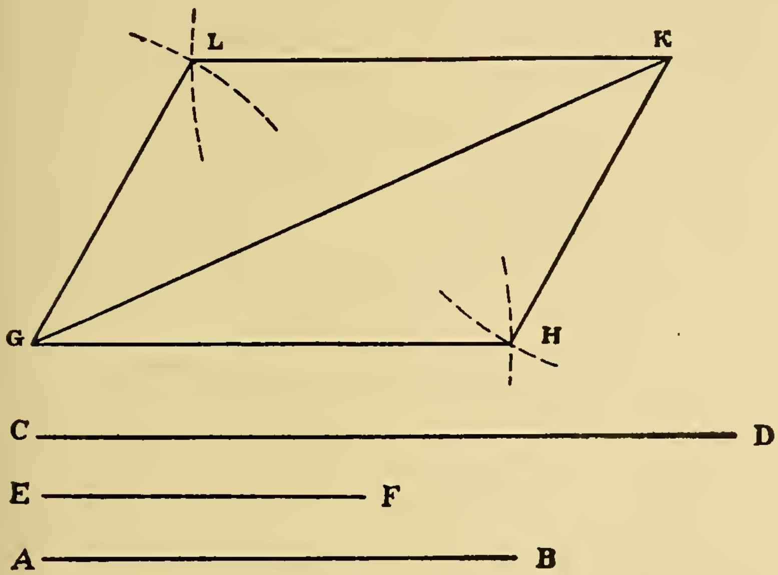


Fig. 185.

Draw a line, GK, equal to the given diagonal CD. From G and K as centers, with radii equal in length to AB and EF describe arcs intersecting at L and H. Join GL, LK, KH and HG. GHKL is the required parallelogram.

To find the center of a given arc, its radius being given. (See definition, page 33.)

Let AB be the given arc and E the radius, Fig. 186.

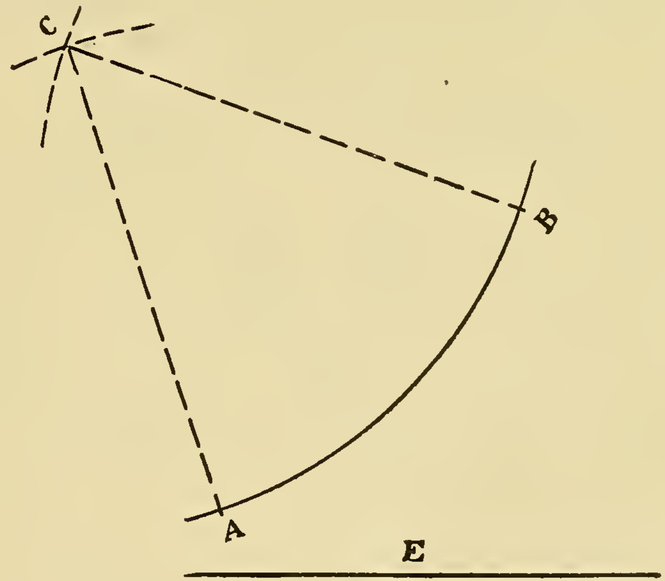


Fig. 186.

From any two points A and B on the given arc, as centers, with a distance equal to the radius E describe arcs intersecting at C; then C will be the required center.

To find the center and to describe the circle, three of whose points are given; that is, to describe the circumference passing through three given points.

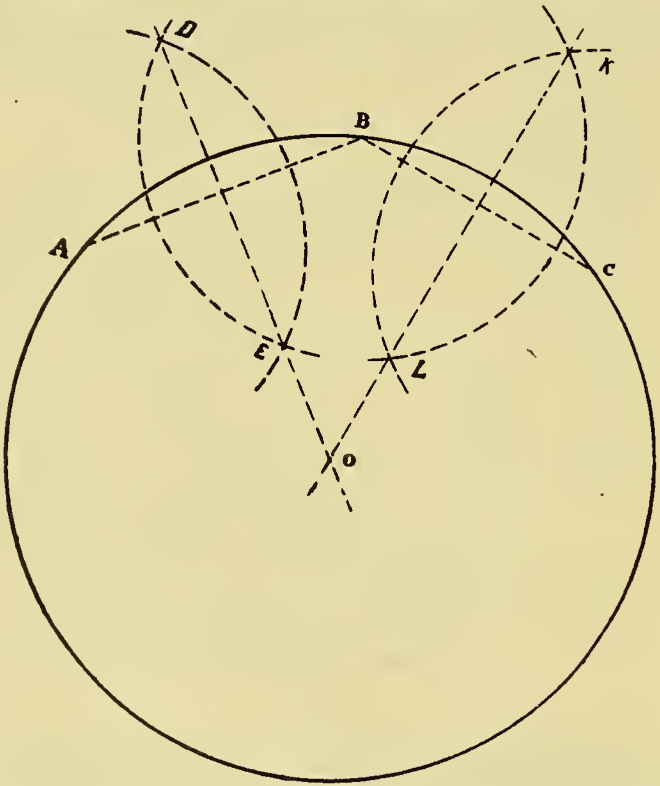


FIG. 187.

Let A, B and C be the given three points, Fig. 187.

With A, B and C as centers and any convenient radius, draw arcs cutting each other at D and E and at K and L, and through the points of their intersection draw lines KO and DO; the intersection of these lines at O is the required center. With O as a center and OA as a radius, describe the required circle.

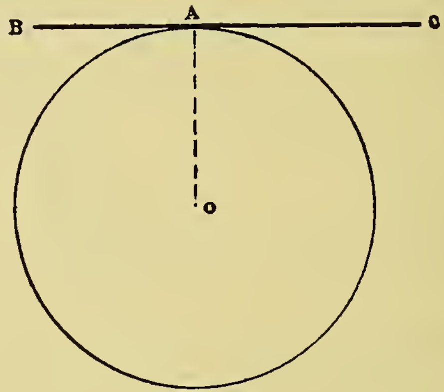


FIG. 188.

To draw a tangent to a circle, passing through a given point on the circumference. (See definition, page 34.)

Let A be the given point on the given circumference, Fig. 188.

From A to the center O of the circle, draw the radius AO. Through A draw the line BC perpendicular to AO. The line BC is the required tangent.

To draw a tangent to a circle from a given point without the circumference.

Let A be the given point and C the center of the given circle. Fig. 189.

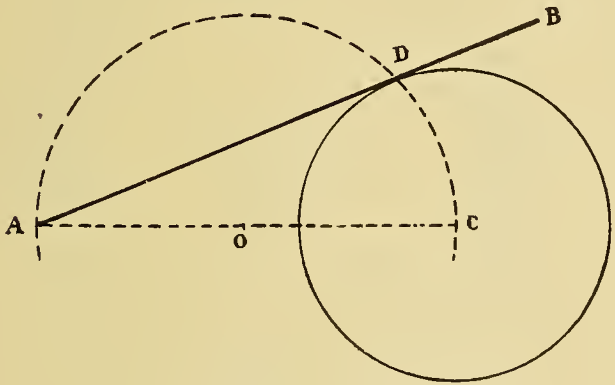


FIG. 189.

Join AC and bisect it at O. From O as center, with a radius equal to OC or OA describe a semicircle, cutting the given circle at D. The required tangent is a line passing through A and D.

To draw lines tangent to two given circles.

CASE I.—From O, the center of the larger circle, Fig. 190, draw any radius OE on which set off from E, a distance EG equal to the radius of the smaller circle. With O as a center and OG as radius describe the circle GHI and draw tangents PH and

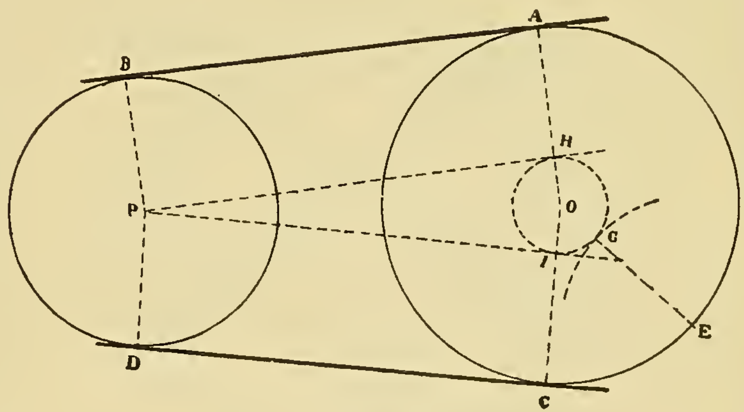


FIG. 190.

PI to this circle from the center P of the other circle. (See the preceding problem.)

From O and P draw perpendiculars to these tangents and continue them until they cut the given circles at AB and CD. Join the points. The lines AB and CD are the required tangents.

To draw lines tangent to two given circles.

CASE II.—From O, the center of one of the given circles, Fig. 191, draw any radius OE and lengthen it outside of the circle up to G, making the distance EG equal to the radius of the other circle.

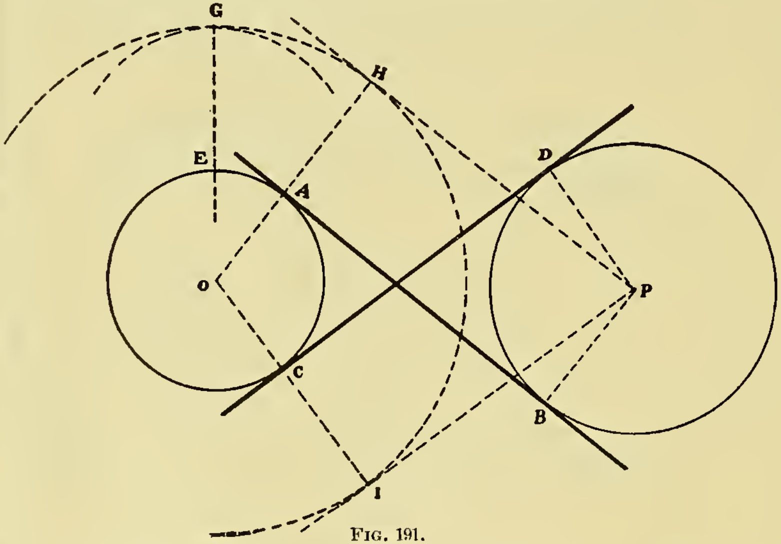


FIG. 191.

From O as center and OG as radius, describe the circle GHI; draw tangents PH and PI to this circle from the center P of the other circle. Draw perpendiculars to these tangents from O and P and they cut the given circles at the points ABCD. The lines joining the points A and B and C and D are the required tangents.

To inscribe a square in a given circle; that is, to draw a square within the circle, with all the vertices of its angles resting on the circumference.

Let ABCD be the given circle, Fig. 192.

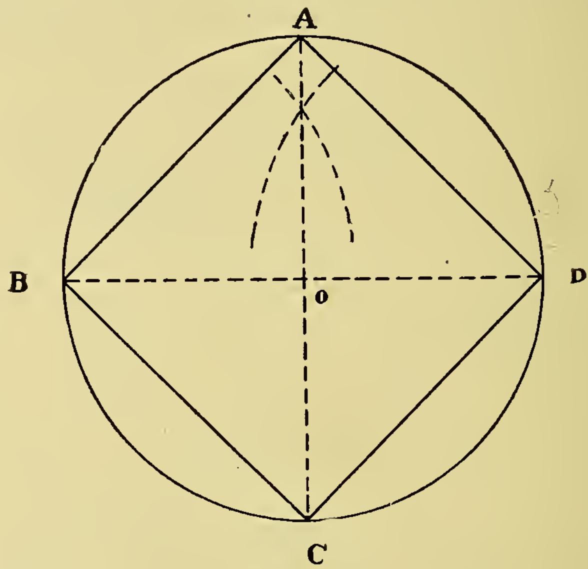


FIG. 192.

Draw two diameters, AC and BD, at right angles to each other. Draw the lines AB, BC, CD, and DA, joining the points of intersection of these diameters with the circumference of the circle ACBD. ACBD is the required square.

To describe a square about a given circle.

Let EGHF be the given circle, Fig. 193.

Draw two diameters, FG and EH, at right angles to each other. At the points EGHF, where these diameters intersect the circumference of the given circle draw lines perpendicular to these diameters.

These lines will intersect each other at ABCD, which is the required square.

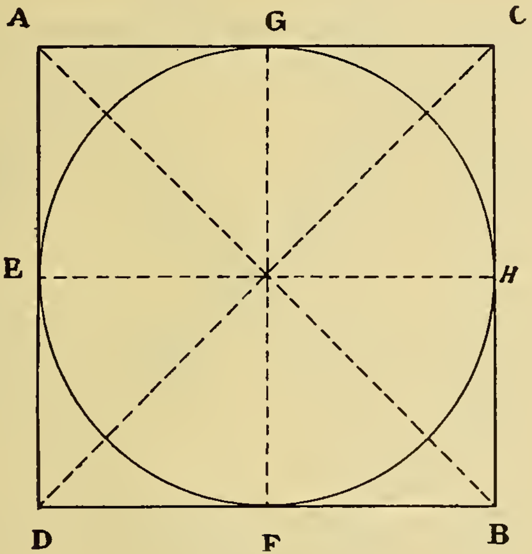


Fig. 193.

To inscribe a hexagon in a given circle. (See definition, page 32.)

Draw a diameter AB in the given circle, Fig. 194.

From A and B as centers, with a radius equal to the radius of the given circle, describe four arcs cutting the circumference of the circle at DEF and G. Join these points by straight lines. ADEBFG is the required hexagon.

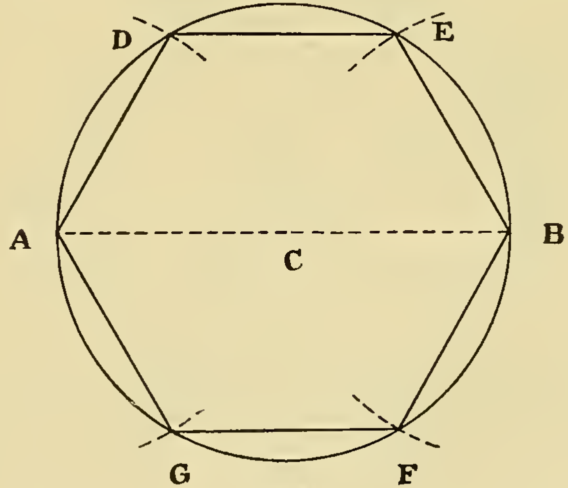


Fig. 194.

To divide the circumference of the circle into six equal parts.

We set the dividers to equal the radius of the circle and get the required result by stepping the radius six times around the circle.

To construct a hexagon upon a given line.

Let AB be the given line and let it equal in length a side of the required hexagon, Fig. 195.

From A and B as centers describe arcs cutting each other at G, the radii of the arcs being equal to AB.

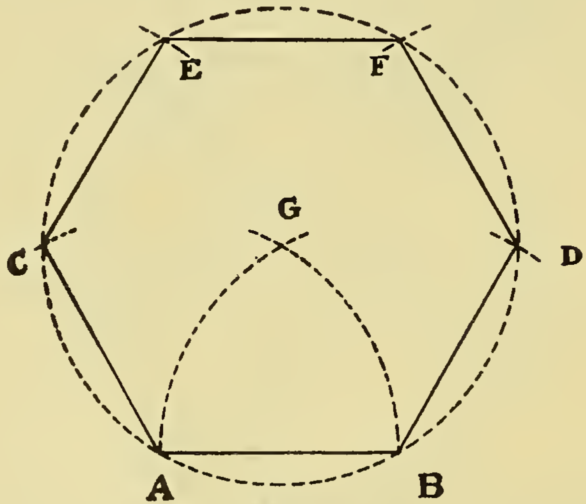


FIG. 195.

From G as center with the same radius describe a circle. With the same radius set off arcs cutting the circumference at CEF and D. Join these points by straight lines and they will form the sides of the required hexagon.

To describe an octagon in a given square. (See definition, page 32.)

Let ABCD be the given square, Fig. 196.

Draw the diagonals of the square cutting at E.

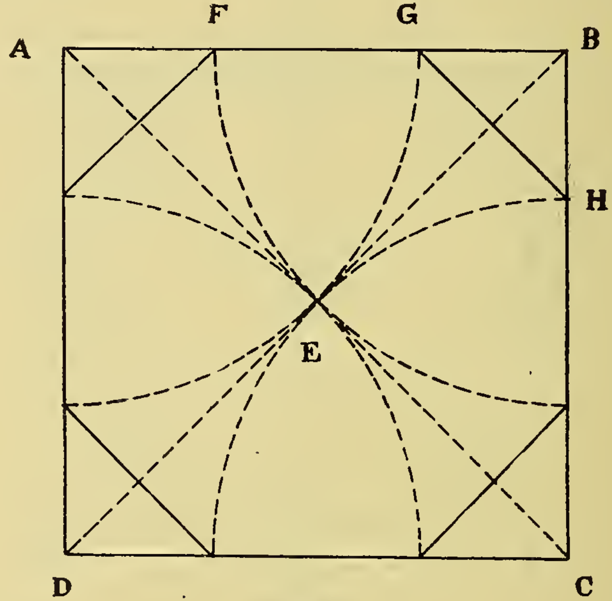


FIG. 196.

From ABC and D as centers, with a radius AE, describe arcs cutting the sides at GH, etc. Join the points so found to complete the required octagon.

To describe an octagon on a given line, one side of the octagon being given.

Let AB be the given side, Fig. 197.

Lengthen the line AB both ways. Erect perpendiculars to this line at A and B.

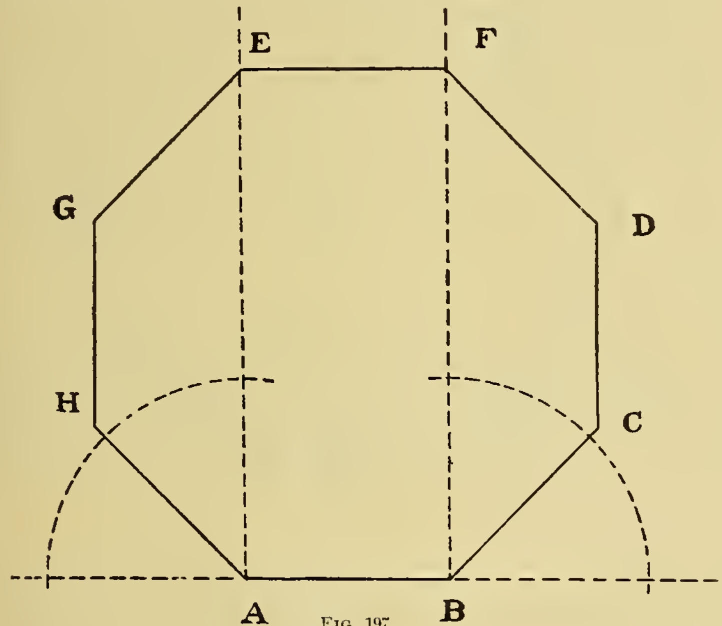


Fig. 197.

Bisect the external angle at A by the line AH, and the external angle at B by the line BC. Make AH and BC equal to AB. Draw HG and CD parallel to AE and equal to AB.

From G as center, with a radius equal to AB, cut the perpendicular AE at E, and from D as center with the same radius cut the perpendicular BF at F. Complete the octagon by joining GEF and D.

To draw a regular polygon of any number of sides on a given line. (See definition, page 30.)

Let C5 be the given side of the required polygon, Fig. 198.

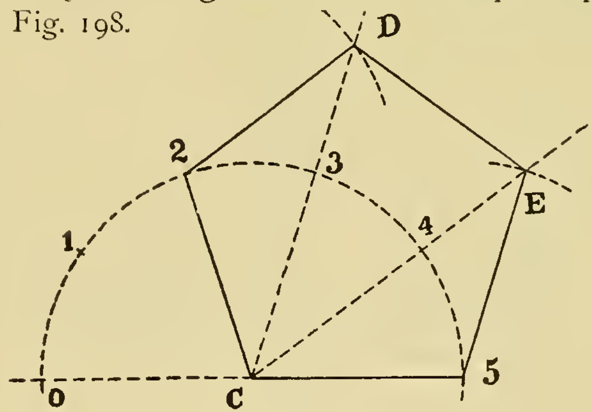


Fig. 198.

Lengthen the line C5 to O. With C as center and a radius equal to C5 describe the semicircle O12345, and divide this into as many equal parts as there are sides in the required polygon. Join C with 2, 3, 4, etc., by straight lines. With 2 as a center and a radius equal to C5 describe an arc cutting the line C3 at D. With D as center, and with the same radius draw an arc cutting the line C4 at E, and so on. Join the points C2D, etc., to form the required polygon.

To inscribe a regular pentagon in a given circle. (See definition, page 32.)

Draw two diameters AC and DB at right angles to each other, Fig. 199.

Bisect the radius OB at I. With I as center and a radius equal to IA describe an arc cutting the diameter DB at J.

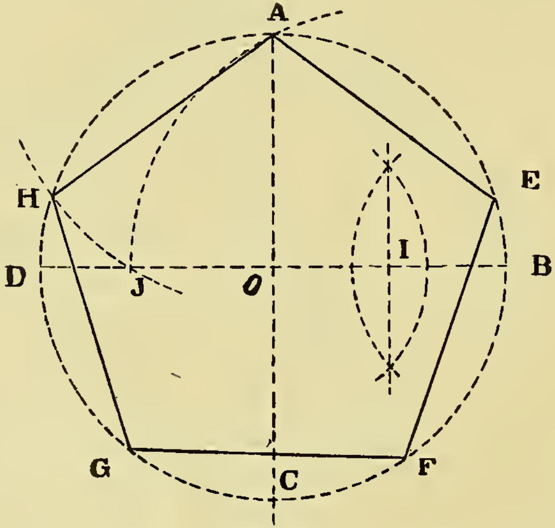


FIG. 199.

A straight line joining A and J is equal to one side of the required pentagon. With arcs of a radius equal to AJ set off on the circumference the points where the sides of the pentagon will terminate.

To inscribe a regular polygon of any number of sides, within a given circle.

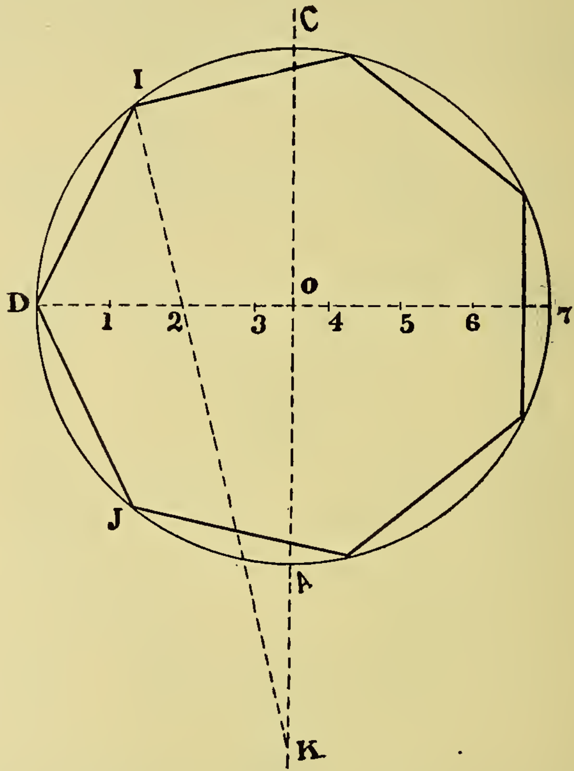


FIG. 200.

Draw two diameters AC and D7 within the given circle, Fig. 200, at right angles to each other.

Divide the diameter D7 into as many equal parts as there are sides in the required polygon. Let it be seven in this case, at the points 123456.

Lengthen the diameter AC making AK equal to three-fourths of the radius of the given circle. Through K and 2 draw a straight line cutting the circumference at I. Join the points D and I by a straight line, and it is equal in length to one side of the required polygon. Set the dividers to equal this side, and set off the other sides around the circumference.

To describe an octagon in a circle.

Draw two diameters at right angles; these diameters divide the circumference into four equal arcs. Bisect these arcs to complete the octagon.

To draw an oval by circular arcs.

Let CD be the major axis and AB the minor axis of the oval, Fig. 201.

Find the difference of the semi-axes and set it off from O to e and f on CD and AB. Bisect ef and set off one-half of it from e to g and draw gh parallel to ef.

From the center O on CD lay off the distance Oi equal to Og and draw hi; through the points i and g draw the lines Ri and gR parallel to gh and hi. With Cg as a radius and the points g and i as centers, draw the arcs jCm and nDp; with RA

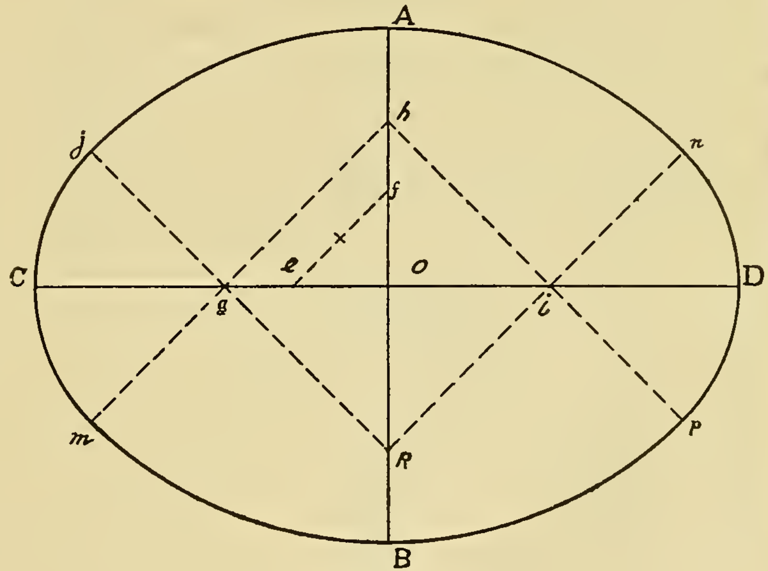


FIG. 201.

as a radius and R and h as centers draw the arcs jAn and mBp meeting the small arcs in the points j and n and m and p. The figure AnDpBmCj is the required oval.

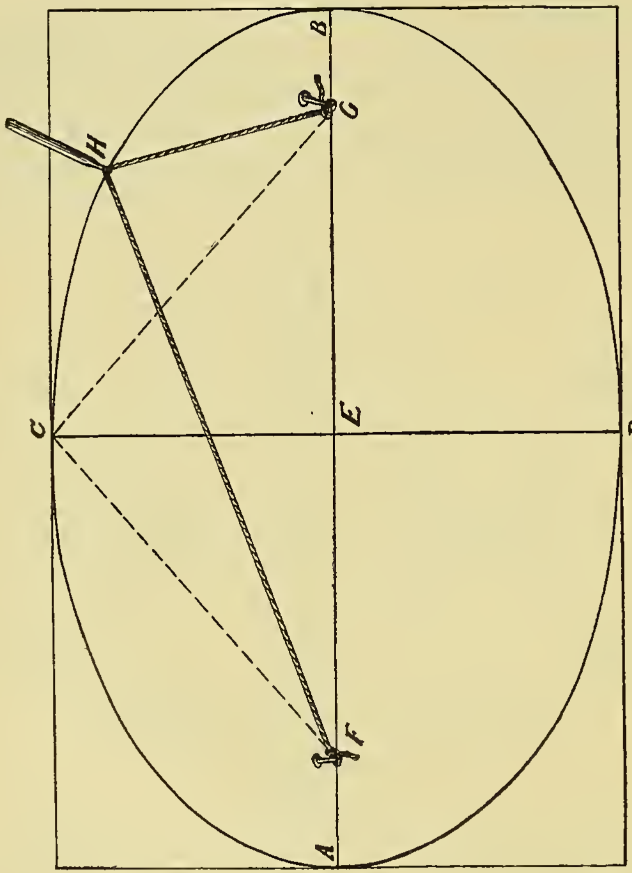


Fig. 202.

To draw an ellipse, the major and the minor axes being given. (See definition, page 36.)

MECHANICAL METHOD.

Draw a line AB equal to the major axis of the required ellipse, Fig. 202.

Bisect the line AB at E. At E draw a line CD perpendicular to AB. Make ED equal to EC and equal to one-half the minor axis. Set the compass to a distance equal to AE or EB, and with C or D as center, describe an arc cutting the major axis at F and G. F and G are the foci of the ellipse.

Fasten the ends of a string, whose length is equal to the length of the major axis, AB, at the foci F and G. This may be done by fixing pins at the foci and by providing the ends of the strings with loops.

Trace a curve with the point of a pencil H pressed against the string so as to keep it stretched. The curve thus traced will be the required ellipse.

GEOMETRICAL METHOD.

Draw a rectangle ABCD enclosing the axes of the ellipse, Fig. 203.

Let EF be the major axis and HJ the minor axis. Divide AB, DC and EF into a like number of equal parts making the number an even one. The greater the number the more accurate will be the resultant ellipse. Let the number in this case be 8.

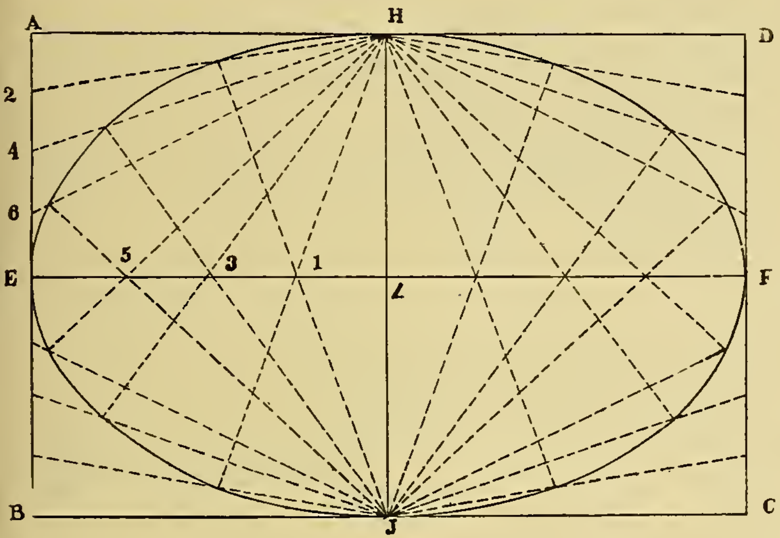


Fig. 203.

From 2, 4, 6, and from corresponding points in DF draw lines to H. From the points placed on EB and FC draw lines to J. From J and H draw lines through 5, 3 and 1 and through corresponding points on LF to meet those already drawn. Through the intersection of 2H with J1, 4H with J3, etc., draw the outline of the ellipse. Finish carefully in pencil, freehand, and then ink in with aid of an irregular curve.

To describe a parabola, the base BC and the altitude EF being given. (See definition, page 36.)

On the given line BC construct the rectangle ABCD with an altitude or height EF, Fig. 204.

From F the middle point in BC erect the perpendicular EF; divide AB and BF into the same number of equal parts, say four. In like manner divide DC and FC. Draw lines from 2, 4 and 6 on AB and from corresponding points on DC to E; from 5, 3 and 1 and from corresponding points in FC draw lines parallel to EF, meeting the lines drawn to E from 2, 4, 6, etc.

Through the intersection of 5 with 6, 3 with 4 and 1 with 2 and corresponding points, draw the curve of the parabola.

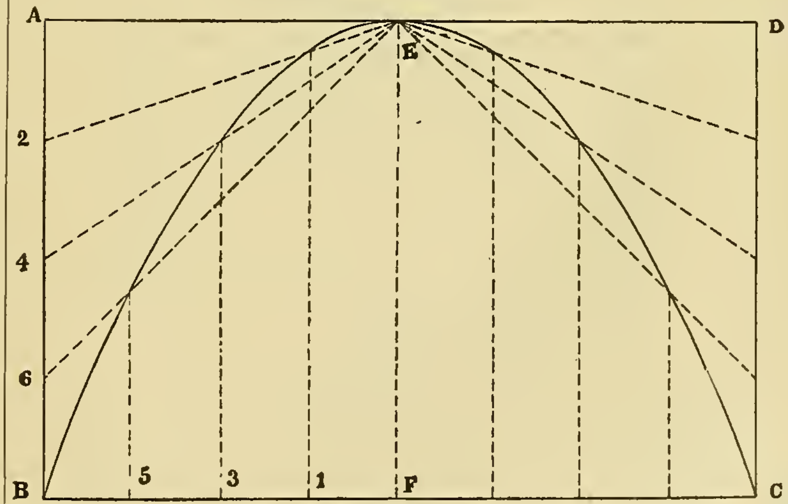


Fig. 204.

To describe a hyperbola, the transverse axis, the altitude and the base being given. (See definition, page 36.)

Let FI be the axis of the hyperbola, EI its altitude and BC its base, Fig. 205.

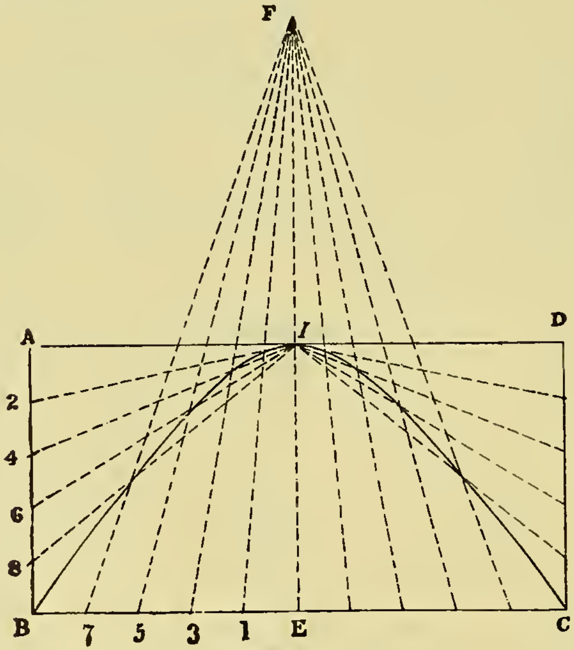


Fig. 205.

On BC construct a rectangle ABCD with EI as its altitude.

Divide AB and BE into the same number of equal parts, say 5. Divide DC and EC in like manner. From F draw lines to the points of division on BC. From the points of division on AB and DC draw lines to I.

Through the intersection of 8 with 7, 6 with 5 and corresponding points, draw the curve of the hyperbola.

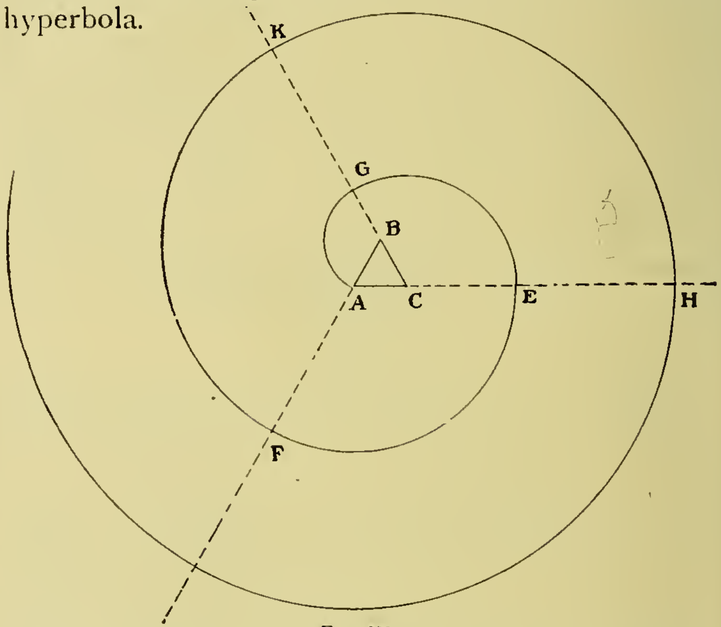


Fig. 206.

To construct a spiral composed of arcs of various radii.

Let ABC be a small equilateral triangle, Fig. 206.

Note.—A spiral is a curve described about a fixed point, and which makes any number of revolutions around that point without returning into itself.

Lengthen the sides AB, BC and CA. With B as a center, BA as a radius, describe the arc AG meeting the line BC prolonged at G. With C as center and CG as radius, describe the arc GE meeting the line AC prolonged at E. With A as center and AE as radius, describe the arc EF meeting BA prolonged at F, and so on, using successively the points BCA for centers.

By using any regular polygon in the same manner, that is, lengthening its sides and taking the angular points of such figure for centers successively in order, as in the above problem, a different spiral may be formed.

To draw the outline of a snail by circular arcs.

Let C be the axis or center of rotation upon which the snail is fixed, Fig. 207. The point B nearest to the center and the point A most distant from the center being also given.

From the center C describe a circle whose diameter shall be equal to one-third of AB and divide the circumference into any number of equal parts, as 1, 2, 3, 4, etc.

Draw through each of these points tangents to this circle. Then from the point 1 as center, 1A as radius, draw the arc 1′–2′ and from 2 as center, 2–2′ as radius, describe the arc 2′–3′; and from 3 draw the arc 3′–4′ and so on, taking in order the points 1, 2, 3, 4, etc., as centers.

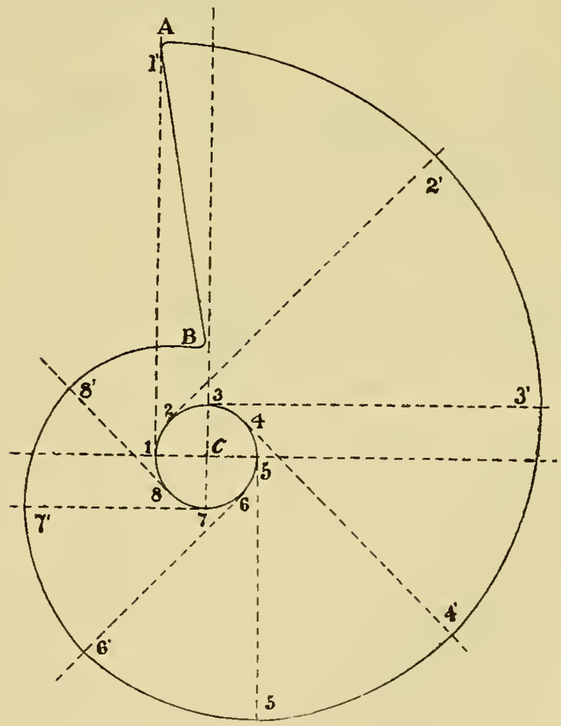


FIG. 207.

NOTE.—The snail is a mechanical movement used for a great variety of purposes, as in time-pieces, drop motions, etc.

To draw the outline of a heart-wheel.

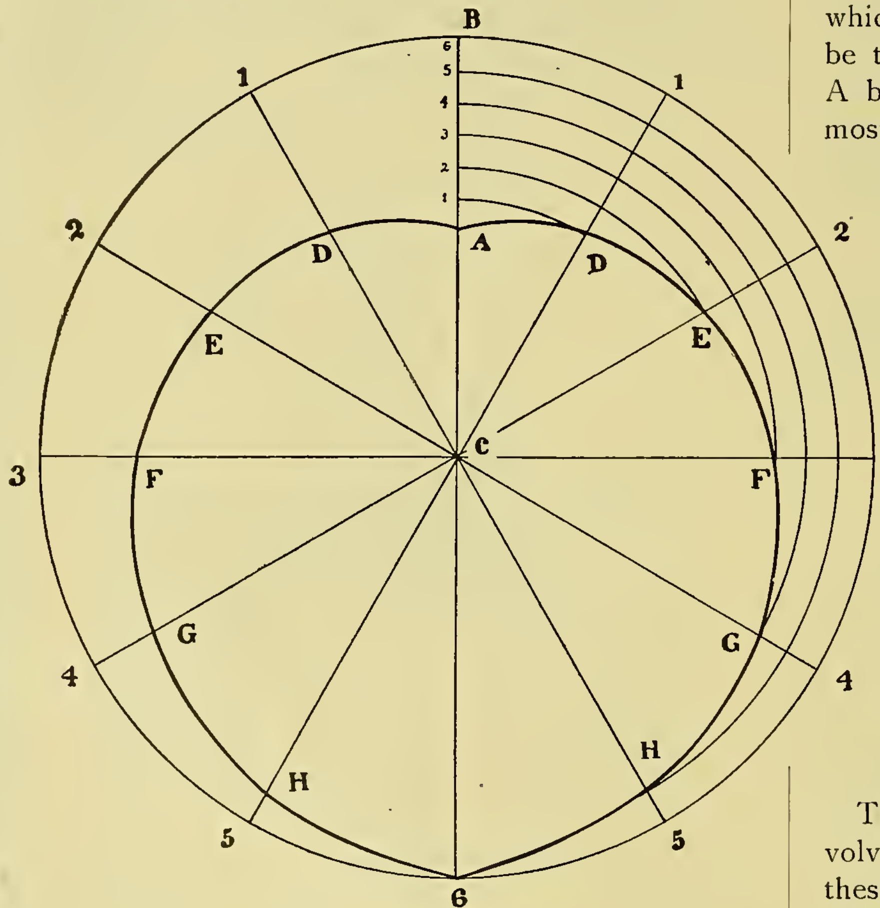


FIG. 208.

NOTE.—The heart-wheel is a popular mechanical device producing uniform reciprocating motion.

Let C be the axis or center of rotation, upon which the heart-wheel is fixed, Fig. 208, and let AB be the required extent of the rectilinear motion, A being the nearest point to the center and B the most distant.

From the center C with a radius equal to CB describe a circle. Divide this circle into any number of equal parts, say 12, and through the points of division draw radii C1, C2, C3, C4, etc.

Divide the line AB into half the number of equal parts, the circle is divided into (in this case six), as 1, 2, 3, etc. Then from the center C with the distance C1 on the line AB, describe an arc cutting the first radius at the point D; then take the other divisions on the line AB and in succession with them from the center C draw arcs, cutting their respective radii C1, C2, C3, etc., at the points DEFG and H, which are the points in the required heart-wheel curve, its highest point being C and its lowest A.

The construction of various machine parts involves many problems similar to the preceding; these will be introduced when treating of the design of mechanical motion and the construction of parts of various machines.

ISOMETRIC, CABINET AND ORTHOGRAPHIC PROJECTIONS
AND
DEVELOPMENT OF SURFACES.

The word projection means to throw forward, and in mechanical drawing it is the projecting or throwing forward of one view from another; in drawings the lines in one view or plan may by this system be used to find those of others of the same object, and also to find their shape or curvature as they would appear in other representations.

Isometric projection is that in which but a single plane of projection is used.

Cabinet projection is somewhat like isometric projection; the cabinet projections are: 1, a horizontal line; 2, a vertical line and 3, a 45-degree line; all measurements on the drawing must be laid off parallel to these axes; cabinet projection is one of several systems of *oblique* projection.

Orthographic projection. The primary geometrical meaning of the word orthographic is "of or pertaining to right lines or angles," hence all the projecting lines are either *horizontal* or *vertical.*

Drawings made up in this manner will be easily understood by many people unacquainted with the special methods of drawing generally used in mechanical branches.

Development of surfaces will be defined and illustrated under its own chapter, page 162.

Objects represented as thus described give a clear understanding of all their dimensions, and approximately show them as they appear to the eye of the observer; the method of representing objects as they really appear to the eye is called *perspective drawing.* This latter method, however, presents so many difficulties of construction, that various other means have been devised, all aiming to give the advantages of perspective, and avoiding at the same time the difficulties of construction. These methods, also called *false perspective*, are described under the heading of *isometric projection*, and will be further explained in the following chapter under the title "*Cabinet Projection.*"

ISOMETRIC PROJECTION.

Figure 209 shows a solid figure, a cube, with equal sides and resting on one of its corners; the lines ac, ab and ag are called *isometric axes;* these axes form an angle of 120 degrees with each other.

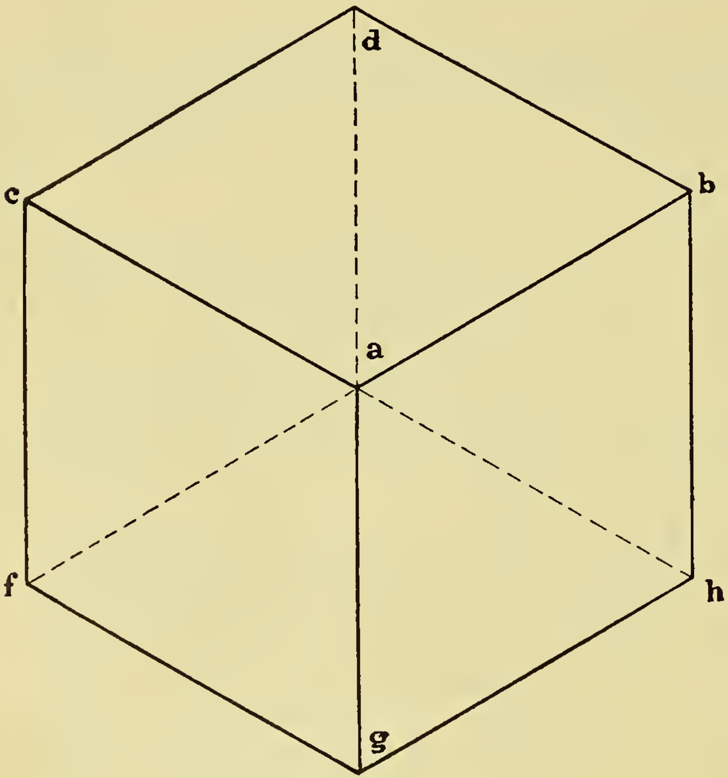


FIG. 209.

They may be drawn by the 30° and 60° triangles; the lines ac and ab forming angles of 30° with a horizontal line; ag is a vertical line.

All the lines in this figure are parallel to these axes, viz.: all the lengths are parallel to ab and all the widths are parallel to ac.

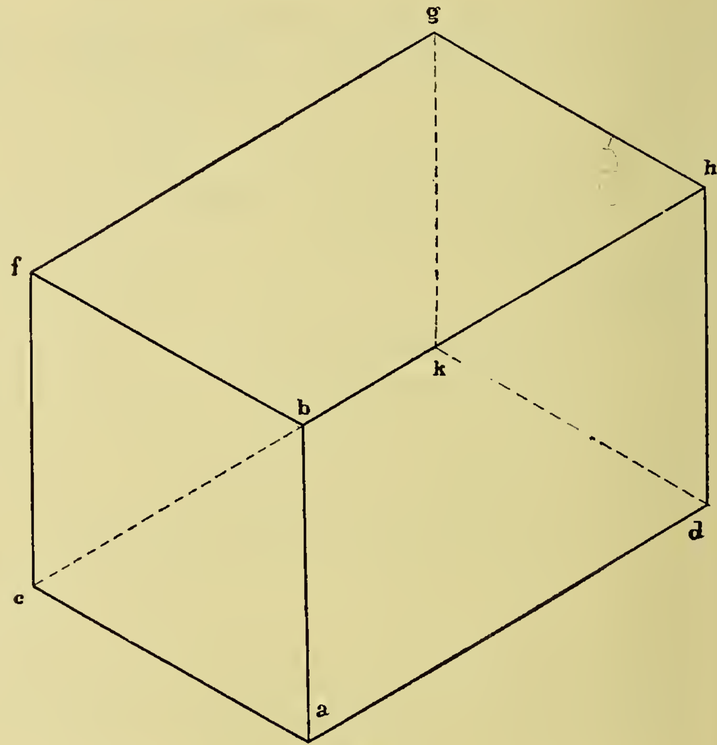


FIG. 210.

The method of thus representing objects is called *isometric projection;* drawings made in this manner show very clearly, with one view, the object as it appears when looked upon; all the sizes of the object are drawn full size, or made to one scale, parallel to the isometric axes.

With these rules in mind several objects will be represented in isometric projection in order to explain its principles.

To draw a square block, 4" by 2" by 2", Fig. 210.

First draw the isometric axes, ab, ac and ad; ab is a vertical line whereas ac and ad are lines forming angles of 30° with a horizontal line; make ab equal to 2 inches, ad equal to 4 inches and ac equal to 2 inches; from c draw cf, parallel and equal to ab, and from d, draw dh, also parallel and equal to ab.

Join the points b and f; and the line bf will be equal and parallel to ac. Then join the points b and h and the line bh will be equal and parallel to ad; from the point f, draw the line fg equal and parallel to bh, then draw the line gh, which will be equal and parallel to bf; from the point of intersection g draw the vertical line gk, from c and d draw the lines cb and dk, respectively, and parallel to ad and ac.

To draw a rectangular frame made of wood ½" thick, the outside dimensions being 16" long, 8" wide and 2" deep, as shown in Fig. 211.

First draw the isometric axes ab, ad and ac: make the line ab equal to the depth required, or 2", the line ad equal to 16" or the length desired for the frame, and finally the line ac equal to 8" or the width.

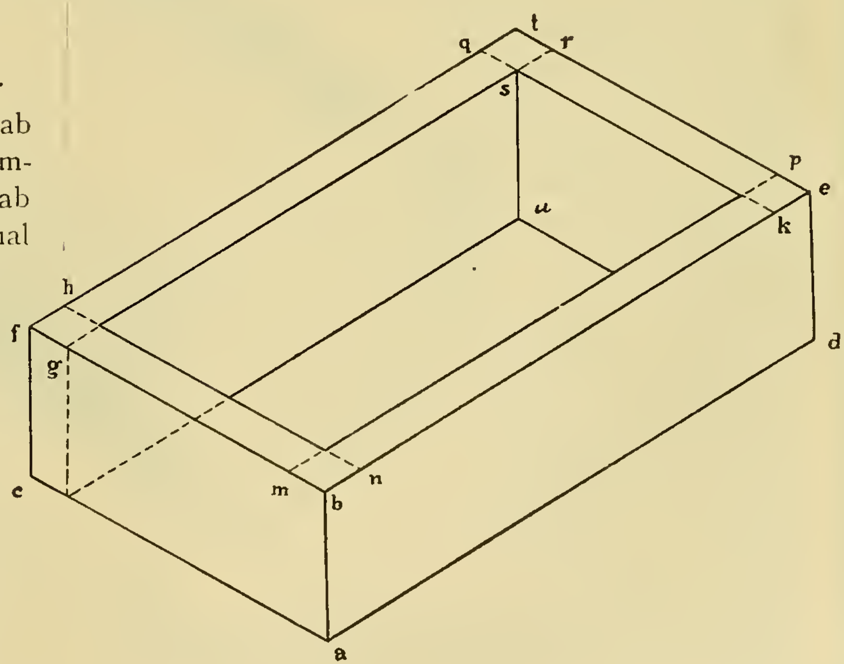


FIG. 211.

Now draw the lines cf and de equal and parallel to ab and then draw the lines fb and eb, equal and parallel to ac and ad, respectively. From the point f draw ft equal and parallel to ad.

Next join the points e and t and the line et will be parallel and equal to ac.

Now make mb and bn, tq and tr, each equal to ½″ for the thickness required in this example; draw the lines mp and gr parallel to eb and also draw the lines qk and hn parallel to bf. The two lines gr and qk intersect at s; from this point s, draw a vertical line su, parallel and equal to ab.

From u draw a line parallel to ad in the direction of ac and cutting this latter line; also draw from u a line parallel to ac in the direction of mp and cutting said line.

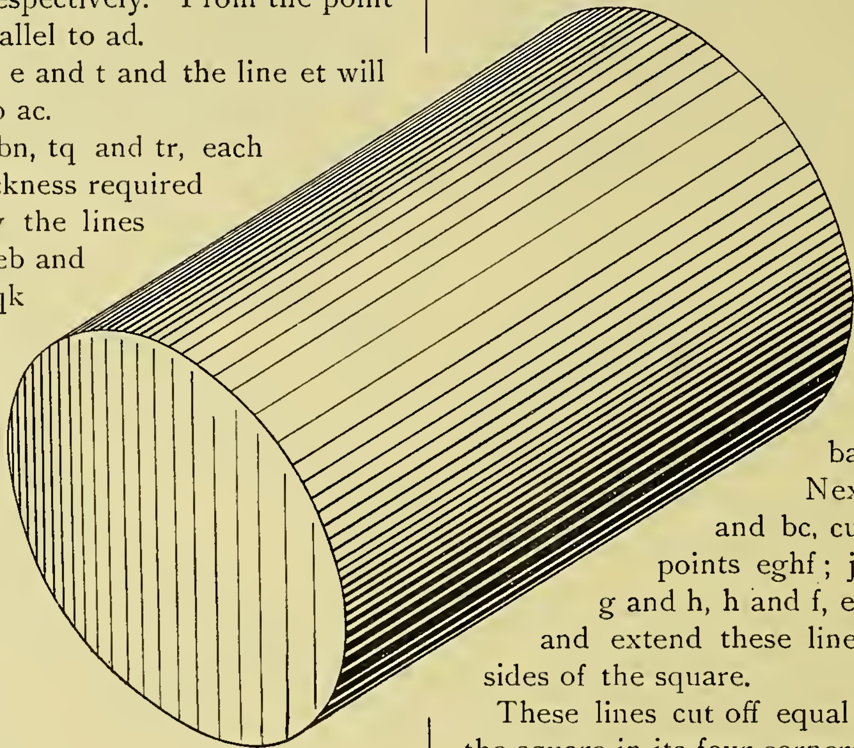


Fig. 212.

NOTE.—For objects as represented in figures 210 and 211 an isometric projection is desirable, but when the objects to be drawn contain curved surface lines the application of the above described method is limited.

To draw a right cylinder in a horizontal position, as shown in Fig. 212.

Draw a square abcd, Fig. 213, with sides of exactly the same length as the diameter of a circle whose surface is to be the base of the required cylinder. Within this square draw a circle efgh, tangent to the square and its diameter equal to that of the base of the cylinder.

Next draw the diagonals ad and bc, cutting the circle at the points eghf; join the points e and g, g and h, h and f, e and f by straight lines and extend these lines until they meet the sides of the square.

These lines cut off equal lengths of the sides of the square in its four corners, so that a1=a2=d3=d4, etc.

Now suppose that the required cylinder is placed in a square prism, so as to exactly enclose the cylinder as shown in Fig. 214.

It is evident that the prism will have two ends equal to the square shown in Fig. 213, and that the length of the prism will be equal to that of the cylinder.

Then draw the prism in isometric projection as explained on page 115; draw the diagonals AD and BC in the end ABCD of the prism and lay out the isometric projection of the circle which is to form the base of the required cylinder. Set off on the line AC a distance A1 equal to a1 in Fig. 213; from the point D on the line DB, set off the distance D4, equal to a1, in Fig. 213, or equal to A1 in Fig. 214.

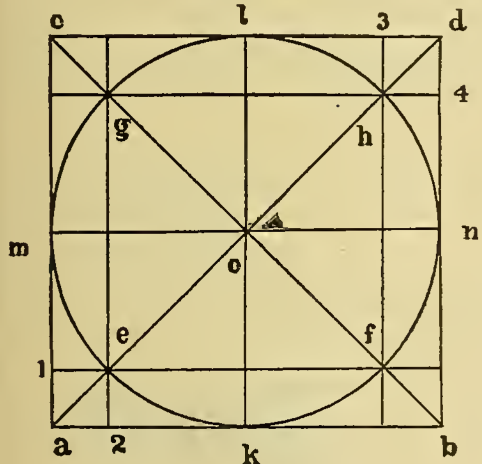


FIG. 213.

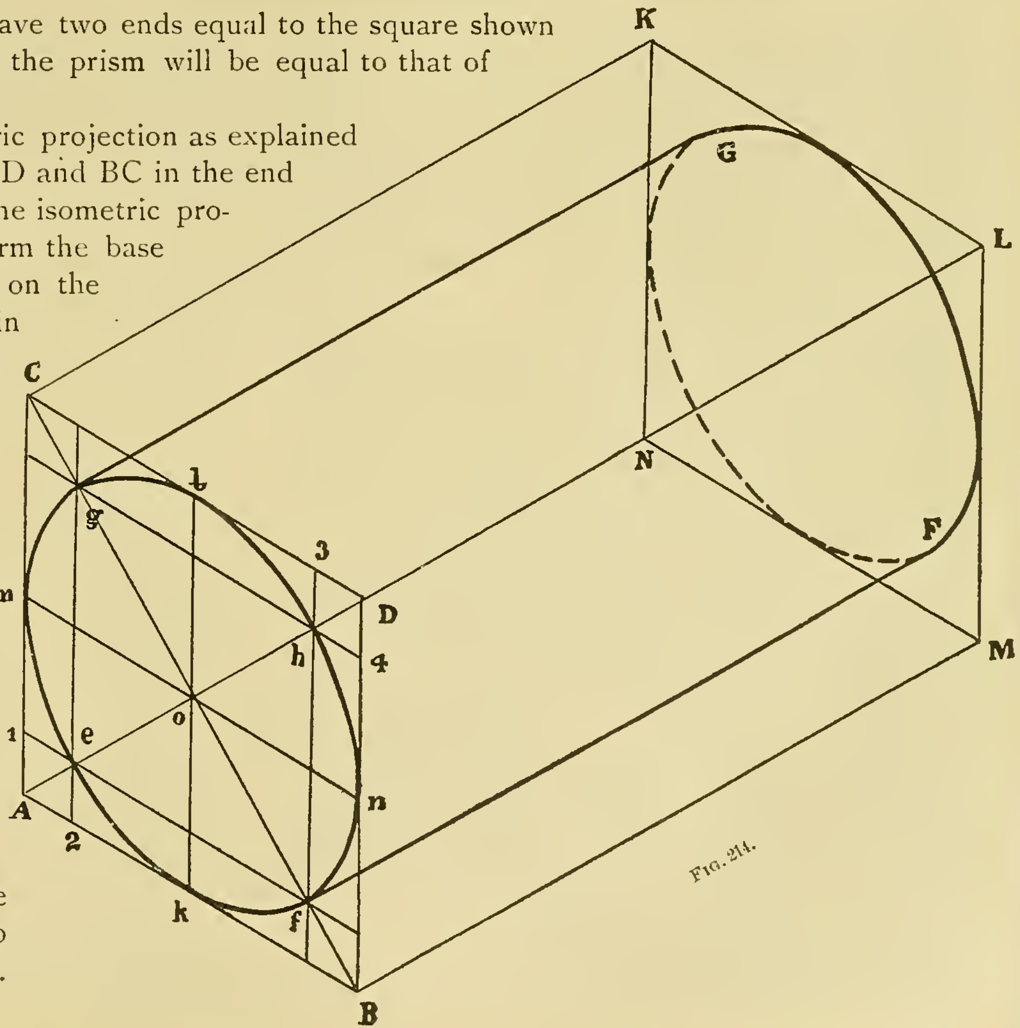


FIG. 214.

Through the point 1 draw a line parallel to AB, cutting the diagonals AD and BC at the points e and f; through the point 4 draw also a line parallel to CD intersecting the diagonals at the points g and h; draw the line mn through o, parallel to AB, cutting AC at m and BD at n; draw a line parallel to AC through the same point O, cutting the line CD at l and the line AB at k.

The points k, e, m, g, l, h, n and f are points through which the required circle drawn in isometric projection will pass. The curve thus obtained is evidently not a circle, but has the form of an ellipse, its minor axis being eh and its major axis fg. This ellipse may be drawn by any method explained in the section pertaining to Geometrical Drawing.

The other end of the cylinder, which is to be inscribed in the figure KLMN, may be drawn in the same manner as already explained, and the ellipse GF will be obtained.

In order to complete the isometric projection of the cylinder draw the lines Gg and Ff, joining both faces of the cylinder; these lines are to be drawn through the ends of the major axis of both ellipses and they are tangent to these two curves.

To draw a pattern of a crank, shown in Fig. 215, isometric projection.

The pattern consists of two cylinders joined by a board. The larger cylinder into which the shaft will fit is 3″ in diameter and 2½″ long; the smaller cylinder to which the crank pin is to be fitted, is 2″ in diameter and 2″ long. The distance between the center lines of the two cylinders is 5″.

Proceed as follows:

Describe a circle 3″ in diameter, as in Fig. 216, and draw a square around it, and within the square draw two diagonals and other lines as in Fig. 213; draw the isometric projection of a prism having Fig. 216 as a base and a length equal to 2½″; said prism is marked ABCDdab and its hidden parts are not shown.

In this prism lay out the isometric projection of the larger cylinder, whose front face will be the ellipse klNcjM.

Fig. 218 shows only a small part of the ellipse forming the rear end of the cylinder and this small visible part is represented by *mi*.

Through the center of the first ellipse draw the line MN parallel to CD and the line kc parallel to AD; then draw the line cg through the point c and parallel to Aa and equal to 1½″.

The point g indicates the place where the board, connecting both cylinders, is fastened to the first cylinder. The board intersects the cylinder, forming an additional ellipse, or more properly, a part of an ellipse, represented in Fig. 218 by uge; this part of the ellipse is exactly equal to the part jcN of the ellipse McNk,

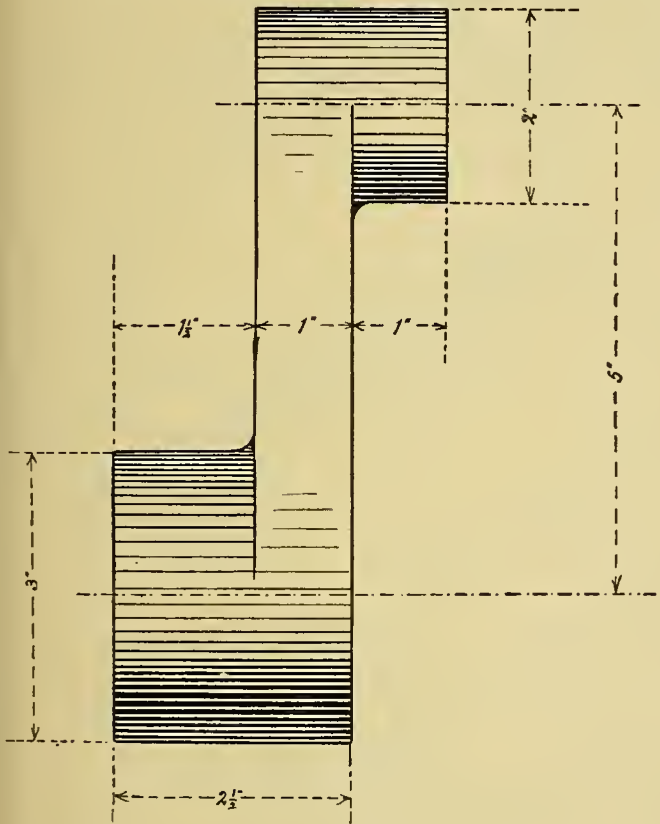


FIG. 215.

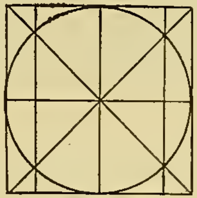


FIG. 217.

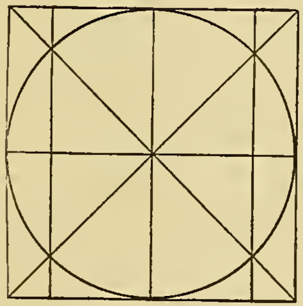


FIG. 216.

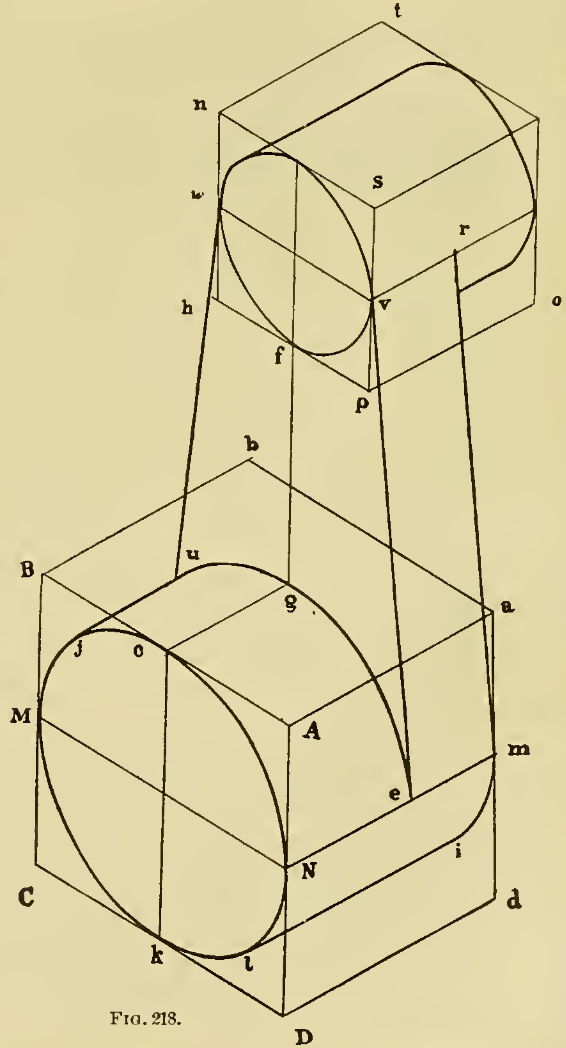


FIG. 218.

and may be constructed by drawing from different points of the curve, jcN, a number of lines parallel and equal to cg.

The line uj is a tangent to both of these curves.

From the point g draw the line gf parallel to ck and equal to 2½″; through f draw the line hp parallel to CD so that hf is equal to fp, each of these being equal to one inch; from the line hp draw the isometric projection of the prism hpsnto, which is to enclose the smaller cylinder.

The base of the latter is shown in Fig. 217 and represented in Fig. 218 by the ellipse vfw. The length of the prism is to be equal to 2″.

When the small cylinder has been drawn in isometric projection within this prism draw the line vw through the center of the ellipse vfw and parallel to hp; draw the line vr through the point v, the distance vr being made equal to one inch and through the point r draw the line rm, tangent to the ellipse mi.

The lines wu and ve are both tangent to the ellipse uge. The hidden parts of the object are not indicated in Fig. 218.

Fig. 219 represents a tool chest drawn in isometric projection It is given here as an example of a large class of objects well adapted for representation by this method.

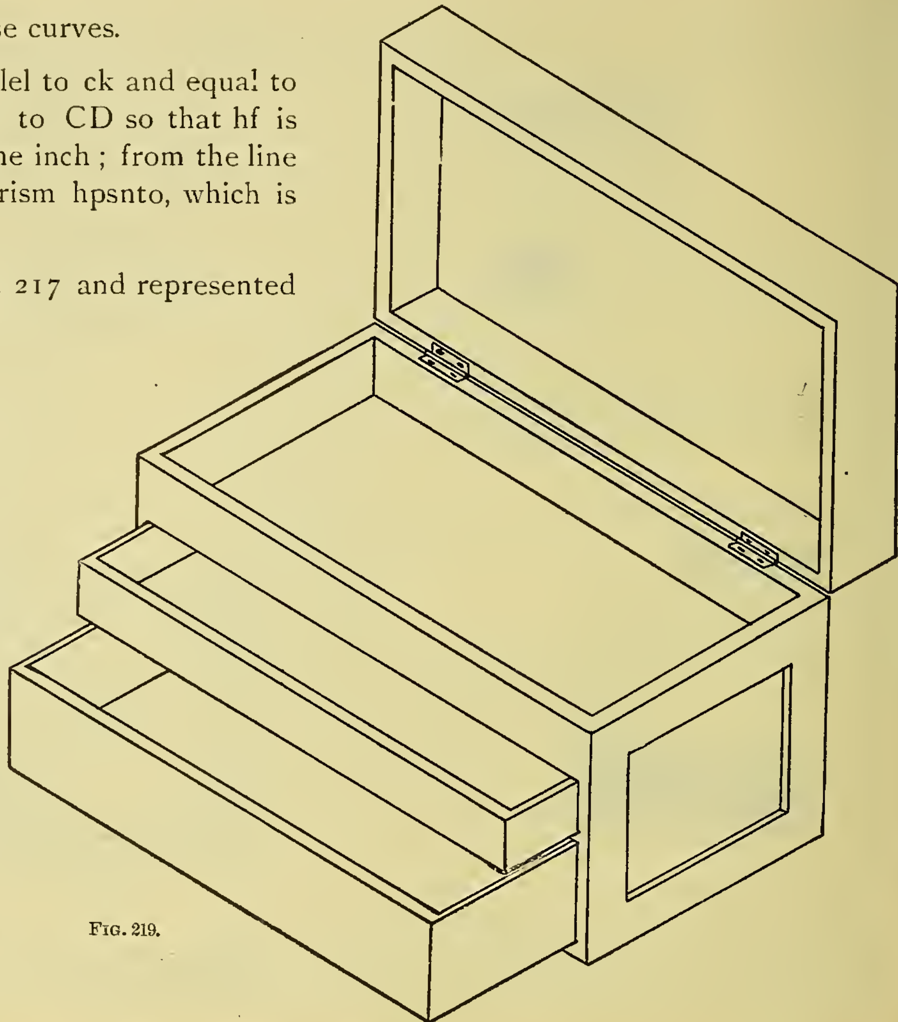


Fig. 219.

CABINET PROJECTION.

Cabinet Projection is somewhat similar to Isometric Projection; its difference consists in selecting *three axes* to which all measurements of the object are drawn parallel; see a, b, c, following:

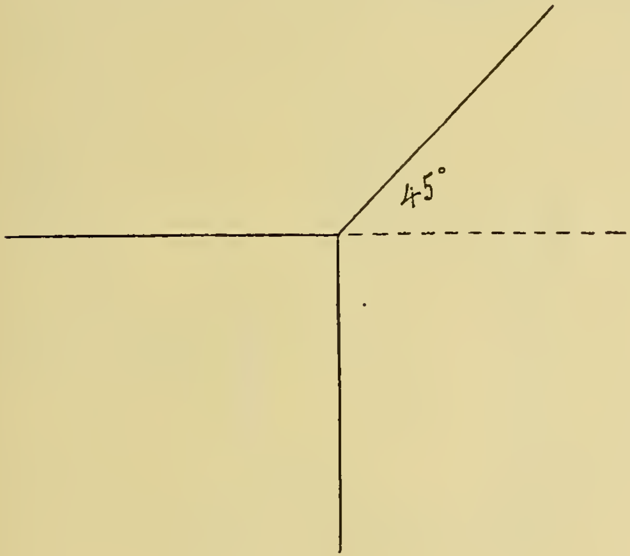


FIG. 220.

The axes for cabinet projection are: 1, a horizontal line; 2, a vertical line; and 3, a 45° line, as shown in Fig. above.

It is to be remembered that:

a. All horizontal measurements, parallel to the length of the object must be laid off parallel to the horizontal axis, in their actual sizes.

b. All vertical measurements, parallel to the height of the object, must be drawn parallel to the vertical axis, in their actual sizes.

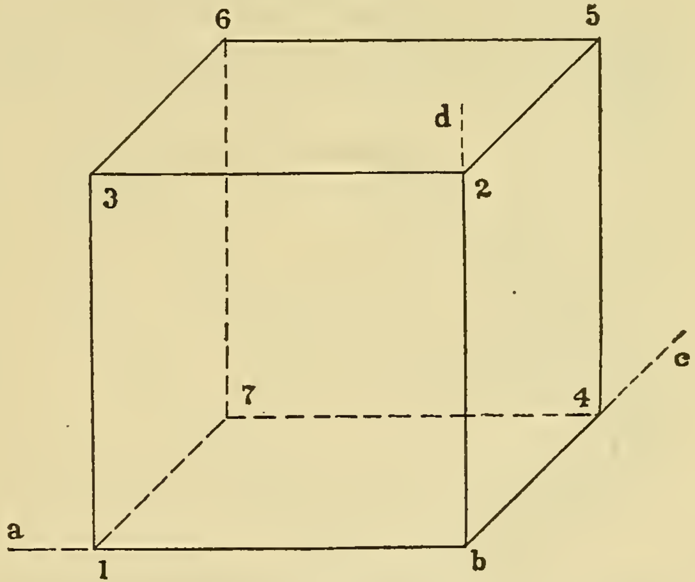


FIG. 221.

c. All measurements parallel to the thickness of the object must be laid off on lines parallel to the 45° axis, in sizes of only one-half of the actual corresponding measurements.

It is not essential which side of the object should be considered its length and which side its thickness.

To draw a cube in cabinet projection, as shown in Fig. 221.

Suppose each side of the cube to be 3″ long.

Draw the three axes: ab=horizontal axis, bd=vertical axis, and bc=axis inclined 45°. On the line ab set off, from the point b, the distance b1=3″; on the line bd, from b, lay off b2=3″; and on the line bc measure off $\frac{3}{2}$″=1½″. A vertical line drawn

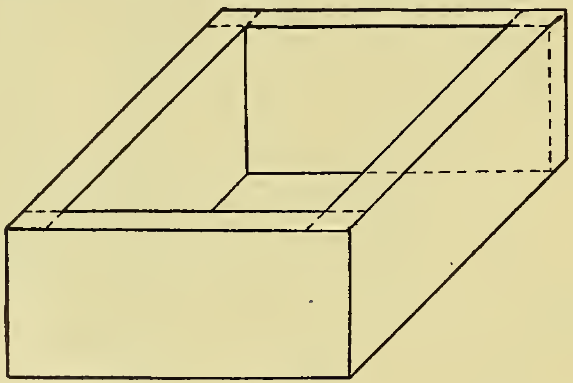


FIG. 222.

through point 1 parallel to the vertical axis bd and a horizontal line drawn through point 2 parallel to the horizontal axis ab will intersect at point 3 and thus complete one face of the cube b-2-3-1.

Now, through the point 4 draw a vertical line parallel to bd and through point 2 draw a line inclined 45° with the horizontal; these two lines intersect at the point 5 and complete the side b-2-5-4 of the cube.

The remaining lines are drawn in a similar manner, parallel to the axis, from the points 3 and 5, intersecting at the point 6 and showing the top of the cube 3-6-2-5.

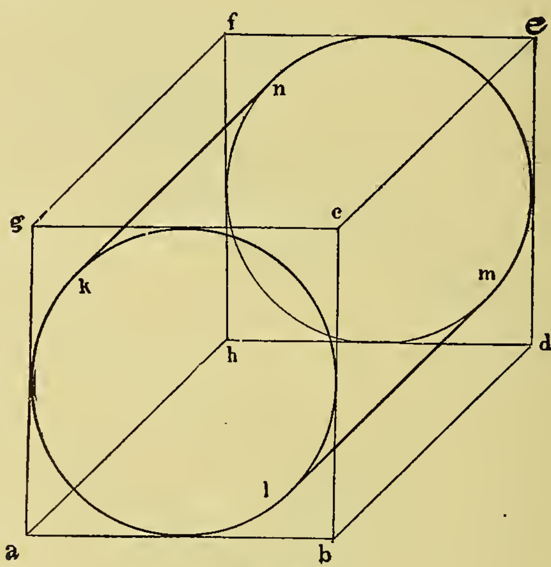


FIG. 223.

Next draw through the point 4 a horizontal line and parallel to ab and through the point 1 a line inclined at 45° and parallel to bc; these two lines cut at the point 7; join the points 6 and 7 by a straight line and cube is complete.

In Fig. 222 is shown in cabinet projection the frame represented in Fig. 211. The length of the frame, 16 inches in actual measurement, is represented here on the 45° axis by only one-half of its actual size or 8 inches long; all the other measurements are equal to the actual sizes of the object, as described on page 122.

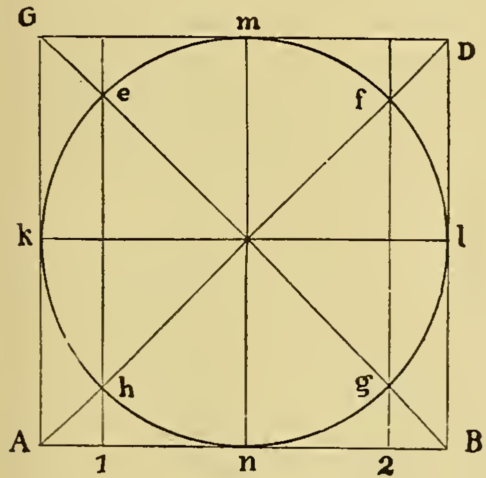


FIG. 224.

zontal axis; 3, parallel to the vertical axis, that is, in a standing position.

The first position of the cylinder being the most convenient for drawing it in cabinet projection; it will be considered here before the others.

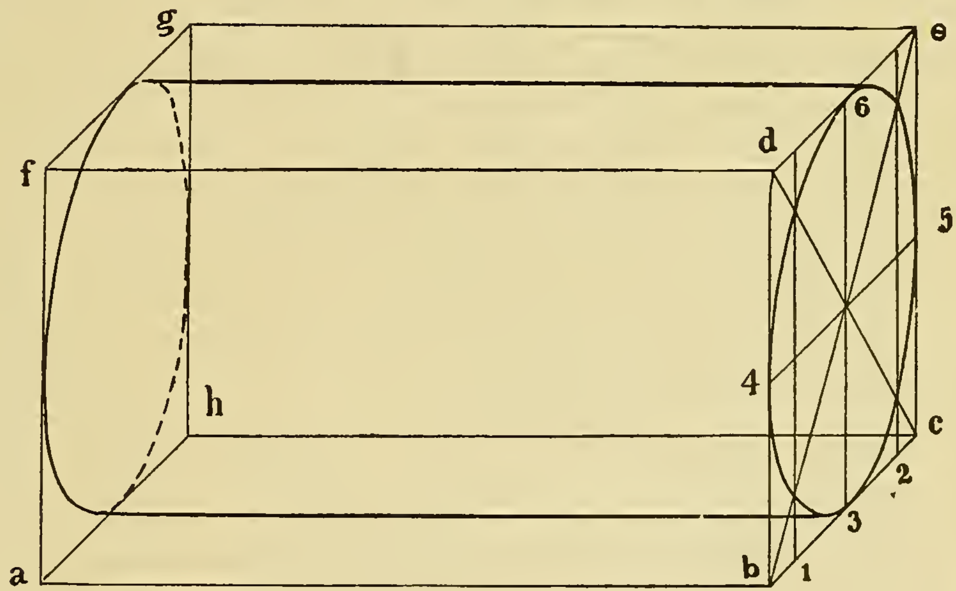


FIG. 225.

To draw a right cylinder in cabinet projection, its base to be the circle shown in Fig. 224.

The cylinder may be placed in the following positions:

1, parallel to the 45° axis; 2, parallel to the horizontal axis; 3, parallel to the vertical axis, that is, in a standing position.

EXAMPLE I.—*Draw in cabinet projection, the prism abcgfedh, Fig. 223, enclosing the cylinder;* the face of the prism, abcg, will contain the visible base of the cylinder; which is shown in Fig. 223 by the circle kl, which is equal to it.

In the rear end of the prism draw the circle nm for the other end of the cylinder, and draw the lines kn and lm tangent to both circles; this completes the cabinet projection of the cylinder.

It is advisable to select this position for all cylinders, as much as possible, when they are to be drawn in cabinet projection, as the circles representing the faces of the cylinder may be drawn by circles and the drawing of ellipses is avoided.

EXAMPLE II.—*Describe the circle forming the base of the required cylinder, Fig. 225, within the square ABDG, Fig. 224, and draw the diagonals BG and AD, cutting the circle at the points hefg.*

Through the points e and h draw the line *eh1* and through the points fg the line *fg2*; the distance A1 will be equal to the distance B2.

Now, assuming that the cylinder is contained within a rectangular prism, each end of which is equal to the square shown in Fig. 224 and the length of which is equal to that of the cylinder, draw this prism in cabinet projection as shown in Fig. 225.

Lay out the axes ab, bd and bc; make ab equal to the length of the prism, that is, equal to the length of the required cylinder; make bd equal to AG, Fig. 224, and bc equal to ½ of the distance AB in Fig. 224.

Through the point c draw a vertical line ce equal and parallel to bd, then join the points d and e by a straight line thus forming the figure bdec, which will be one end of the prism; from the points a and f draw the lines ah and fg, each equal and parallel to bc; then draw the line gh equal and parallel to af.

The figure afgh thus obtained is the other end of the prism.

Now, lay out one face of the cylinder within bdec. In order to do this draw the diagonals dc and eb, set off from b on the line bc the distance b1 equal to one-half of the distance A1 in Fig. 224 and on the same line bc, Fig. 225, point off the distance 2c from the point c and equal to b1.

Through the points 1 and 2 draw vertical lines which will intersect the diagonals eb and cd; the points of intersection thus obtained together with the points 4, 5, 3 and 6—it is evident how these points are found—define the position of the curve which will represent the circle forming one face of the cylinder as it appears in cabinet projection.

The curve within afgh is to be drawn in a similar manner for the other end of the cylinder. Two horizontal lines, each tangent to both these curves, will complete the cabinet projection of the cylinder.

EXAMPLE III.—*From the drawing in this figure 226, it is evident that the construction in this case is exactly the same as in case 2.*

From the above problems it will be seen that

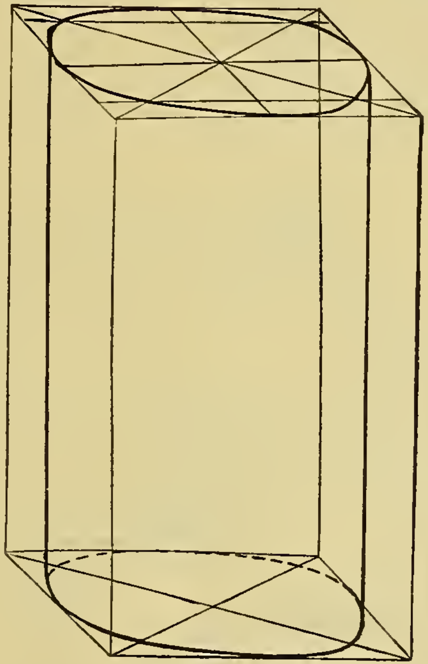


FIG. 226.

objects with circular forms which are to be drawn in cabinet projection should be placed preferably with all or most of its circles as in the cylinder rep-

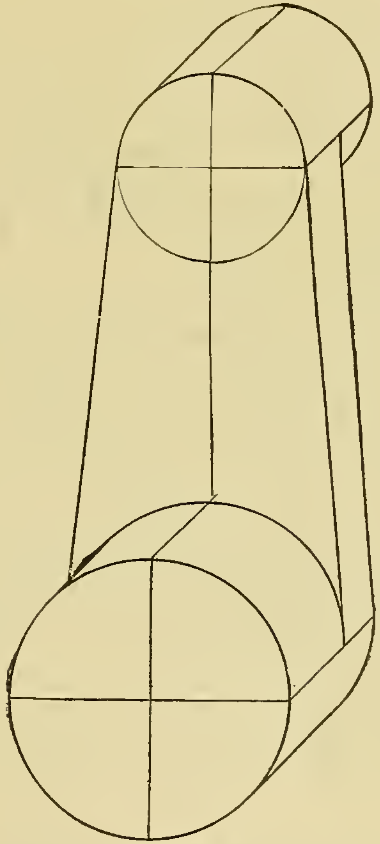


FIG. 227.

resented in Example I; in this position, as already previously stated, all circles in the object will be represented by their actual sizes in the cabinet projection and in this manner the construction of difficult curves may be avoided.

Isometric projection does not offer this advantage as in that method, all circles, without exception, will appear as ellipses; consequently, cabinet projection has a distinct advantage, and is therefore oftener employed when a drawing of an object in false perspective is required.

As an illustration of the principles explained in the preceding pages the cabinet projection of the pattern for a crank, shown in isometric projection in Fig. 215, will be given in Fig. 227.

At a glance it will be seen that the cabinet projection of this object can be drawn in much less time than its isometric projection. It is, however, necessary to bear in mind, that, whereas all measurements in isometric projection are equal to the actual sizes of the object, those in cabinet projection which are parallel to the 45° axis are drawn equal to ½ of their actual size.

Figs. 228, 229, 230, 231, and 232 represent additional illustrations of objects drawn in cabinet projection.

NOTE.—The thorough knowledge of cabinet and isometric projections will be of great advantage, both to the student and the mechanic, as they will thereby be enabled to represent different objects in drawing in such a manner as to be easily understood by persons who would not understand a mechanical drawing executed in another, though perhaps a more generally approved manner.

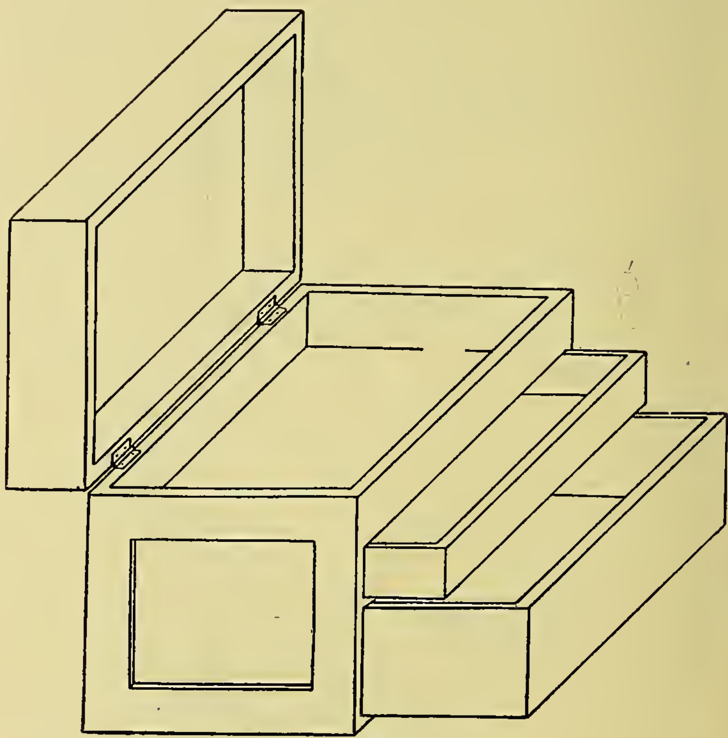


FIG. 228.

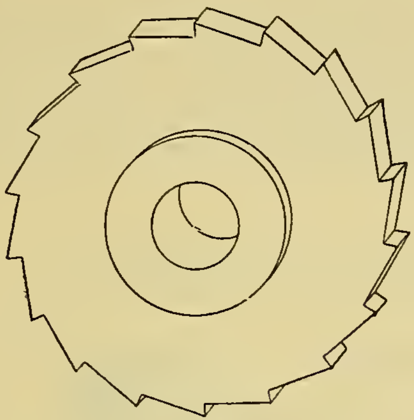


FIG. 229.

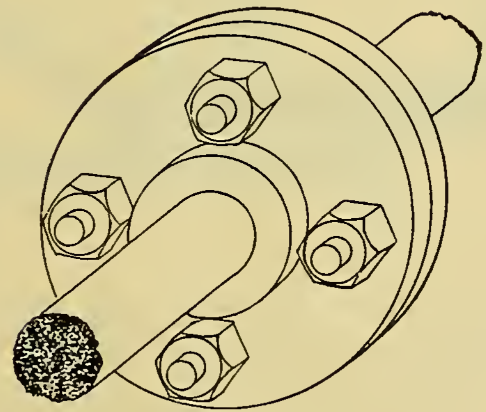


FIG. 230

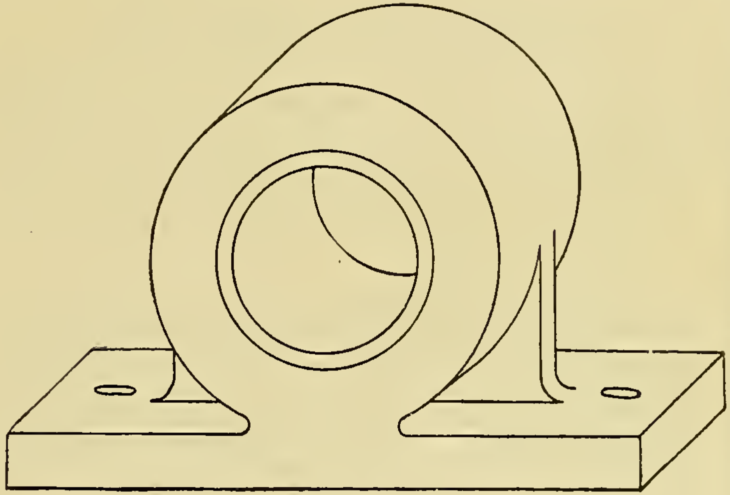


FIG. 231.

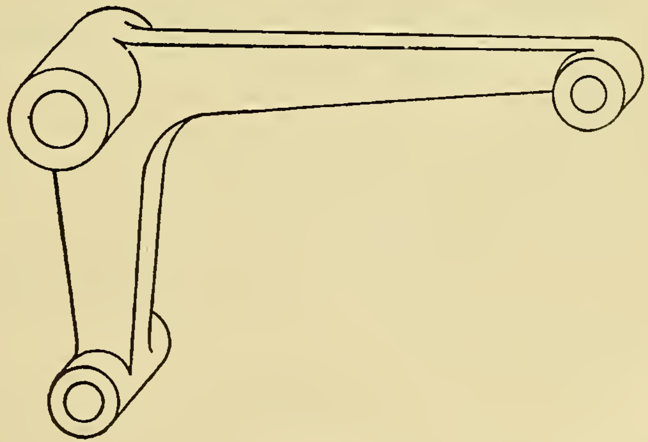


FIG. 232.

ORTHOGRAPHIC PROJECTION.

Isometric drawing and cabinet projection, while showing the object as it really appears to the eye of the observer, are neither of them very convenient methods to employ where it is necessary to measure every part of the drawing for the purpose of reproducing it in the shop.

All shop drawings, or working drawings as they are usually termed, are made by a method known as orthographic projection; in isometric or cabinet projections, three sides of the object are shown in one view, while in a drawing made in orthographic projection, but one side of the object is shown in a single view.

To illustrate this, a clear pane of glass may be placed in front of the object intended to be represented.

In Fig. 233 a cube is shown on a table; in front of it, parallel to one face (the front face) of the cube, the pane of glass is placed.

Now, when the observer looks directly at the front of an object from a considerable distance, he will see only one side, in this case only the front side of the cube.

The rays of light falling upon the cube are reflected into the eyes of the observer, and in this manner he sees the cube. The pane of glass, evidently, is placed so that the rays of light from the object will pass through the glass in straight lines, to the eye of the observer. The front side of the object, by its outline, may be traced upon the glass, and in this manner a figure drawn on it (in this case

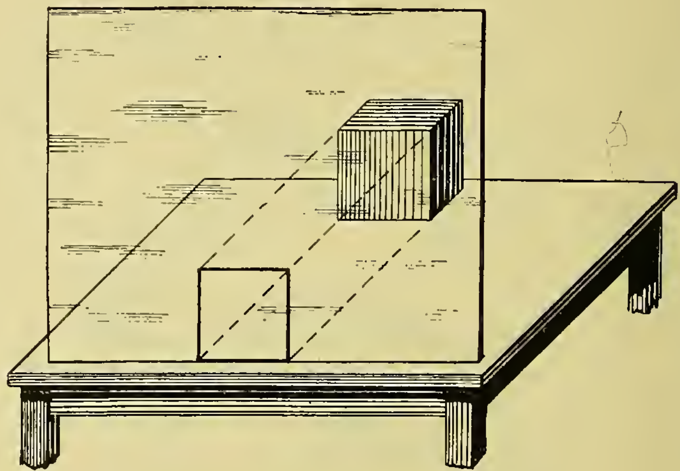


FIG. 233.

a square) which is the view of the object as seen from the front. This view is called *the front elevation.*

One view, however, is not sufficient to show the real form of a solid figure. In a single view two dimensions only can be shown, length and height; hence the thickness of an object will have to be shown by still another view of it, as the top view.

Now, place the pane in a horizontal position above the cube which is resting on the table, Fig.

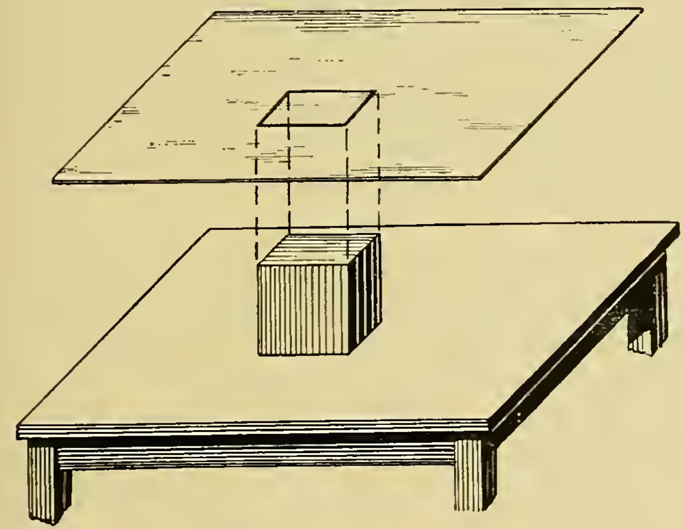


Fig. 234.

234, and looking at it from above, directly over the top face of the cube, trace its outline upon the pane; as a result, a square figure is drawn upon the glass, which corresponds to the appearance of the cube, as seen from above. This square on the glass is the top view of the cube, or its "*plan.*"

In Fig. 235 is shown the manner in which a side view of the cube may be traced; the glass is placed on the side of the cube, which rests on the table as before, and the outline of the cube on the glass in this position, is called its "*side elevation.*"

Usually either two of the above mentioned views will suffice to show all dimensions and forms of the object. In complicated pieces of machinery, however, more views, three and even more may be required to adequately represent the proportions and form of the different parts.

A drawing which represents the object as seen by an observer looking at it from the right side is called *the right side elevation* and a drawing showing the object as it appears to the observer looking at it from the left side is called *the left side elevation.*

A view of the object as seen from the rear is called the rear view or rear elevation, and a view from the bottom, the bottom view.

The different views of an object are always arranged on the drawing in a certain fixed and generally adopted manner, thus—

The front view is placed in the center; the right side view is placed to the right of the front view, and the left side view to the left; the top view is placed above the front view and the bottom view below it. The different views are placed directly opposite each other and are joined by dotted lines called *projection lines.*

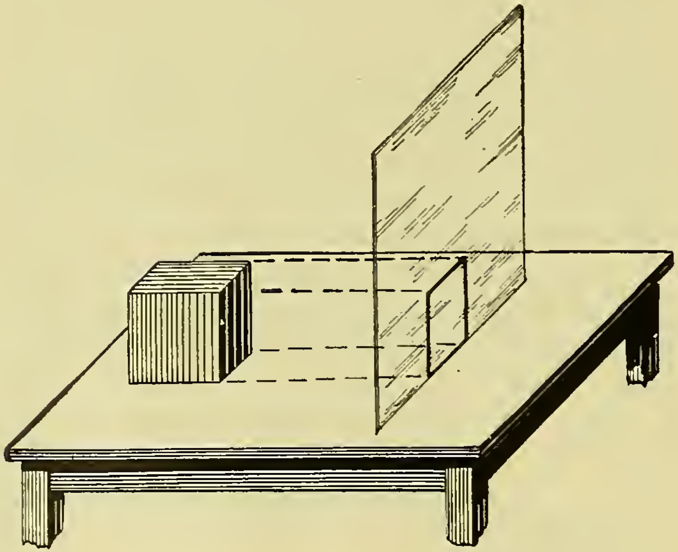


Fig. 235.

By the aid of projection lines, leading from one view to the other, measurements of one kind may be transmitted from one view to the other; for instance, the height of different parts of an object may be transmitted from the front view to either one of the side views; in like manner the length of different parts of the object may be transmitted by the aid of projection lines, to the bottom view and top view.

It is often desirable to show lines belonging to an object, although they may not be directly visible. In Fig. 236 the top view and the bottom view show plainly that the object is hollow; looking at the object from the front or from the sides, however, the observer could not see the inside edges of the object, except it were made of some transparent material.

For mechanical drawing, we may assume that all objects are made of such material, transparent enough to show all hidden lines, no matter from which side the object is observed. It is the general practice to draw the hidden edges by lines made of dashes—dash lines—as in Fig. 236.

In the following articles the student will find a number of exercises on the application of orthographic projection.

Note.—Mechanical drawing is used mainly to represent *solids*, but solids are bounded by *surfaces* which in turn are bounded by *lines* which by themselves are limited by *points;* views of a solid can therefore be found by drawing the views of its limiting points, lines and surfaces, according to the principles of orthographic projection.

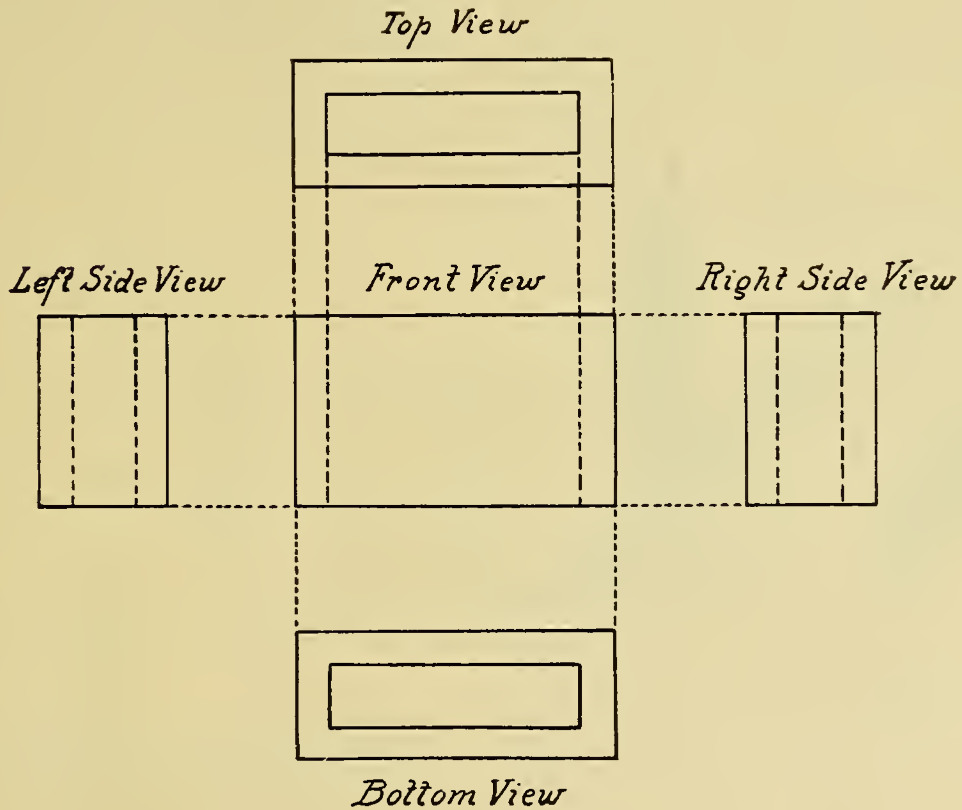

Top View
Left Side View
Front View
Right Side View
Bottom View

FIG. 236.

Draw the front view, left side view and top view of the rectangular prism shown in Fig. 237.

Fig. 238 shows the drawing of the prism in the three required views; the lines showing the dimensions are made by long dashes drawn very thin.

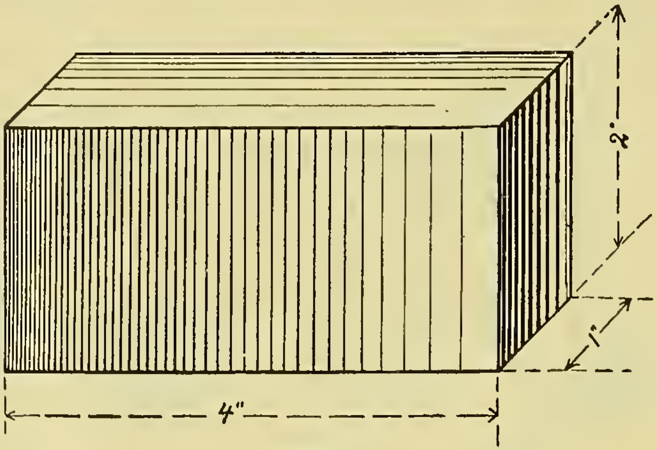


FIG. 237.

It is important to remember that dimension lines must be drawn parallel to the distances, the size of which they are intended to show. The dimension lines terminate in arrow heads drawn with an ordinary writing pen. If a dimension line is carried outside of a view, short auxiliary dotted lines are employed to join the part of the object to which the dimension line refers. The dimension line is left open near the middle, where the figure denoting the measurement is placed. These figures should be written very plainly and placed so as to read along the dimension line; for horizontal lines from

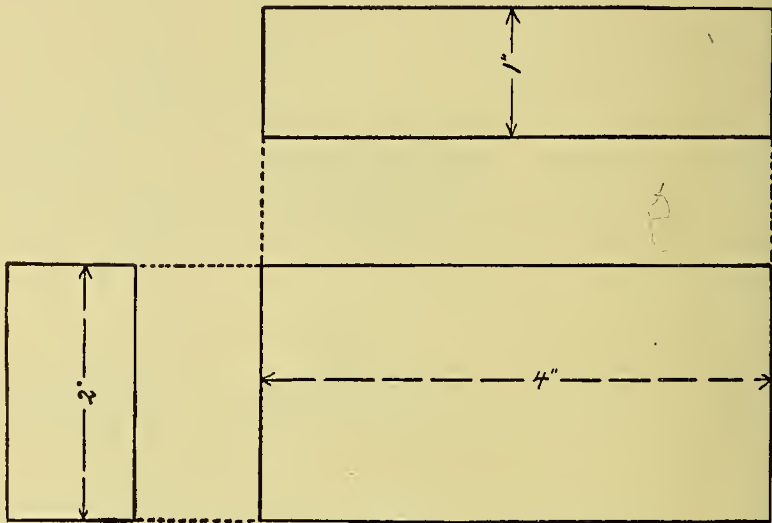


FIG. 238.

the bottom of the drawing, and for vertical lines from the right hand side of the drawing.

The inch is marked ″ the foot ′ —for example: 1 foot, 3 inches is represented by 1′ 3″. More information concerning dimensions will be found in the chapter treating on working drawings.

Draw a front view, top view and right side view of the wedge shown in Fig. 240.

Draw the front view first. Lay off a straight line, on which mark two points 3″ apart; through the point on the right erect a perpendicular, which make one inch long; two sides of the right-angled triangle forming the front view of the wedge are thus found.

Join the two ends of these sides by a straight line and the front view is complete. The student will draw the side view and the top view in corresponding positions to the right side and above the front view, as in Fig. 239.

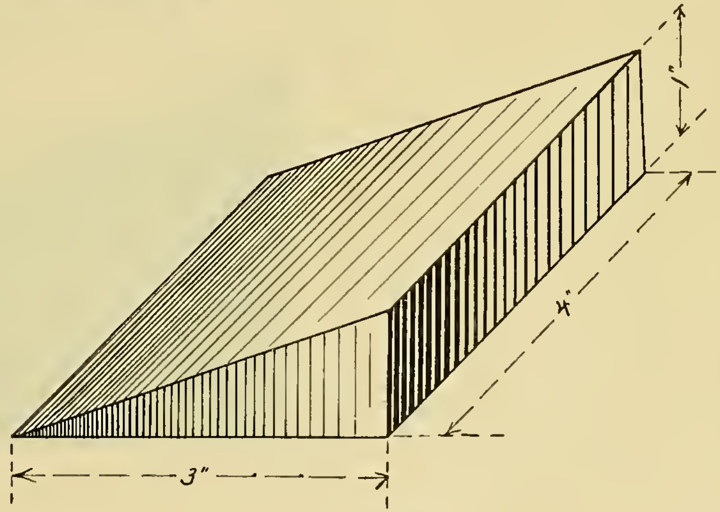


FIG. 240.

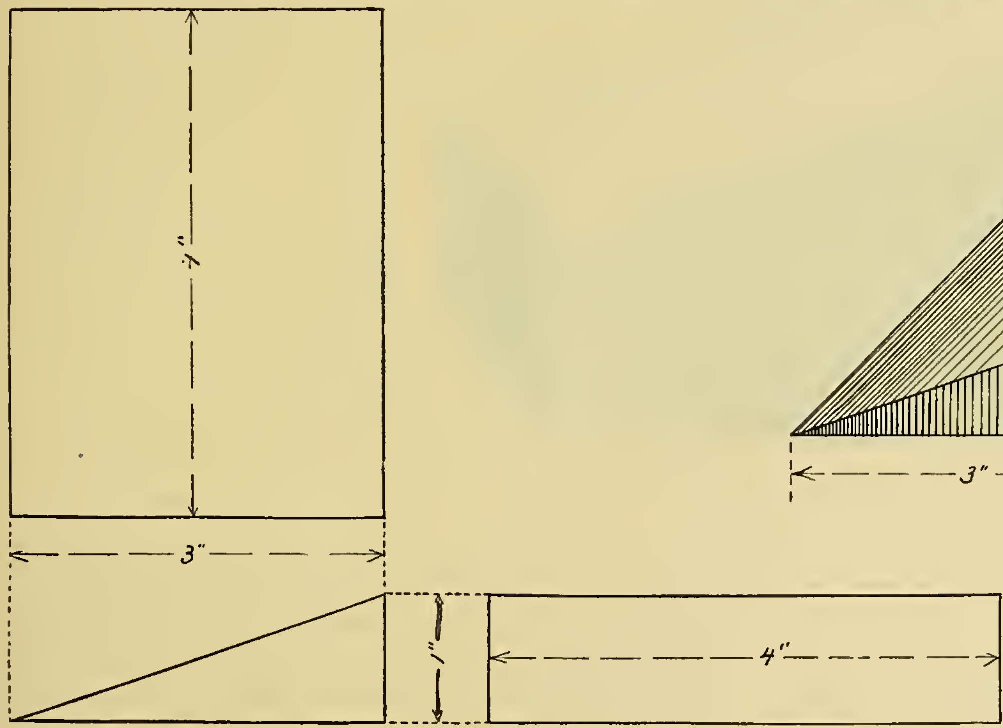


FIG. 239.

Draw a front view, both side views and top view of the object shown in Fig. 241.

Fig. 242 shows the required views of the object. The edge ab which is visible in the right side view

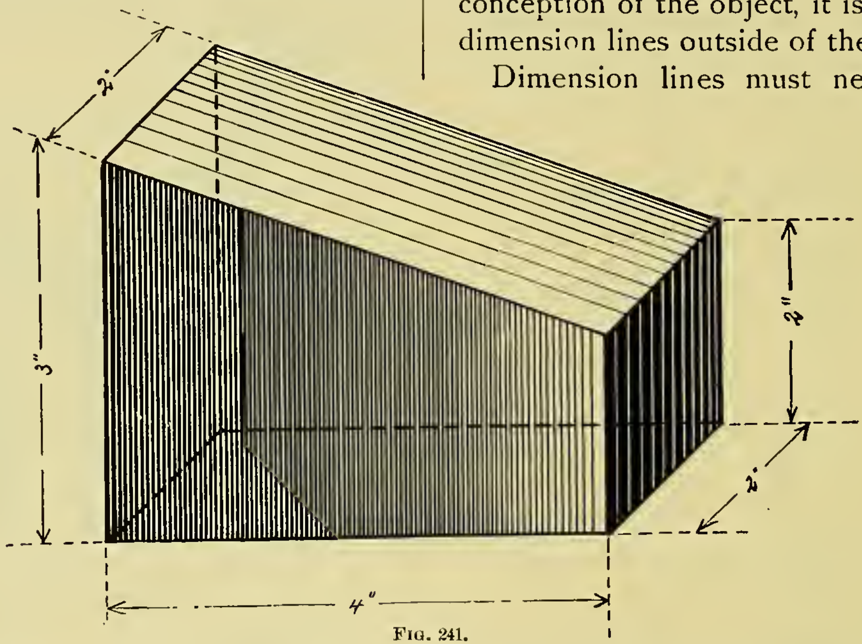


FIG. 241.

is hidden in the left side view and therefore is represented by the dash line cd.

It may often be possible to put in the dimension lines within the views, when the object is not of a complicated nature, and when the dimension lines will not make the understanding of the view more difficult.

Whenever the view is so complicated that any additional lines would only tend to obstruct a clear conception of the object, it is advisable to carry the dimension lines outside of the view.

Dimension lines must necessarily be of three kinds: 1, parallel to the lengths of the different parts of the object; 2, parallel to the width of these parts, and 3, parallel to the height. *The dimension line must always be parallel to the line or edge whose length it represents.*

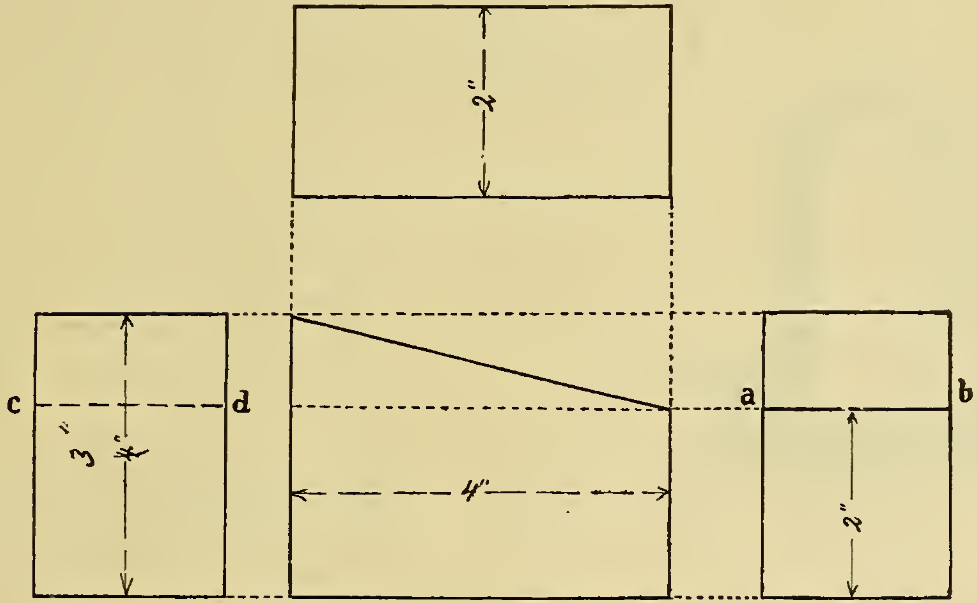


FIG. 242.

Draw a front view, side view and top view of the model shown in Fig. 243. As the object to be drawn has the same appearance from either right or left side, it does not matter which side view is to be drawn.

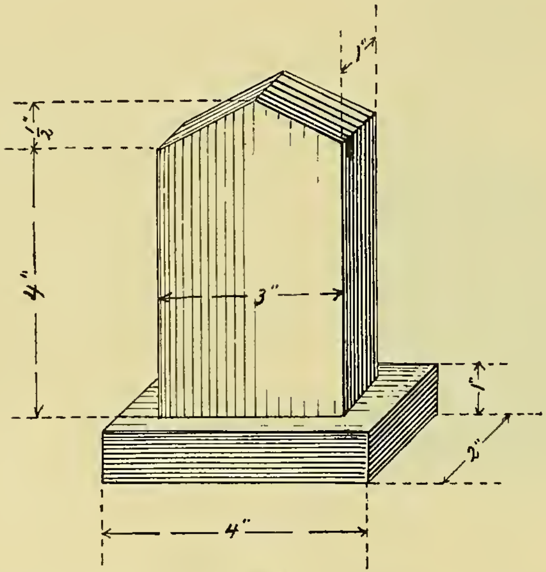


Fig. 243.

The construction of the views is so obvious that no explanation need be offered with the drawing shown in Fig. 244. It will be noticed that this figure, as well as all others in this chapter, are shown with lines representing the sides of the different parts of the object.

Draw two elevations (a front view and a side view) and a top view of a hexagonal prism 5" long and 2½" between any two parallel sides.

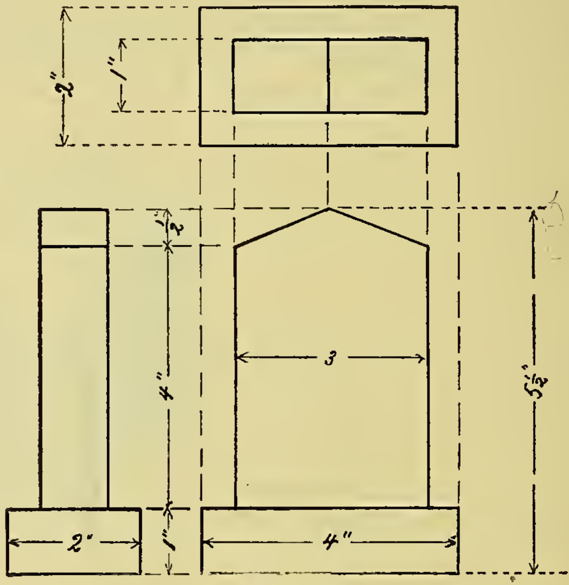


Fig. 244.

It is evident that a hexagonal prism has six faces and of these three are parallel to the remaining three faces. The distance between any two parallel faces or sides is the same; in this case it is equal to 2½"; let us draw the top view of the prism first of all.

Draw two lines, AB horizontal and CD vertical, Fig. 245, intersecting each other at the point O. If it is intended, as in this case, that the intersection, O, of these two lines should coincide with the center of the view which is to be drawn, then these lines are called center lines; the use of center lines in projection drawing is very extensive.

Make the line CO equal to OD and each equal to 1¼", so that the line CD is equal to 2½", the distance between the parallel sides of the prism. Through C and D draw the lines eCd and aDb parallel to AB; then through the point O draw two 60-degree lines eb and ad, cutting the lines eCd and aDb at the points e, b, a and d.

Through these points draw the remaining sides of the hexagon, parallel to the lines eb and ad. The hexagon, aAedBb shows the top view of the prism.

To draw the front view proceed as follows:

Through the points Aab and B draw the vertical lines AE, aH, bj and BF.

Draw the horizontal line NGP, make PF equal to 5", the height of the prism and through the point F draw the horizontal line KEF; then the figure, EHJ FPG is the front view of the prism.

It will be noticed that the front view shows three faces of the prism: HEGS, HSRJ and JRPF, the faces HEGS and

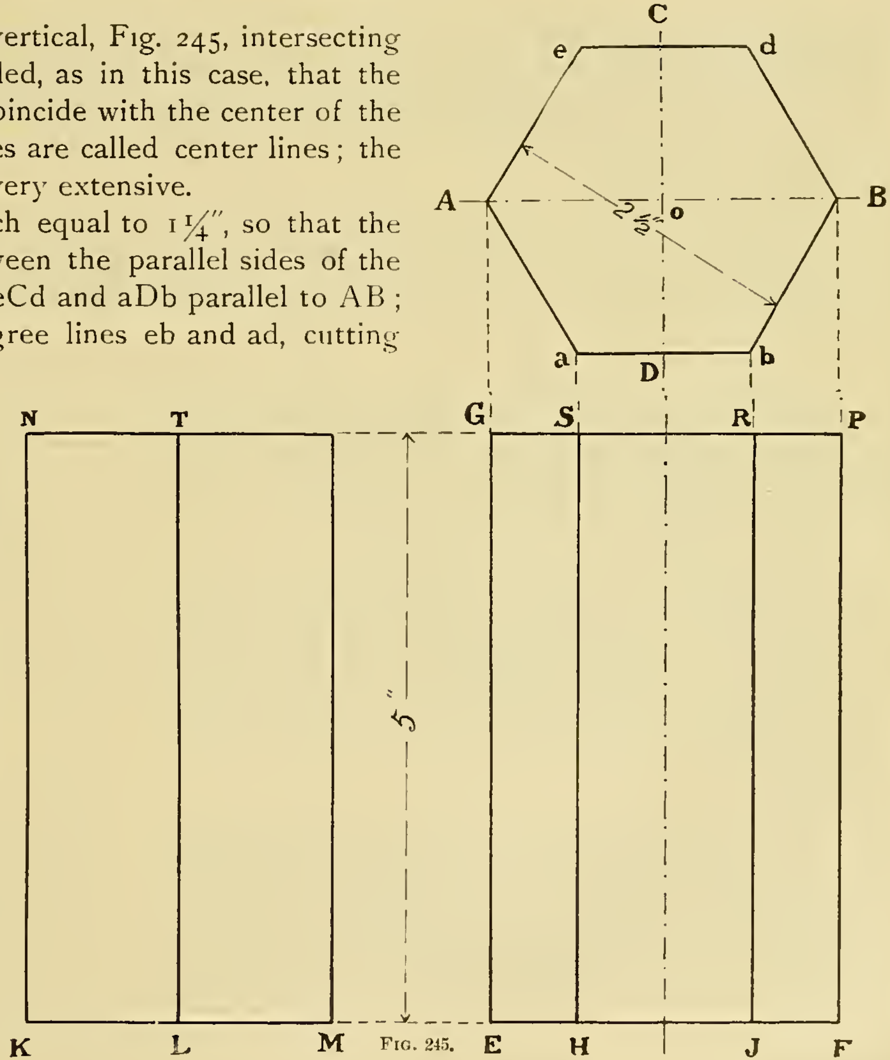


Fig. 245.

JRPF appear narrower than the face HSRJ, the latter being situated right in front of the observer and parallel to the plane of the paper is seen in its true size, while the other two faces seen in the front view being in an inclined position relative to the front face appear narrower than their true width.

The side view KNTLM shows only two faces of the prism. The distance KM is equal to CD, the edge LT corresponding to the edge marked by the letter A in the top view, cuts the line KM into two equal parts, KL and LM.

To draw the top view, front view and side view of a hexagonal pyramid 5″ high, each side of the hexagonal base being equal to 1½″. The top view of the pyramid must be drawn first.

Fig. 246 shows the required views. The top view appears as a regular hexagon, in which all diagonals are drawn by lines as heavy as the sides, as these diagonals show the edges of the faces of the pyramid. The center of the hexagon where all the diagonals meet represents the vertex of the pyramid.

The front view and the side view are drawn in the manner explained in the construction of these views of the hexagonal prism, the edges of the faces in this case all meeting in the vertex which is placed 5″ above the middle of the line representing the base.

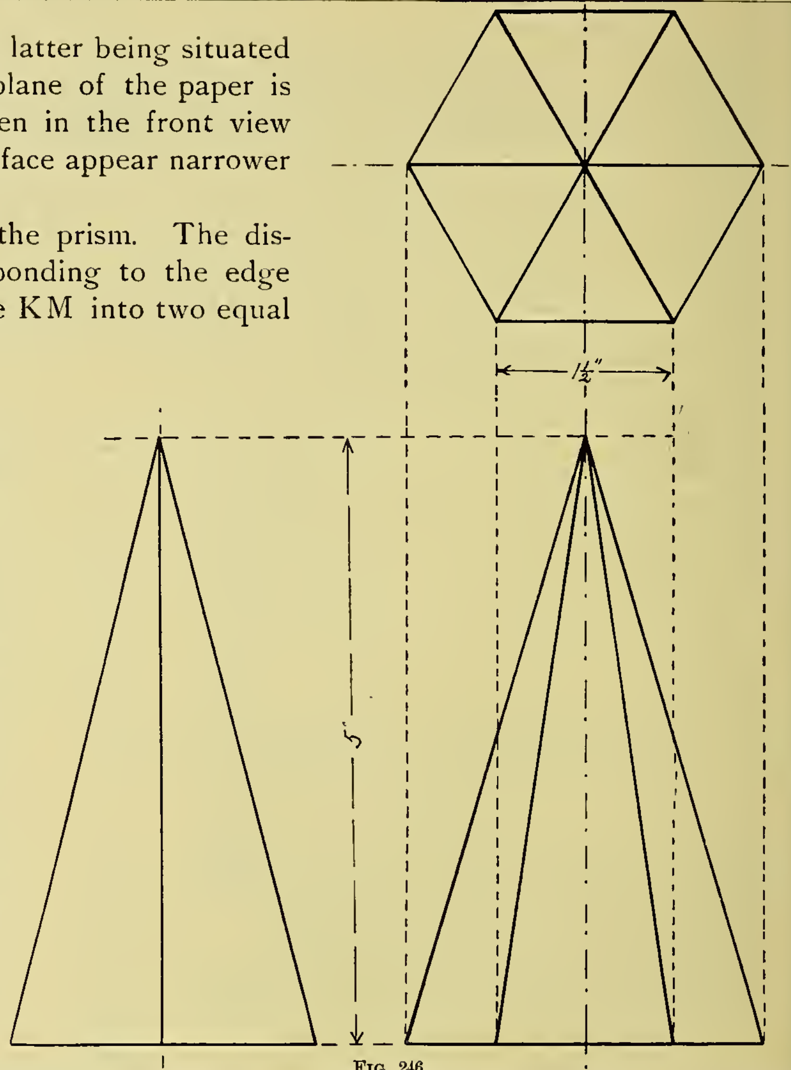


Fig. 246.

To draw a top view and a front view of an octagonal prism. Let each side of the octagonal bases be equal to one inch and let the height of the prism be 8″.

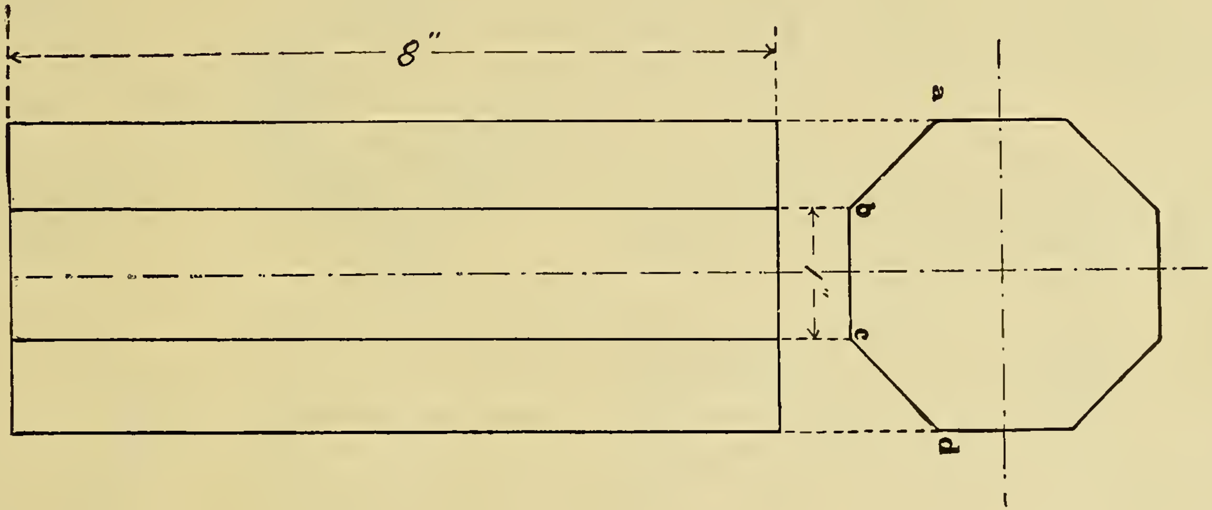


FIG. 247.

Draw the top view first. Fig. 247 shows the required views. The top view is an octagon, each side of which is equal to one inch. The front view is drawn by projecting vertical lines from the points a, b, c, and d of the octagon. These vertical lines form the vertical edges of the faces of the prism.

To complete the front view, intersect these lines by two horizontal lines 8″ apart. The side view of this figure is identical with the front view.

Fig. 248 shows three views of a sphere, each of which appears as a circle.

The lines, AB, CD, EF and GH are center lines. They are composed of long and short dashes, alternating, and are usually extended indefinitely beyond the outlines of the views.

Center lines are drawn through the middle of the view in all cases where such a line will divide the view into two perfectly equal parts so that one part will have all its details situated opposite the corresponding details of the other part, so that if the paper on which the view is drawn is folded along the center line, all parts in one half of the view will cover exactly all corresponding parts in the other half of the view.

We say then that the view (or object) is *symmetrical with regard to the center line.* In Fig. 245 the top view and the front view are symmetrical with respect to the center line CD.

The top view, however, may be folded along the line AB, and in this case the lines of the hexagon on one side of the line AB will exactly cover the lines in the other half of the hexagon ; we see then, that the hexagon is symmetrical in regard to the center line AB also.

In all cases where a view is symmetrical in respect to two lines, both of these lines must be drawn. Wherever the view is symmetrical to one line only, not more than one center line must be drawn ; in Fig. 248 all views are symmetrical to both horizontal and vertical center lines ; center lines continued from one view to the other show that the views belong together, just as projection lines would indicate the same.

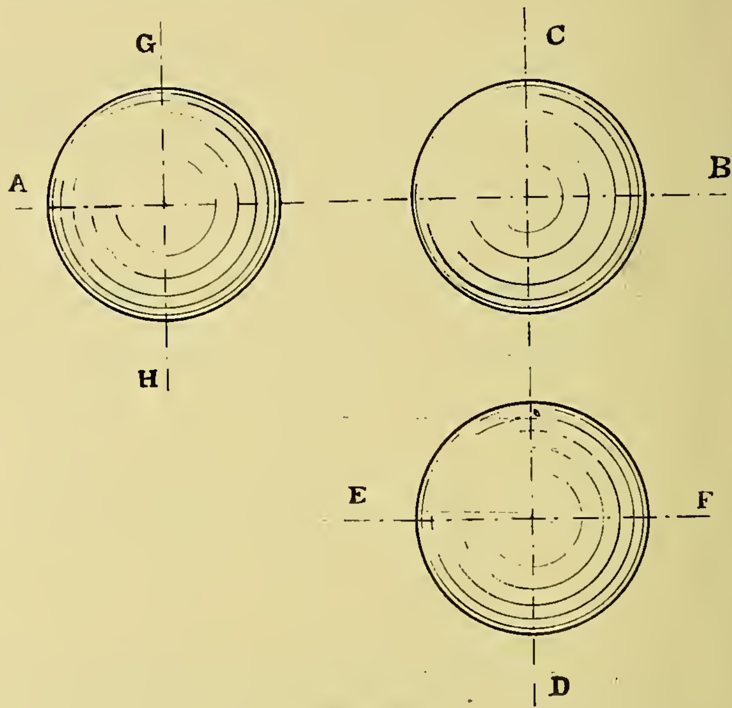


Fig. 248.

A center line should never be used as a dimension line, but such lines may be laid off from the center line on both sides of it.

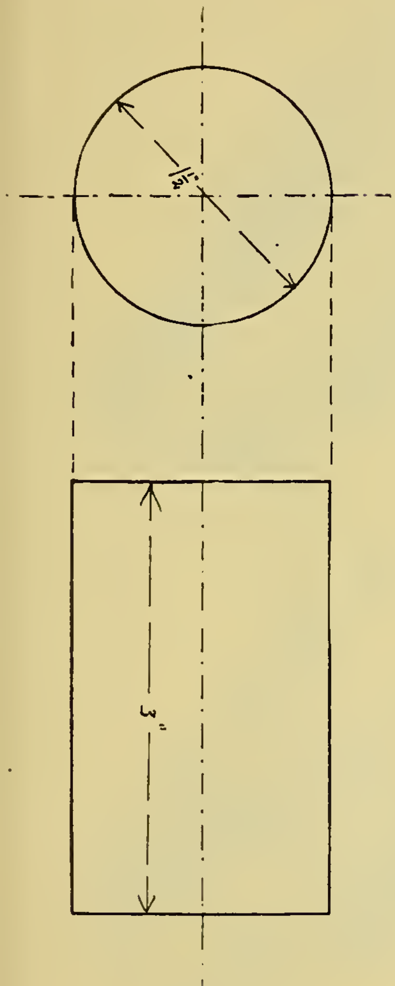


FIG. 249.

In Fig. 249 is shown the top view (or plan) and front view (or elevation) of a cylinder, 3" high and 1½" in diameter. The top view is a circle 1½" in diameter, the front view a rectangle 3" by 1½". All side views of the cylinder are the same.

As in all figures standing on a base of an irregular shape, the top should be drawn in this case before the front. The width of the front view is determined by projection lines from the top view; observe that the top view has two center lines, a horizontal and vertical one; the front view has only one line of symmetry, the vertical.

Draw the front view and side view of a cylindrical pipe 8" long, outside diameter 4", inside diameter 3"; in Fig. 250 the required views are shown.

The two dash lines in the front view show the inside walls of the pipe, which are represented in the top view by the smaller circle.

Fig. 250 may also represent two views of a pipe into which a cylinder has been inserted. We have here an interesting illustration of a case where two views of an object, a front view and a top view, do not define sufficiently the true character of the object represented. A similar difficulty may arise with most hollow objects, and it is evident that some method must be devised to overcome any

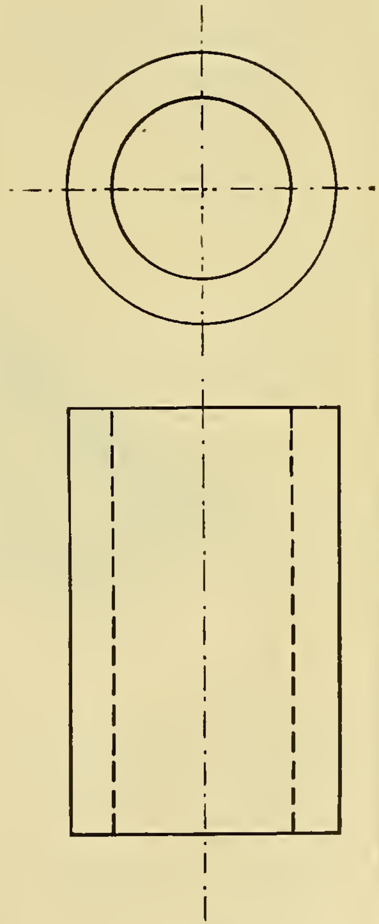


FIG. 250.

such misunderstanding as to the true nature of the object represented.

This may be done by representing the front view of the pipe as if it were cut in half like the cylinder

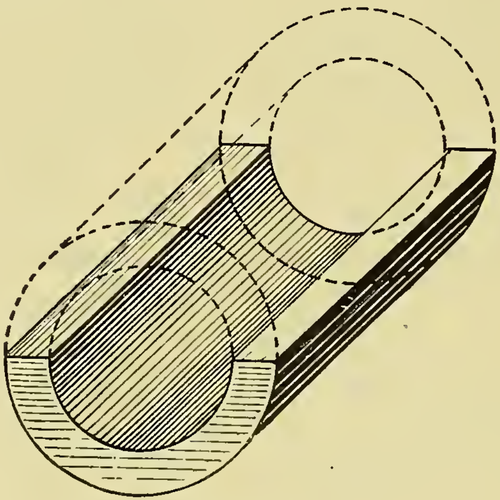
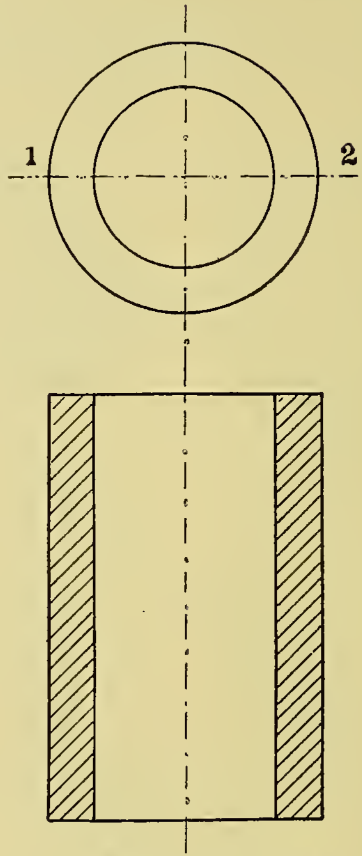


FIG. 251.

shown in Fig. 251; a front view of such a pipe cut in half is shown in Fig. 252; the top view is that of a whole pipe. The line 1–2 shows the manner in which the cylinder is supposed to be cut, and is called *the line or plane of section.*

The front view in Fig. 252 we call the section view or section on 1–2. *The line of section should be made up of dashes alternating with two dots.*



Section on 1-2.

FIG. 252.

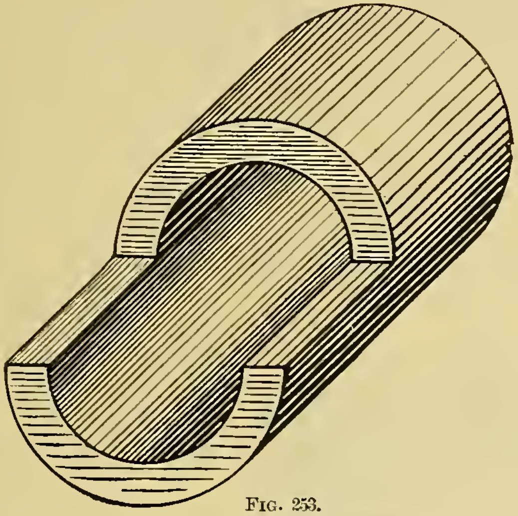


FIG. 253.

The inner part of the material of the pipe exposed by cutting, is covered by lines about $\frac{1}{16}$th

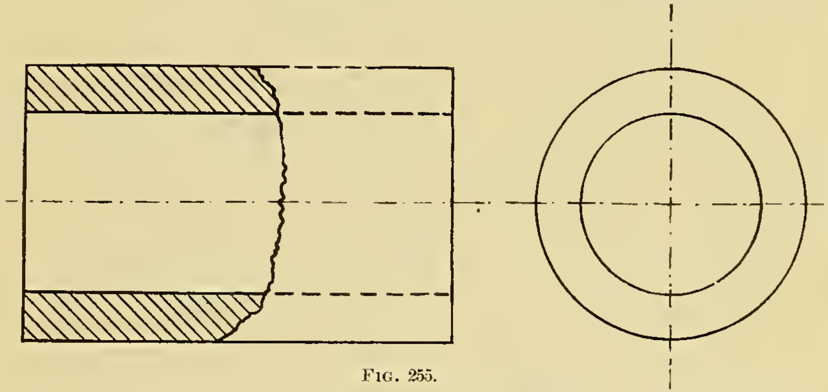


FIG. 255.

inch apart and inclined 45 degrees. Fig. 253 shows the same pipe with only a portion of its upper half cut away; in Fig. 255 is shown this partial section of the pipe.

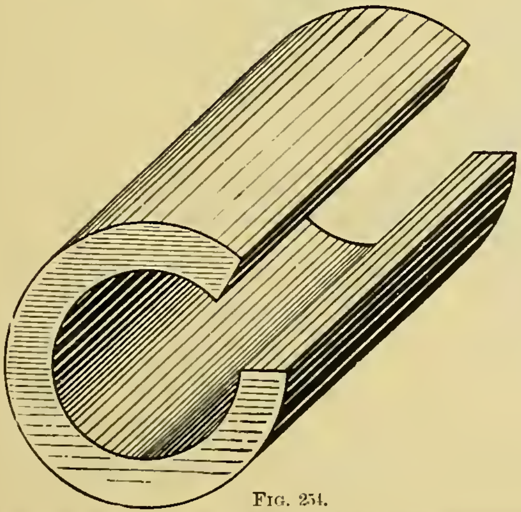


FIG. 254.

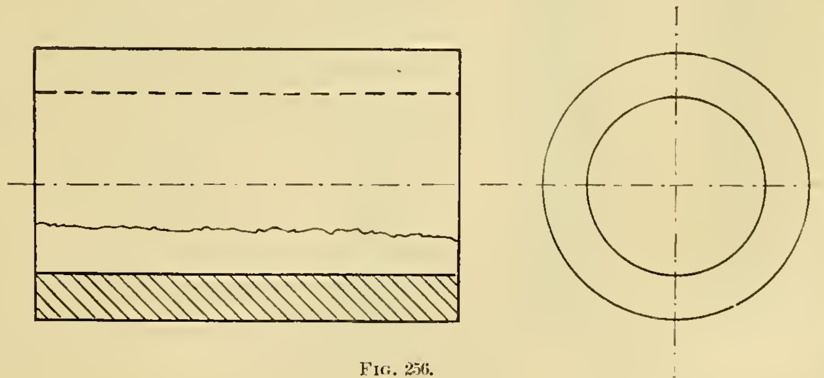


FIG. 256.

In Fig. 254 is shown still another way of cutting the pipe, and in Fig. 256 appears the corresponding front view, with a similar partial section.

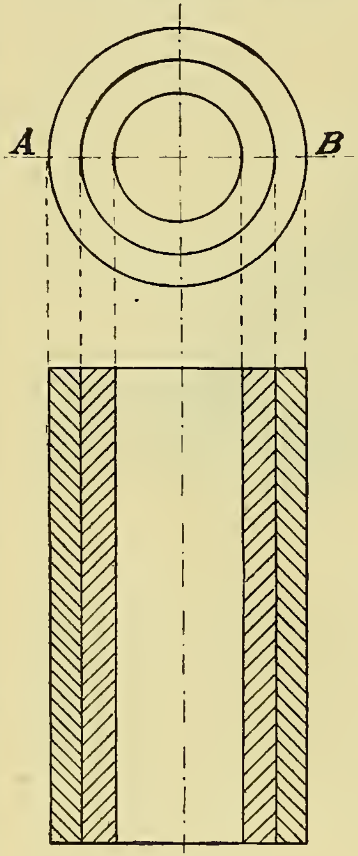


FIG. 257.

Within the pipe described in the preceding problem (8″ long, 4″ outside and 3″ inside diameter) is placed another pipe 8″ long, 3″ outside diameter and 2″ inside diameter.

Draw the top view and section of these two pipes. The top view (Fig. 257) shows three circles, 4′, 3″ and 2″ in diameter; the section on the line AB shows one-half of one pipe within the half of the other pipe. The section lines in the one pipe run in a different direction from those in the other; this is done in order to show more distinctly that there are two separate pipes.

Draw two views of a cylindrical ring.

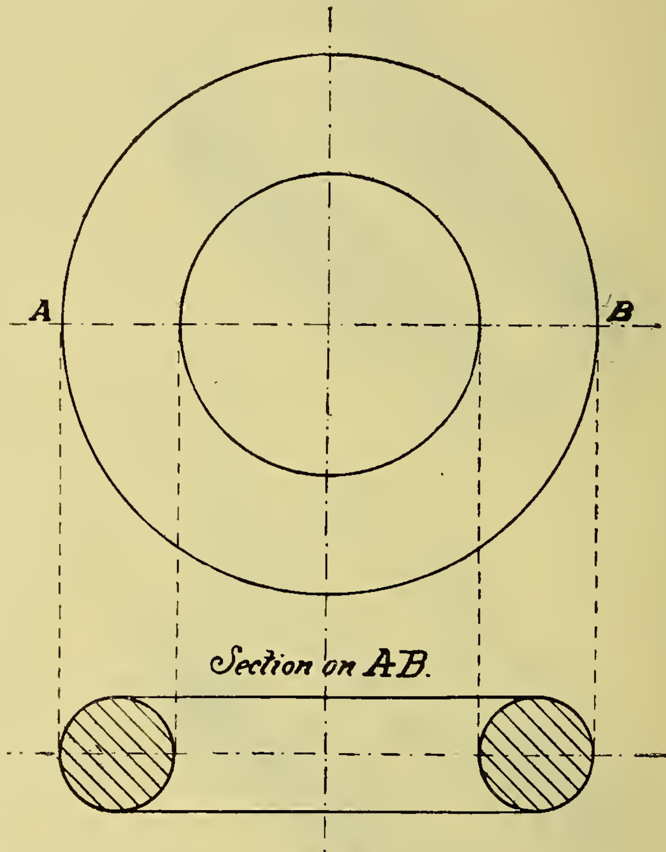


FIG. 258.

Fig. 258 shows the plan and section of such a ring. The drawing does not require any special explanation.

Draw two views of the cylinder with square flange shown in Fig. 259.

Let the side of the cylinder be 10″ long (entire length) outside diameter 4″, inside diameter 3″, and the flange 6″ by 6″ and ½″ thick.

The flange has four bolt holes, each ½″ in diameter.

The top view and section of this figure are shown in Fig. 260.

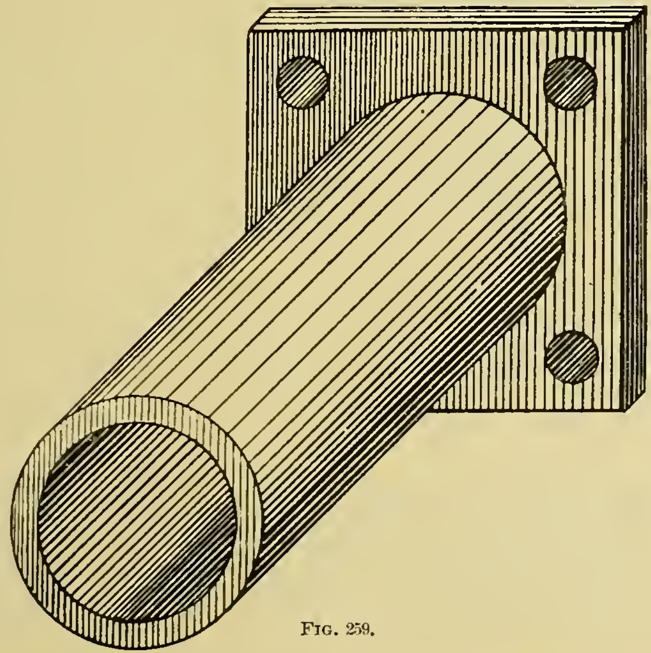


FIG. 259.

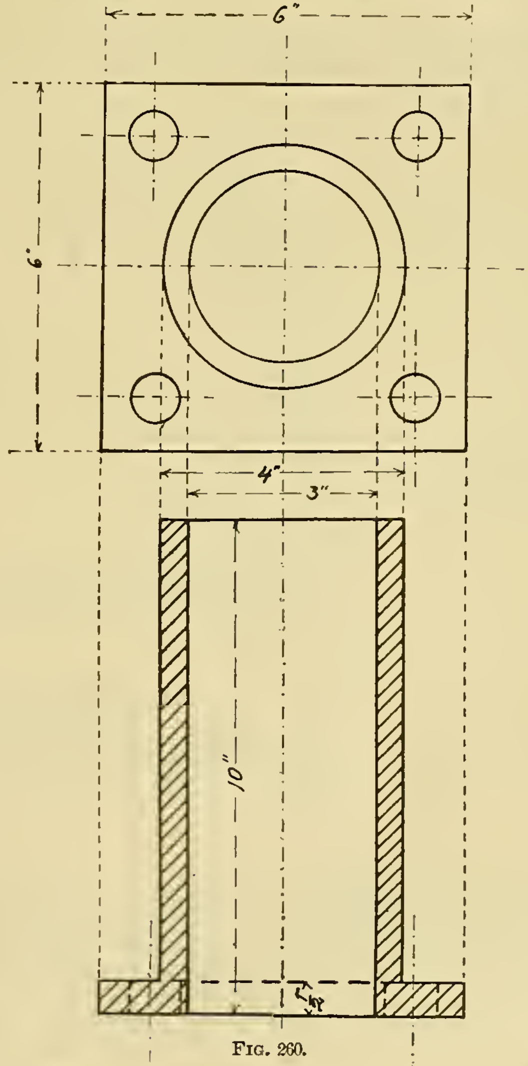


FIG. 260.

Fig. 261 shows the top view and two sections of a bed plate.

view, is a section parallel to the short side of the bed plate and is called *a cross section or a lateral section.*

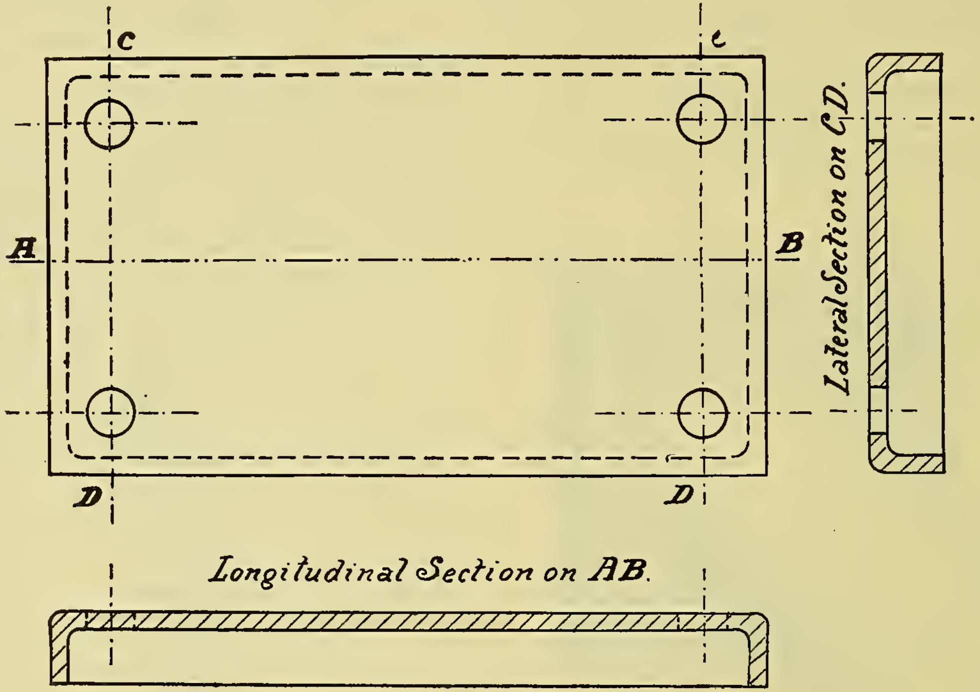


Fig. 261.

The longer section which shows the appearance of the bed plate when cut in a plane parallel to the longest side of it, is called *the longitudinal section.* The other section, placed to the right side of the top

In Fig. 262 is shown a top and front view, and lateral section of a hexagonal nut.

The figure shows an arrangement of views which is frequently adopted in order to economize space.

Fig. 261 is an illustration of the same principle. In that figure the advantage of this method of arrangement is even more striking; the breadth being considerable, as compared to the height, it is evident that, if the lateral section had been placed in line with the longitudinal section, the three would have occupied more space than with the arrangement shown.

In explaining the way in which we derive the different views of an object, we have placed it in Figs. 233, 234, 235 on a table, and in front of the object (a cube in this case) we hold a pane of glass and in all the illustrations, we have placed the pane of glass parallel to one of the faces of the cube.

In the exercises in projection so far taken up, we have placed the object in a similar position; that is, one of the faces of the object was supposed to be parallel to the table or paper on which the drawing was to be made, the sides of the object were either horizontal or vertical and the center lines were also either horizontal or vertical; it is always desirable to select such a position for the object which is to be drawn.

Small parts of machinery, shown in detail drawings, are nearly always drawn in this manner. It may happen, however that some parts of a machine will appear with their sides at different angles to the plane of the paper, or it may even be desirable to place the object in such a position purposely.

Drawings made in this manner, will as a rule, offer more difficulties to the draughtsman, as most

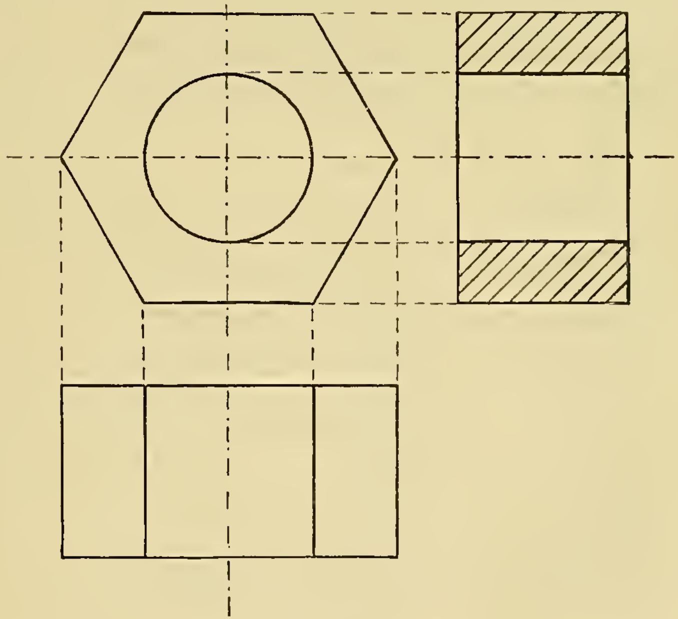


FIG. 262.

views will appear more complicated when the object is placed in an inclined position. The following exercises will show the objects drawn before, now placed at different angles.

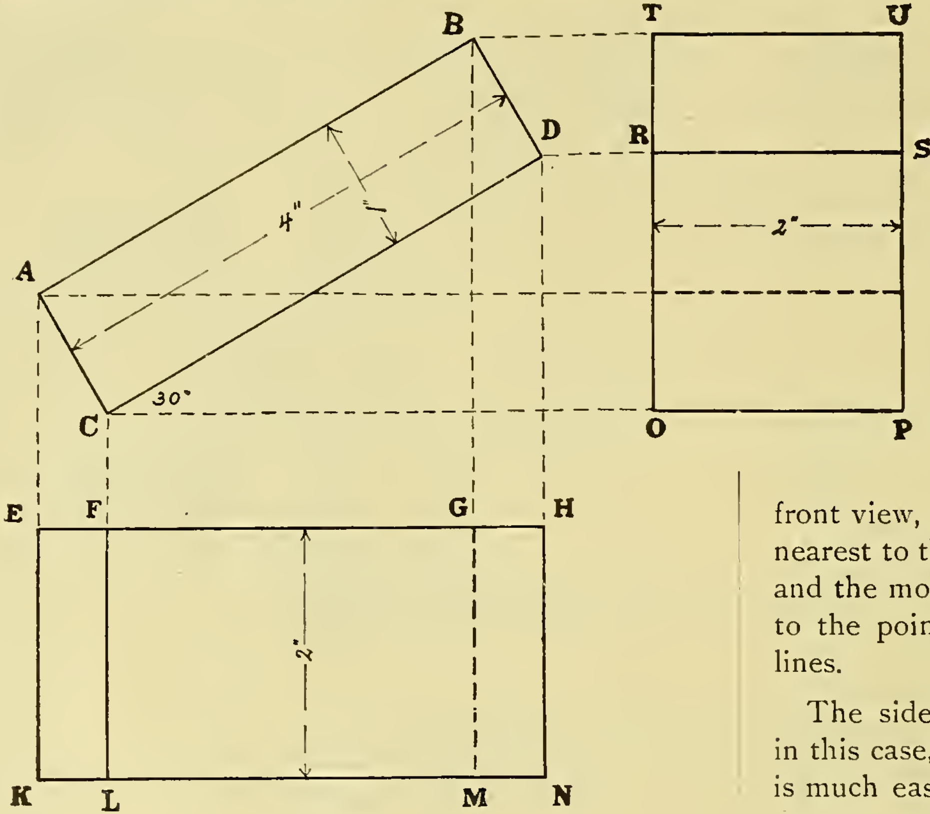


FIG. 263.

Draw a front view, top view and right side view of a prism 4"x 2"x 1" standing with its face 4"x 1" on a horizontal plane, and the long vertical side of the prism forming an angle of 30 degrees with the lower edge of the drawing board.

Draw the top view (plan) first; to do this, draw the rectangle ABCD 4" long and 1" wide, so that the line CD forms an angle of 30 degrees with a horizontal line, Fig. 263.

To draw the front view, draw the horizontal lines, EH and KN 2" apart; from the points ABCD in the top view draw vertical lines cutting the lines EH and KN at the points E, K, F and L, G and M and H and N.

The figure KEFGHNML is the front view, FL being the vertical edge of the prism nearest to the observer, designated in the plan by C, and the most distant (hidden) edge, corresponding to the point B in the plan is MG shown in dash lines.

The side view is placed opposite to the top view in this case, as in this position the construction of it is much easier.

The vertical edges of the prism will appear horizontal in this position of the side view. They are drawn from the points ABCD in the top view and the edges TRO and PSU, being the lower and the upper faces of the prism, are two inches apart.

Draw a front view, side view and top view of the prism described in the last exercise, placed so that the face forming the base of the prism, 4" x 1" is inclined 45 degrees to the paper and the front face, 4" x 2" remains vertical to the paper and parallel to the lower edge of the drawing board. Fig. 264.

Draw the front view first; it is a rectangle 4" long and 2" wide, the long side of which forms an angle of 45 degrees with a horizontal line.

The figure shows plainly how the top view may be constructed by projecting vertical lines from the front view. In the same manner the side view may be drawn, when it is placed opposite the front view, as in Fig. 264.

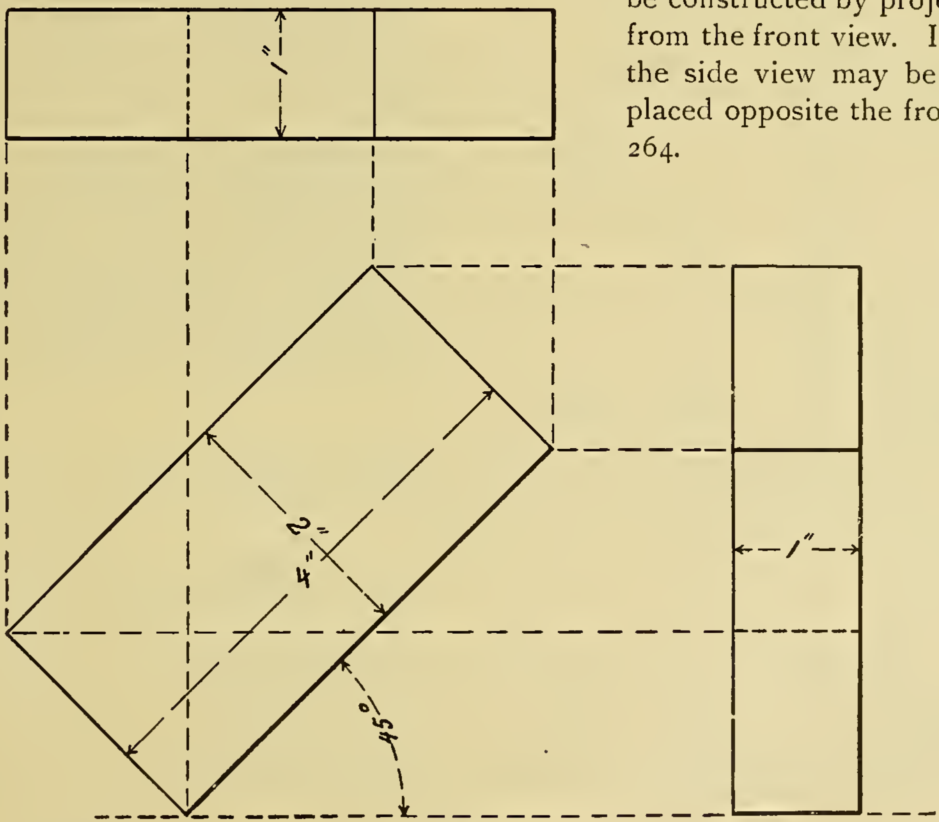


Fig. 264.

Draw the wedge shown in Fig. 265, placed so that the sides of the square corner of it form angles of 45 degrees with the plane of the paper, with both triangular faces vertical to the paper and parallel to the lower edge of the drawing board.

The front view showing the triangular face is drawn first. The two sides of the triangle, which form the right angle (the legs) are drawn at 45 degree angles to a horizontal line.

The construction of the top view and side view is plainly shown in Fig. 265 and requires no special explanation, as they are drawn in the same manner described in the drawing of the top and side views in the two preceding exercises.

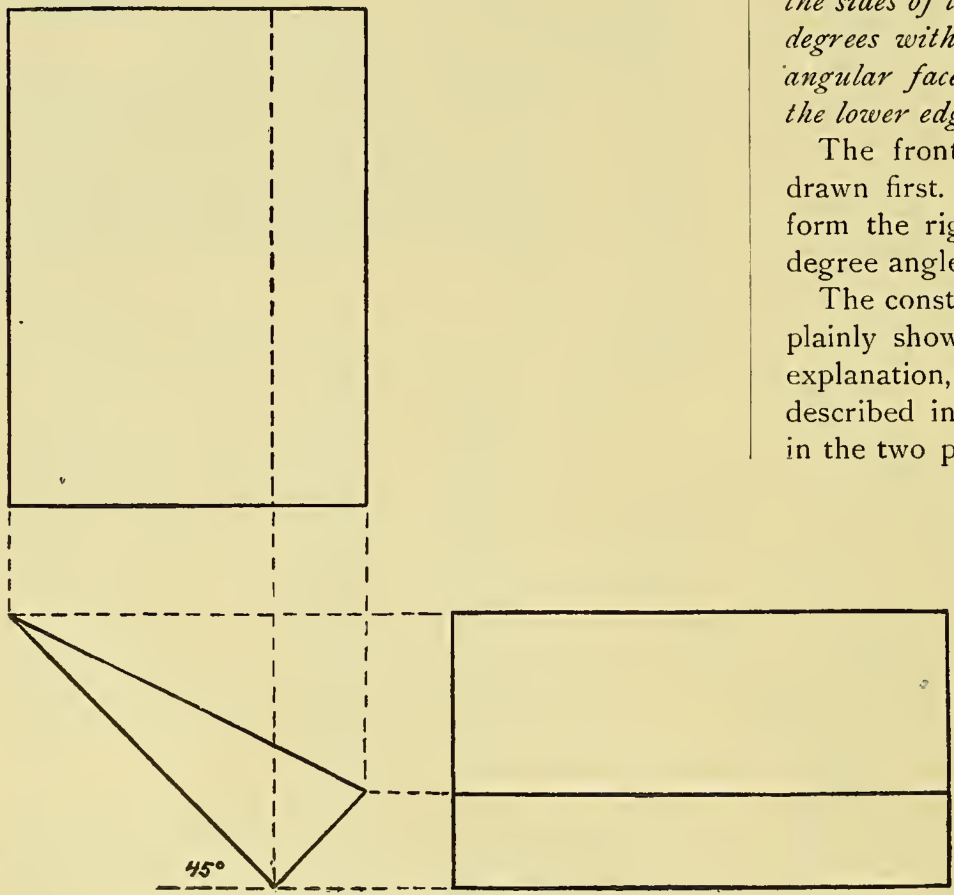


FIG. 265.

The object shown in Fig. 266 is placed with its base upon a horizontal plane (the plane of our drawing) while the two vertical faces visible to the observer, are placed respectively at angles of 30 degrees and 60 degrees to the lower edge of the drawing board.

Let it be required to draw the front view and top view of this object.

Draw the top view first.

To do this, draw the rectangle ABCD, AD parallel and equal to BC, 4″ long, and DC equal and parallel to AB, 2″ long; AD is inclined 30° and DC 60° to a horizontal line, Fig. 266.

To draw the front view, draw the horizontal line FM, and through the points A, B, C and D draw vertical lines meeting the line FM at the points F, H, K and M.

On the side AF set off the distance FE equal to 3″; through the point E draw the horizontal line EG cutting the line BH at G.

On the line MC set off the distance MN equal to 2″ and through the point N draw the horizontal line NL, cutting the vertical line DK at L, join the points E and L, G and N. This completes the required front view; EF and GH are the two longer vertical edges of the object, GH being hidden. LK and MN are the two shorter vertical edges of the object, both visible.

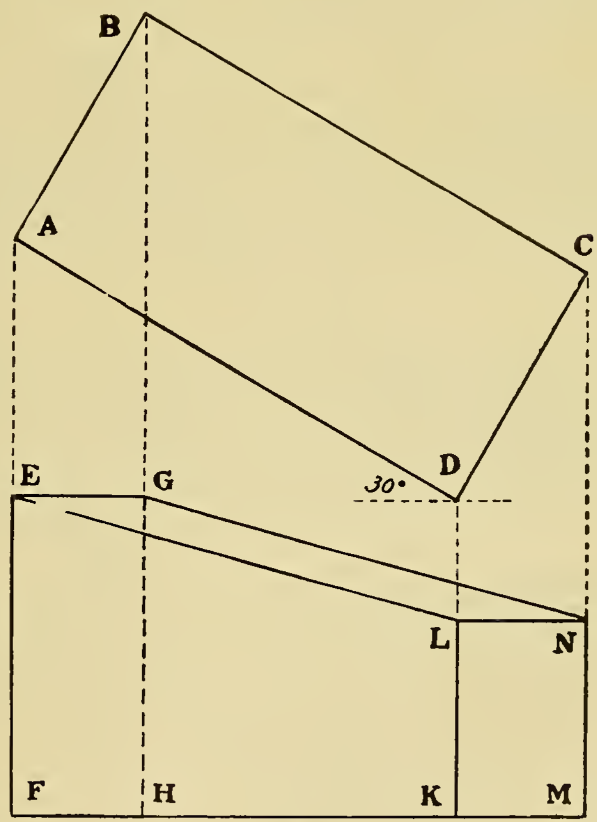


FIG. 266.

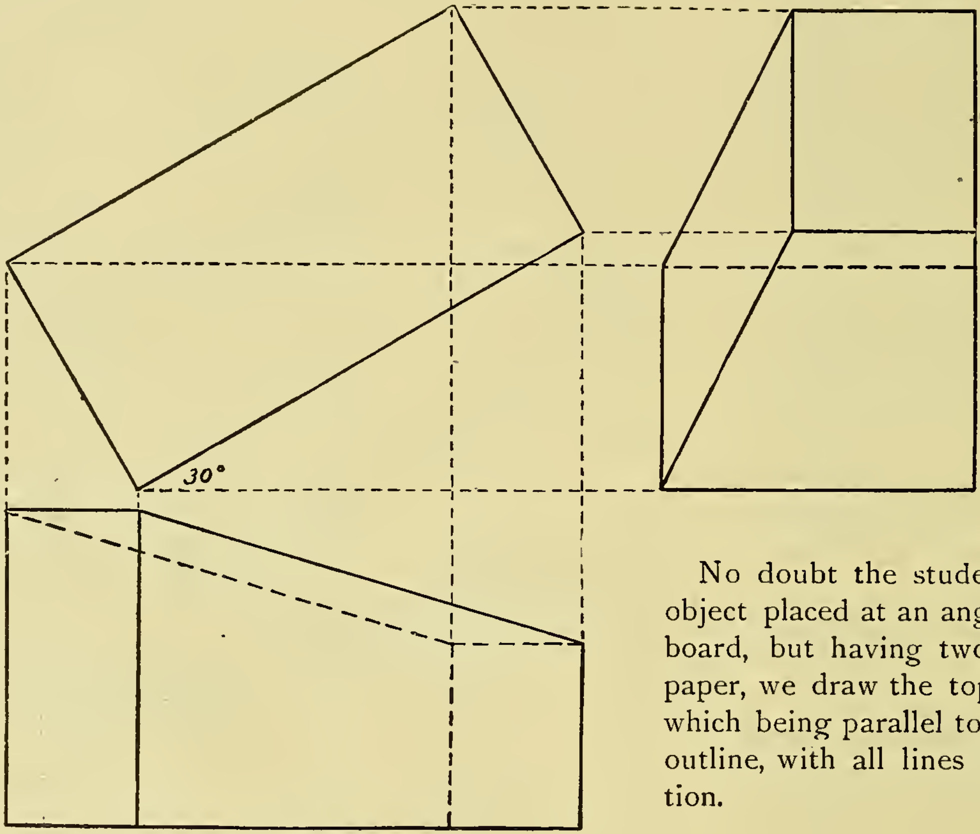


FIG. 267.

In Fig. 267 is shown the front view, top view and side view of the object just drawn.

In this instance the object is placed with its longer vertical edge nearer to the observer; otherwise the position of the object is exactly the same as described in the preceding exercise.

The side view is drawn in a manner similar to the front view, by lines projected from all points (corners) of the top view.

No doubt the student has noticed that in drawing an object placed at an angle to the lower edge of the drawing board, but having two faces parallel to the plane of the paper, we draw the top view first; that is, the view of it, which being parallel to the board, will appear in its simplest outline, with all lines drawn in their true length and position.

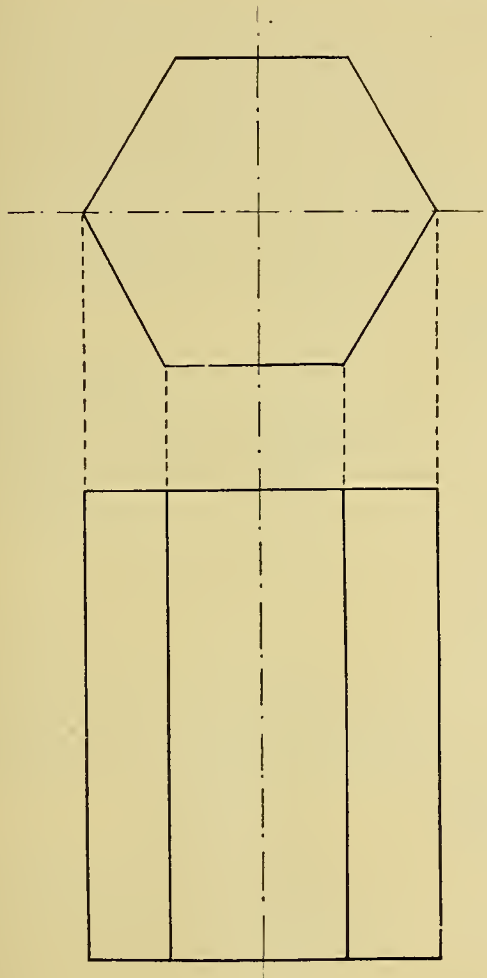


FIG. 268.

To draw the front view and top view of a hexagonal prism, standing upon a horizontal plane and having two of its parallel vertical sides, parallel to the lower edge of the drawing.

Let each side of the hexagon forming the bases of the prism be equal to one inch and the height of the prism be 4″; the top view is drawn first; it is a regular hexagon, length of each side being 1″, Fig. 268.

The front view is drawn by projecting lines from the corners of the hexagon shown in the top view, these lines making the vertical edges of the prism, and then intersecting these lines by two horizontal lines 4″ apart, thus forming the top and the bottom of the prism.

If an object is to be drawn, placed so that it is inclined to the plane of the paper, but having its front face parallel to the lower edge of the drawing board, the front view is drawn first.

As a rule it will be observed that *that view is drawn first, which is drawn easiest*, and especially the view which shows the object in its true form; the other views are drawn by projection from the different points of the view completed.

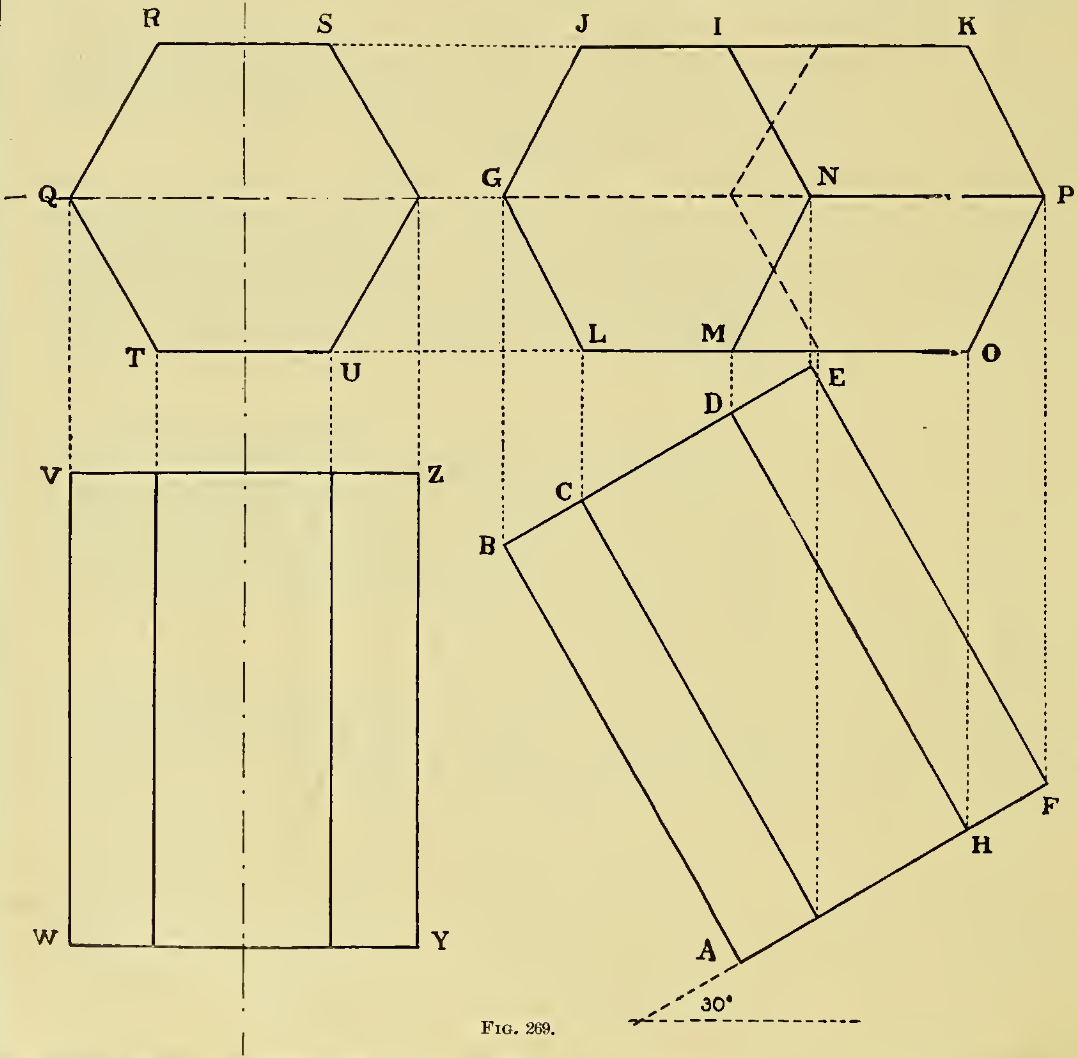


FIG. 269.

Let it be required to draw the top view and front view of the same prism as in the same exercise, but placed so that two of its parallel vertical sides are parallel to the lower edge of the drawing board and the base inclined to the plane of the paper at an angle of 30°.

Draw the front view and top view of the prism, Fig. 269, showing the prism standing in a vertical position; WVZY is this front view and TQRSU is the corresponding top view.

To draw the front view of this hexagonal prism with its base inclined at an angle of 30 degrees, draw a line AF making an angle of 30 degrees with a horizontal line.

Upon this line erect the rectangle which is exactly equal to the front view of the hexagon in its vertical position, as shown in the same figure by WVZY.

To draw the top view, extend the horizontal lines of the top view RS, TU indefinitely; then draw vertical lines through the points B, C, D and E; these lines intersect the horizontal lines RSK and TULO and the center line QGNP in the points, LGJINM forming the upper face of the prism in the required top view.

To complete the top view draw vertical lines through H and F cutting the line JK at the point K, the line GP at the point P and the line LO at the point O.

To draw a hexagonal pyramid, having the sizes of the hexagonal prism in the preceding exercise, and placed in the same position.

The construction in this case is exactly the same as in the last exercise; Fig. 270 shows the required drawing.

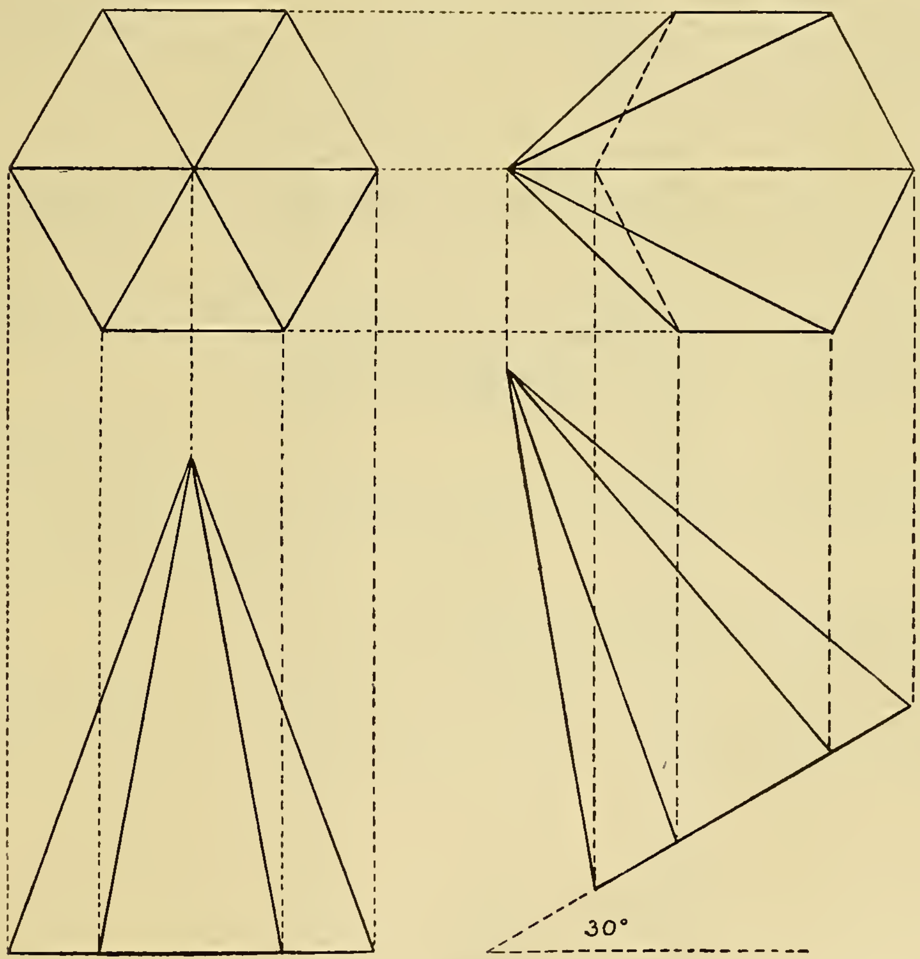


FIG. 270.

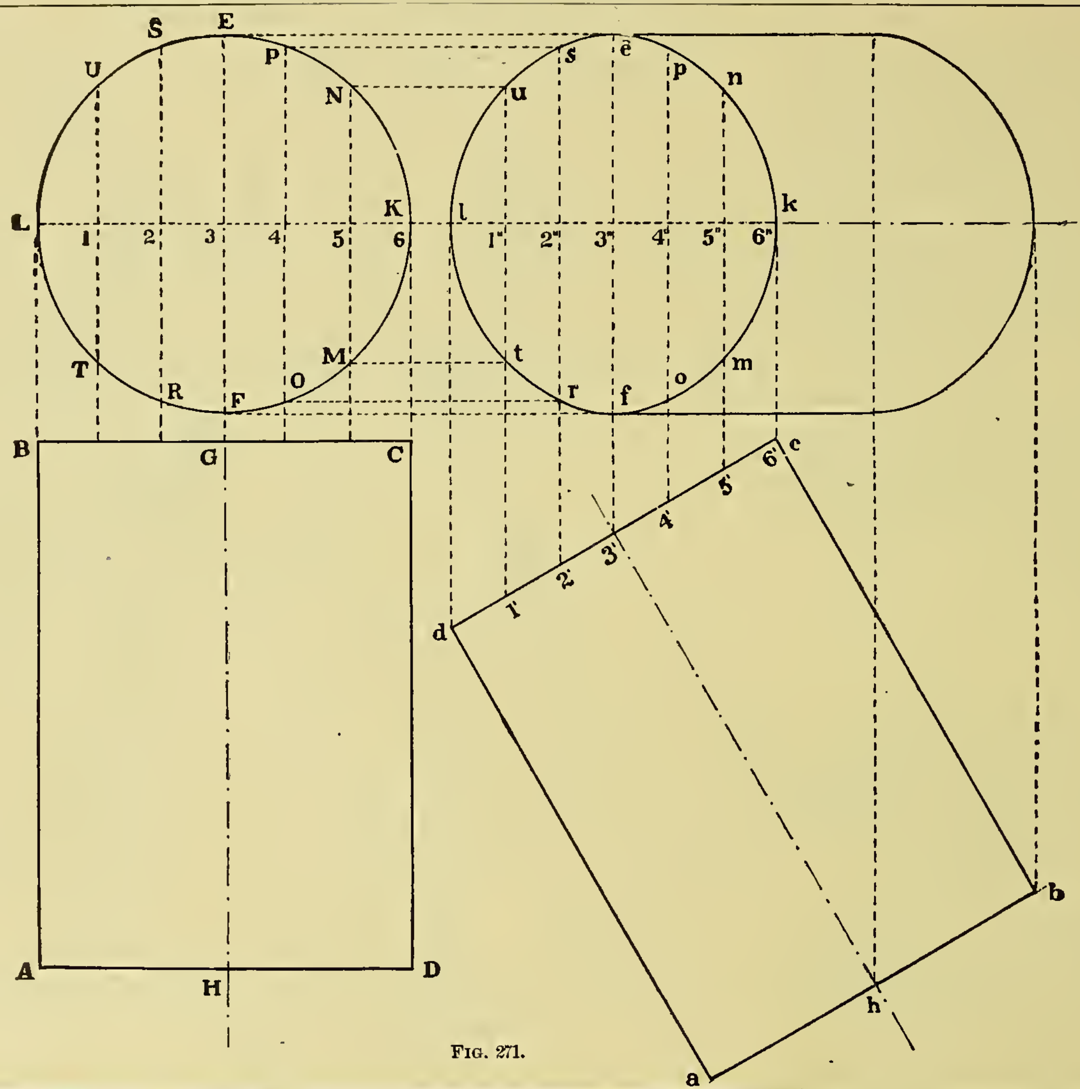


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FIG. 271.

To draw the top view and front view of a cylinder whose axis makes an angle of 60° with a horizontal line and which lies in a vertical plane parallel to the lower edge of the board.

In Fig. 271 ABCD is the front view and EF the top view of the cylinder, when its axis is vertical.

Draw the line 3′h at 60° to the horizontal and let this be the center line of the cylinder in the required inclined position, corresponding to the center line in the front view of this cylinder in its vertical position.

Make abcd equal to ABCD for the required front view. The top view is drawn in the following manner: divide the horizontal diameter KL into any number of equal parts, say six. Through the points of division, 1, 2, 3, 4 and 5 draw vertical lines MN, OP, EF, RS and UT.

Divide the line dc into the same number of equal parts, marked by the division points 1′, 2′, 3′, etc., and draw vertical lines through all these points, as well as through the points c and d.

The vertical lines passing through the points d and c cut the horizontal center line of the top view in the points l and k. The vertical lines drawn through the points 1′, 2′, 3′, etc., cut the center line lk in the points 1″, 2″, 3″, etc.

Through the points E and F draw two horizontal lines cutting the line 3″3′ in the points e and f.

Through the points M and N draw two horizontal lines intersecting the line 1″1′ at the points u and t and cutting the line 5″5′ at the points m and n.

Through the points O and P draw two horizontal lines cutting the vertical lines 2″2′ and 4″4′ at the points s, r, o and p.

A curve traced through the points l, u, s, e, p, n, k, m, o, f, r, t will be the required projection of the upper base of the cylinder.

The lower base may be constructed in exactly the same manner.

To draw the section of a cylinder made by an inclined plane.

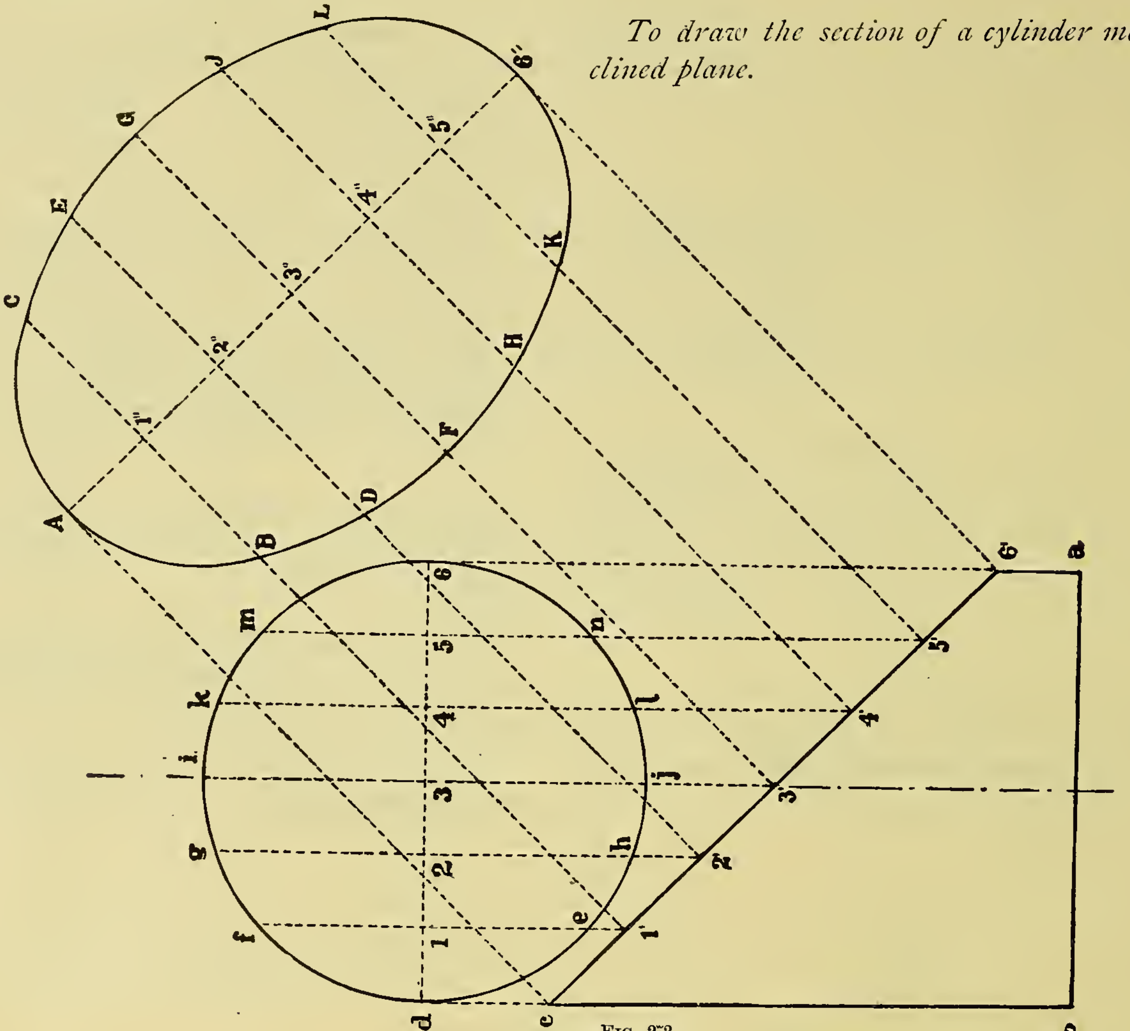


FIG. 272.

The front view of such a cylinder is shown in Fig. 272 by abc6′, where the line c6′ shows the inclination of the plane which makes the section. Above the front view is shown the top view of the cylinder as the circle dgmne.

To draw the form of the section, divide the horizontal diameter d6 into any number of equal parts.

In Fig. 272 this diameter is divided into 6 equal parts.

Through each one of the division points thus obtained, draw vertical lines, which intersect the circle at the points f and e, g and h, i and j, k and l, m and n; the same vertical lines will cut the inclined line c6′ at the points 1′, 2′, 3′, etc., which points will divide the line c6′ into six equal parts.

Through the points c, 1′, 2′, 3′, 4′, 5′, 6′ draw lines perpendicular to the line c6′; at any convenient distance from this line draw the line 6″A parallel to it, and this line will be cut by the perpendiculars at the points 1″, 2″, 3″, 4″, 5″, thus being divided into six equal parts the same as the parts of the line c6″.

Now set off B1″ equal to 1″C each equal to 1f; the same distances set off from the point 5″, making KL equal to BC.

Lay off 2″E equal to 2″D and each equal to 2g, and the same distances set off from the point 4″, making JH equal to ED; then make 3″G equal to 3″F and each equal to 3i so that ii is equal to FG. This line FG is the minor axis and the line A6″ is the major axis of an ellipse, which may be traced through the points ACEGJL6″KHFD and B and which forms the required section.

It will be noticed that the section of a cylinder made by a plane which does not intersect any of the bases of the cylinder, and which is not parallel to the bases (that is, perpendicular to the center line), is *an ellipse*; when the cutting plane is parallel to the bases the section produced is *a circle*, just like the bases; when the cutting plane passes through the center line the section is *a rectangle*, two opposite sides of which are equal each to the height of the cylinder.

An ellipse may be produced also by cutting a cone by a plane which does not intersect the base of the cone, as in Fig. 273, where the line ab indicates the cutting plane.

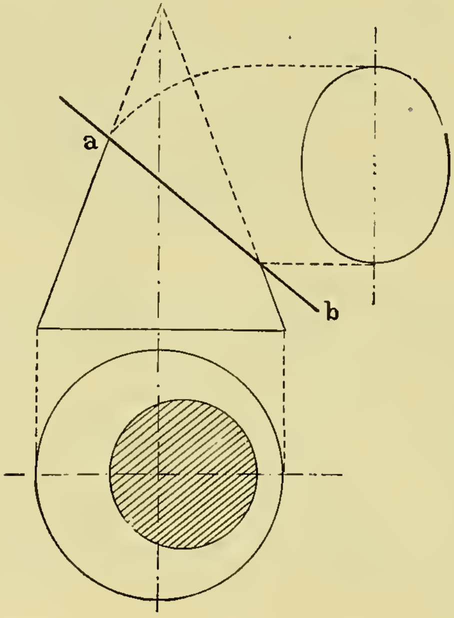


FIG. 273.

When the cutting plane, ab, Fig. 274, is parallel to the line cd, then the figure produced in section is a curve known as *the parabola*. Such a curve is shown in Fig. 275.

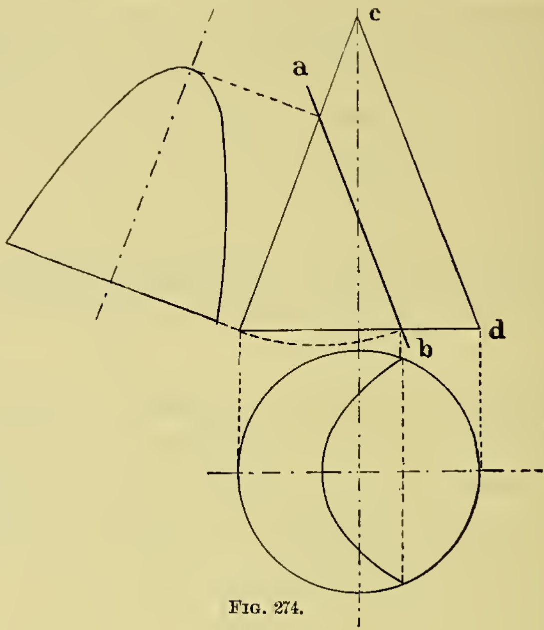


FIG. 274.

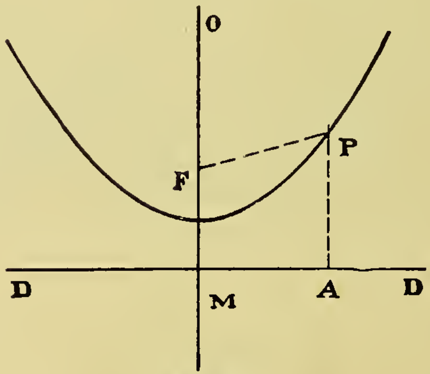


FIG. 275.

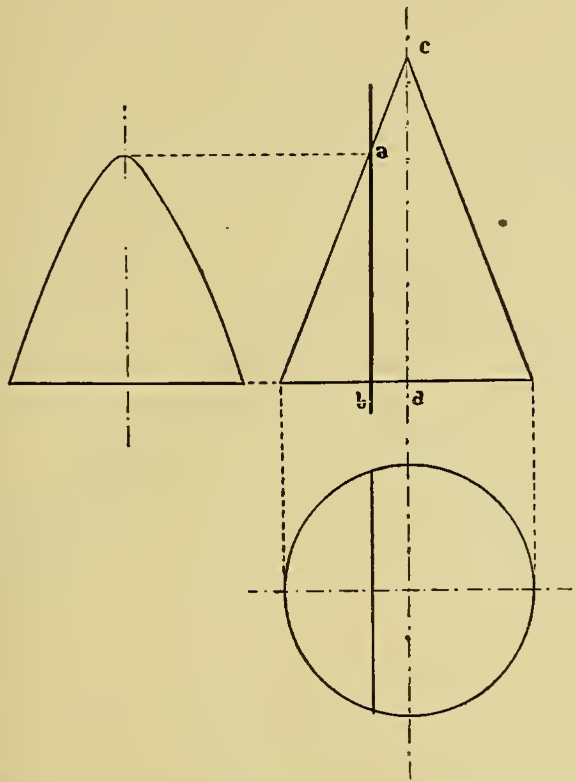


FIG. 276.

Any point, P, of the parabola is equally distant from the line DD and from the focus F, so that FP is equal to PA.

When the cutting plane intersects the base of the cone and is not parallel to any one of the lines on its surface, the curve produced in a section is called *a hyperbola.* In Fig. 276 ab indicates the cutting plane. A hyperbola is shown in Fig. 277.

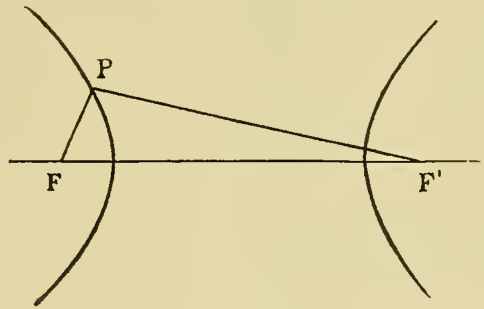


FIG. 277.

The distance between the distance PF′ of any point in the hyperbola from one of the foci, and the distance, PF, the distance of this point to the other focus, must always be equal to a given line.

In the chapter on geometrical drawing several methods have been explained in which an ellipse may be drawn; the way to draw a hyperbola has also been shown. Of these curves the ellipse is ofttimes encountered in mechanical drawing.

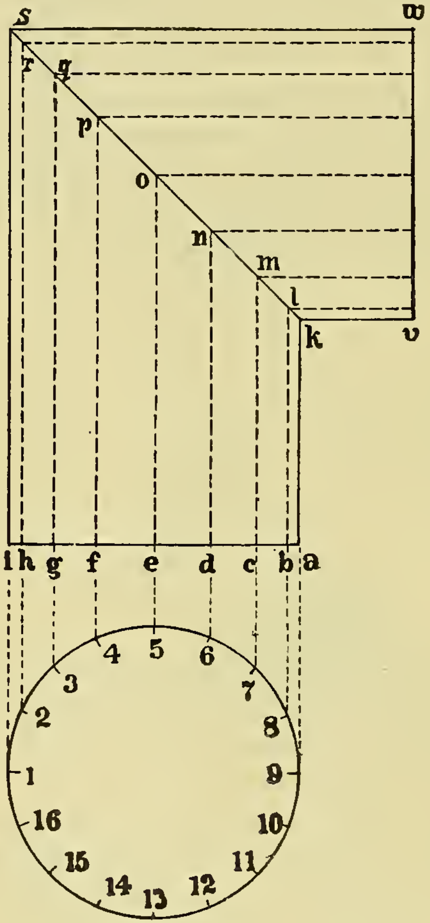
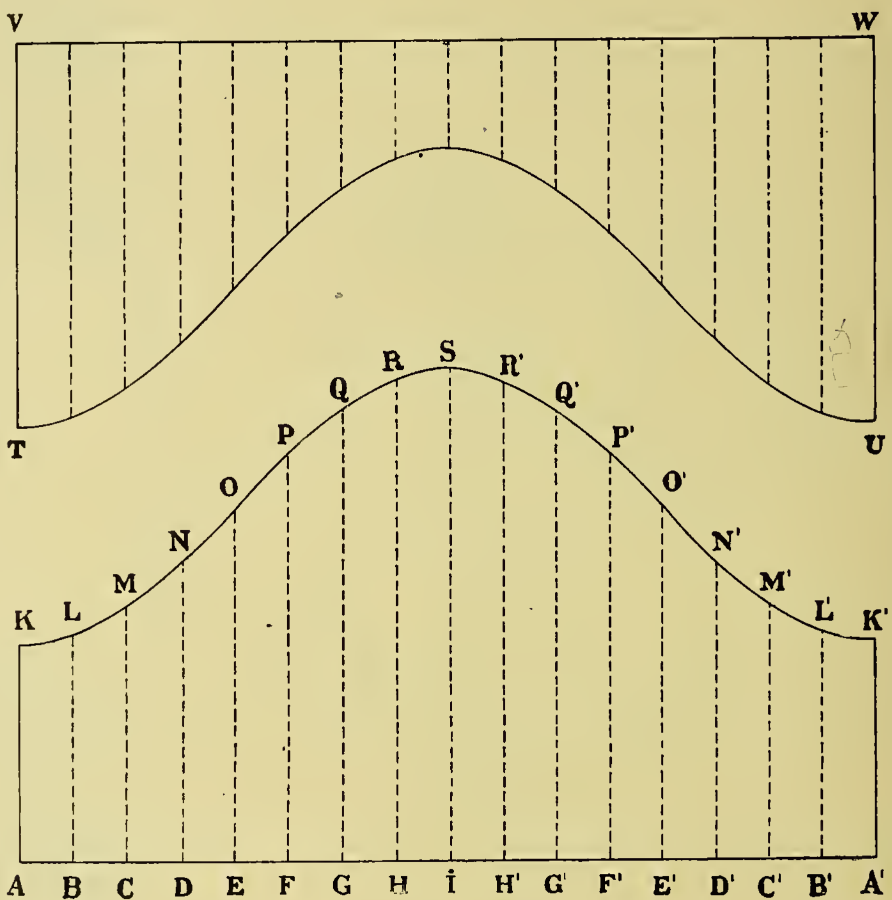


FIG. 278.



FIGS. 279 AND 280.

DEVELOPMENT OF SURFACES.

The principles of projection just explained may be readily applied to the very important problem of development of surfaces.

Whenever it is necessary to make an object of some thin material like sheet metal, as in the case of boiler connections, etc., the surface of the desired object is laid out on sheet metal, in one or in several pieces; these are called the patterns of the object; the pattern being first laid out on the sheet metal and then cut out; when this is done the separate pieces are ready to be fitted together to form the required object.

The method by which the surface of an object is laid out on a plane is called *the development of the object.* A few exercises will sufficiently acquaint the student with the methods used in problems of this character.

To draw the development of a right elbow, Fig. 278.

A right elbow is made by joining two pieces of pipe for the purpose of forming a right angle. It is really *an intersection of two cylinders of equal diameters;* the center lines of the two cylinders meeting at one point, and as the joint is to be a right elbow, the center lines must be perpendicular to each other.

Now, to draw the development of a cylinder, proceed as follows:

Divide the circumference of the cylinder into any number of equal parts, and through the points of division draw lines parallel to the center line of the cylinder.

On these parallel lines mark the points which belong to the curve of intersection with another cylinder, or any other figure as happens to be the case, and then roll out the surface of the cylinder into a flat plate. The rolled-out surface will be equal in length to the circumference of the cylinder, and it will contain all parallel lines, which were drawn upon the cylinder, with spaces between them just equal to the actual space between the parallel lines which were drawn upon the surface of the cylinder.

By marking the points of intersection on the parallel lines in the rolled surface, the development of the cylinder or its part is obtained. In Fig. 278 the circle showing the circumference of the pipe is divided into any number of equal parts by the divisions 1, 2, 3, etc. Lines are drawn through these divisions parallel to the center line of the vertical portion of the joint. These lines are ak, bl, cm, dn, etc.

The points k, l, m, n, o are the points on the parallel lines designating the curve of intersection.

The development of the two branches of the right elbow are shown in Figs. 279 and 280; the length of the development, VW (or AA′) is equal to the circumference of the figure shown in Fig. 278. To obtain this length all spaces, 1, 2, 3, 4, etc., laid out upon the circle in Fig. 278 are set off upon a straight line; these spaces are marked in Fig. 280 by A, B, C, etc., perpendiculars AK, BL, CM, etc., are drawn through the points A, B, C, etc. The perpendicular AK and K′A′ in Fig. 280 are each equal to ak in Fig. 278. The second lines on each side of the development, the lines BL and B′L′ are equal to bl, Fig. 278.

The third lines on each side of the development, the lines CM and C′M′ are equal to the third line cm, Fig. 278.

The fourth lines in the development are made equal to the fourth parallel in the elevation, Fig. 278, and in the same manner all other lines in the development are made equal to the corresponding parallels in the elevation of the pipe in Fig. 278.

The middle line, SI in the development is made equal to the line si in the elevation; the points KLMSM′L′K′, etc., thus found, define the position of the curve of intersection in the development of the cylinder.

The required curve is traced through these points; the development AA′K′K is the pattern for the part aksi of the right elbow shown in Fig. 278.

The other part of the elbow is developed in Fig. 279. It will be readily seen that the figure TVWU is laid out in the manner in which the first development was obtained; in this figure the shortest parallels are laid off above the longest parallels in the first development. This arrangement gives the advantage of cutting out both branches of the right elbow from one square piece of sheet metal without any waste of material.

It will be noticed that the patterns shown in Figs. 279 and 280 do not provide for the lap by which the two branches are held together. A lap of any desired width may be added to the pattern, after it is constructed by drawing an additional curve, parallel to the curve of the above pattern, the distance between the two curves being equal to the width of the desired lap.

To draw the pattern of a tee-pipe in which all branches are of equal diameter.

In Fig. 281 is shown the front view and the side view of a tee-pipe. It is made by the intersection of two cylinders of equal diameters; the section of the cylinders is represented in the front view by two 45-degree lines, ad and dg.

To develop the pipes divide the circle in the end view, Fig. 282, into any number of equal parts, in this case let it be twelve parts.

The greater the number of these divisions the more accurate will be the resultant pattern.

Through the divisions 1, 2, 3, etc., draw horizontal lines cutting the horizontal cylinder in the side view in the points 1″1′, 2″2′, 3″3′, 4″4′, 5″5′, 6″6′, 7″7′; the line 4″4′ just meets the lines of the section in the point d. The line 5″5′ cuts the lines of the section in the points e and c, the line 6″6′ cuts the section lines in the points f and b and the line 7″7′ cuts the lines of the section in the points g and a.

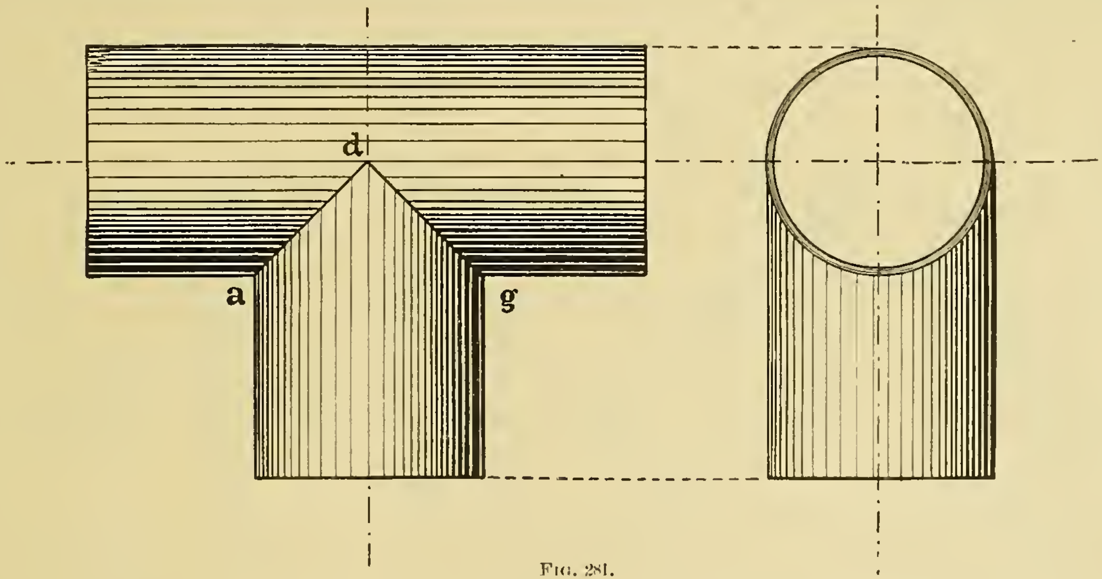


Fig. 281.

Draw vertical lines through the points a, b, c, d, e, f and g. After all these lines are drawn we have all that is necessary to complete the development of the cylindrical surfaces.

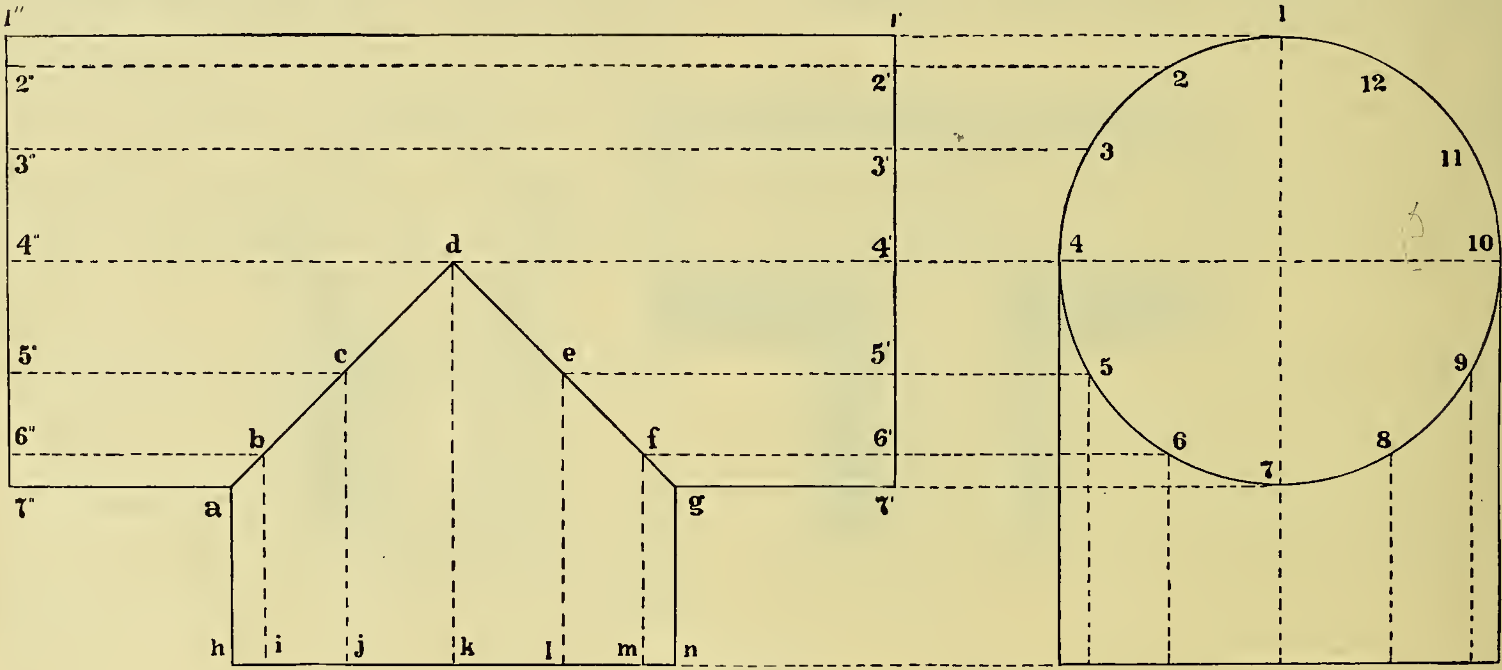


Fig. 282.

Fig. 283 shows the development of the horizontal cylinder; the rectangle ABCD is equal to the cylinder surface. The curve ODGL is cut out within the rectangle for the joint which is the outline of the opening, into which the vertical cylinder will fit.

The rectangle ABCD has one side AB equal to the length of the horizontal cylinder, Fig. 282; the other side AD is equal to the circumference of the circle, showing the end view of the horizontal pipe, Fig. 282. The twelve divisions marked on the circle are set off on the straight line AD (Fig. 283) so

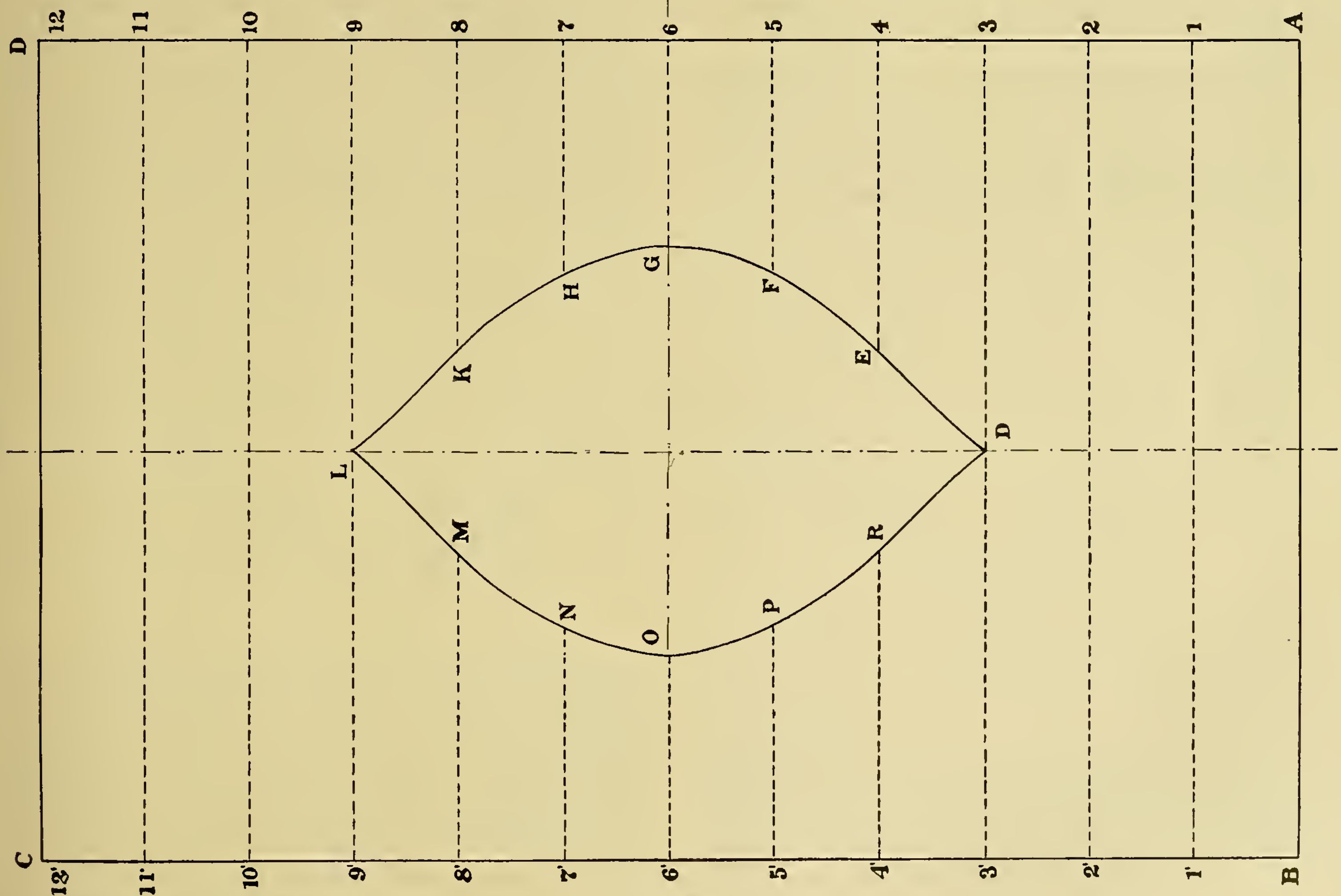


FIG. 283.

that together they are equal to the circumference of the circle.

The outline of the opening for the intersection of the horizontal pipe with the vertical branch is laid out in the middle of the rectangle ABCD in the following manner: On the middle line 6′6 are set off the distances 6′O and 6G each equal to g7′ (or a7″) in Fig. 282, on the lines 5′5 and 7′7 are set off the distances 5′P, 5F, 7′N and 7H each equal to the distance 6′f, Fig. 282 (or b6″). The distances 4′R, 4E, 8K and 8′M are set off on the lines 8′8 and 4′4, to equal the distance e5′ (or c5″) of Fig. 282. The lines 3′3 and 9′9 are touched by the curve of intersection in their center at points D and L.

There still remains to be drawn the development of the vertical branch of the tee-pipe; this is found in the same manner as the horizontal part, *i. e.*, by laying out the surface of the vertical cylinder; that is, by making it equal in length to the circumference of the circle showing the end view of the cylinder. The development is shown in Fig. 284.

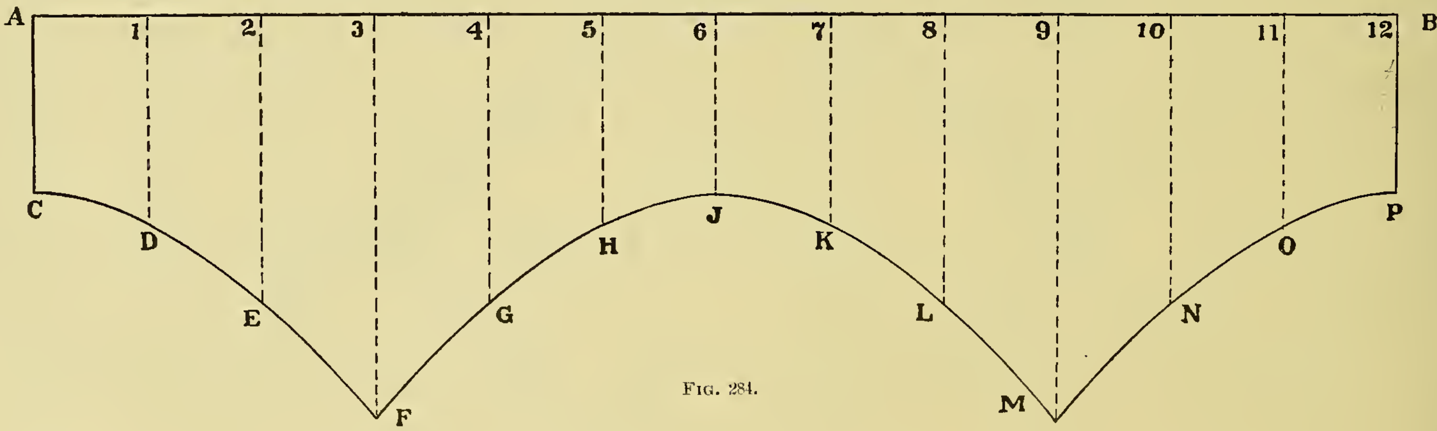


Fig. 284.

On the line AB are set off the twelve parts of the circumference and in each one of these divisions is erected a perpendicular to the line AB; on these perpendiculars are laid off successively the length of the vertical lines drawn on the surface of the vertical branch; the lines AC, 1D, 2E, 3F, G4, 5H and 6J in Fig. 284, are equal correspondingly to the lines ah, bi, cj, dk, el, fm and gn in Fig. 282.

Thus one-half of the development ACJ6 is constructed; the other 6JP12 is exactly equal to the first part.

The method employed in these cases may be applied to nearly all developments of cylindrical surfaces; it consists in drawing on the surface of the cylinder, which is to be developed, any number of equidistant parallel lines. The cylindrical surface is then developed and all parallel lines drawn in it. *By setting off the exact lengths of the parallel lines a number of points are obtained, through which may be traced the outline of the desired development.*

It has been noted in Fig. 282 that the intersection of two cylinders of equal diameters—their arcs intersecting each other—will always appear in the side view as straight lines at right angles to each other. If one cylinder is of a smaller diameter than the other then the intersection will be a curve.

Now, let it be required to find the intersection of two cylindrical surfaces when the smaller cylinder passes through the larger one, their axes intersecting each other. The front view, top view and end view of such two intersecting cylinders is shown in Fig. 285.

The larger cylinder is marked by the letter B in all views, the smaller one by the letter A.

Divide the circle in the top view into any number of equal parts, say twelve, marking the divisions of the numbers 1, 2, 3, 4, etc. Through these points draw vertical lines cutting the small cylinder in the side view in the points t, u, v, w, x, y and z.

Divisions exactly like those made by these points will be set off now on the small cylinder in the end view by the points a, b, c, d, etc., through which vertical lines are drawn cutting the larger cylinder in the points e, f, g, h, etc. Extend the line u 12 downward until it meets a horizontal line drawn through g. These lines give the point k at their intersection.

The point l is obtained by drawing the line v 11 downward until it intersects with a horizontal line drawn through the point f; the point m is obtained by cutting the line 10 w, extended downward, by a horizontal line drawn through the point e.

Thus one-half of the required line of intersection, as it appears in the side view, indicated by the points s, k, l, m, is obtained, the other half, m, n, o, p is exactly the same as the first and may be drawn in a similar way.

NOTE.—Such a line of intersection is one which is frequently encountered in mechanical drawing and it is advisable to retain a good idea of its form. In drawing joints or intersections of this kind, it will not be required, as a rule, to lay out the section in the above accurate manner. Keeping in mind the true section of two cylindrical surfaces of different diameters, the student should be ready to sketch the required section freehand, approximately true to suffice for practical purposes. This is done first in pencil and then in ink.

The intersection in this case, as well as in similar cases, where the precise form is required, should be traced through the obtained points carefully and then inked in with the aid of an irregular curve; for ordinary purposes the section may be represented by an arc of a circle, somewhat approaching the curve laid out in pencil.

The development of the upper branch of the smaller cylinder is shown in Fig. 287. The line AC contains twelve equal divisions, each equal to one division in the circle in the top view, Fig. 285; the length of the line AC is therefore equal to the circumference of the circle, which represents the top view of the smaller cylinder.

Through these divisions on the line AC are drawn perpendiculars which are made suc-

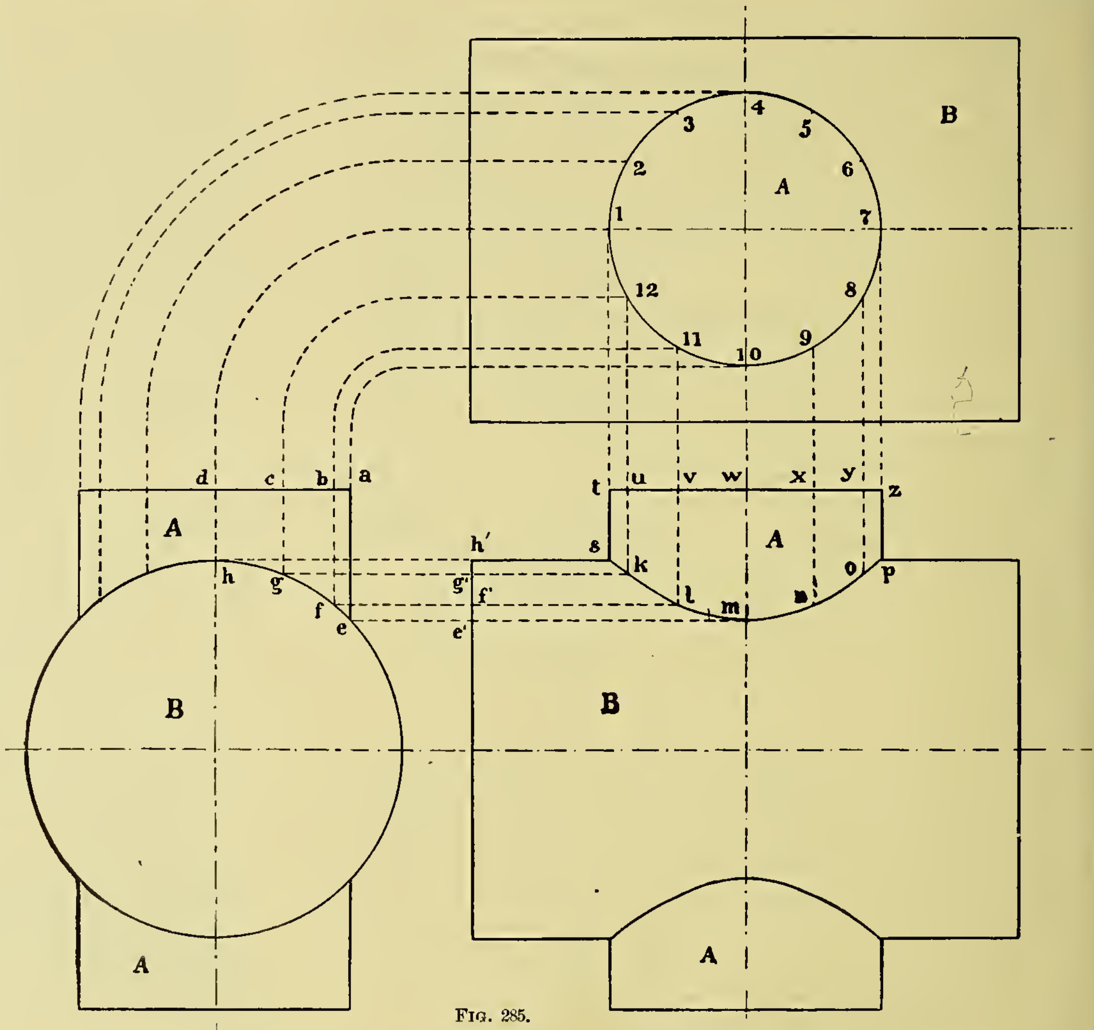


FIG. 285.

cessively equal to the lines st, ku, lv, mw, nx, oy, and pz; in this manner one-half, ADEB of the desired development of the smaller cylinder is

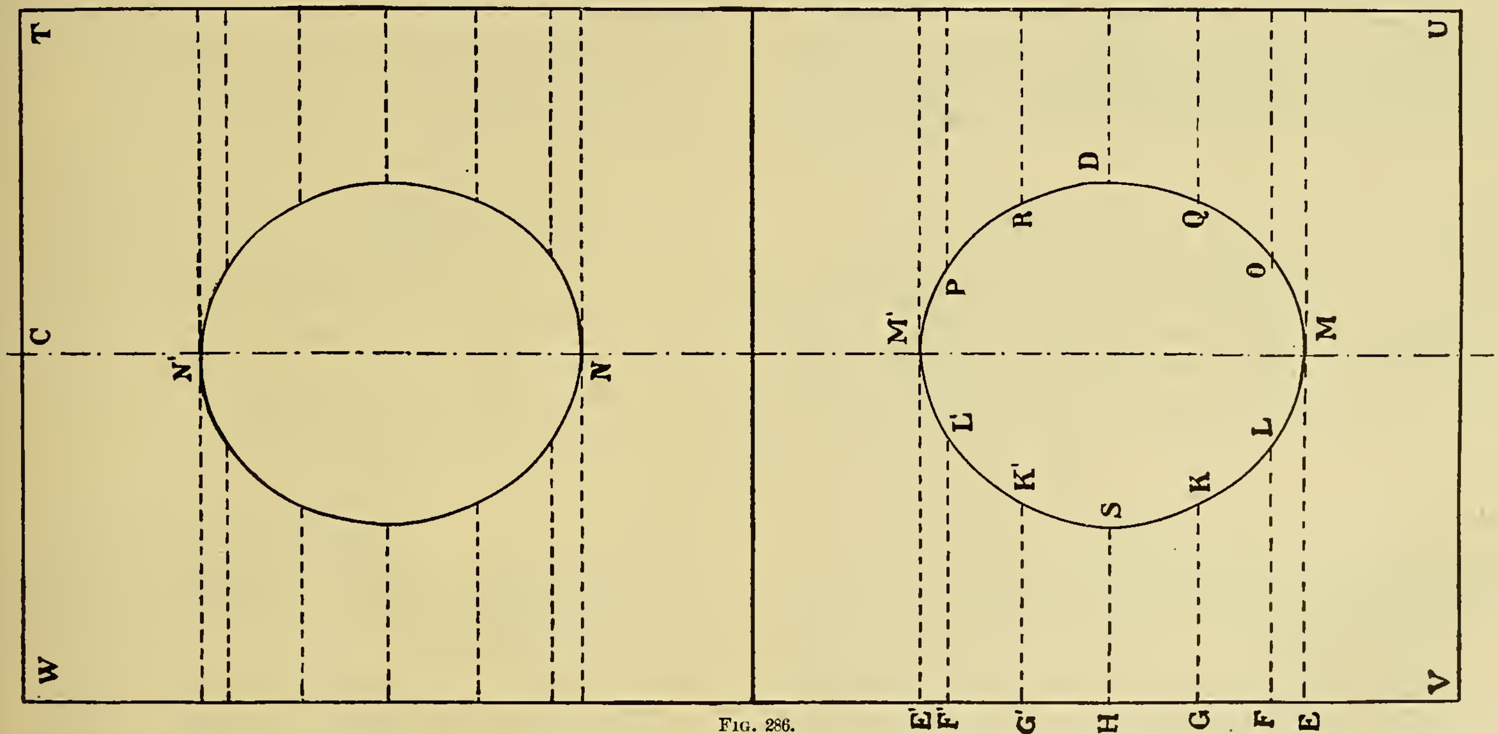


FIG. 286.

obtained; the second half BEFC of the development is an exact duplicate of the first half.

The development of the larger cylinder is shown in Fig. 286. The surface of this is represented by the rectangle VWUT, VU being equal to the length of the cylinder and VW to its circumference. It may be divided into two equal parts, one for the upper half of the cylinder, containing one opening for the upper branch of the smaller pipe, and the other half an exact duplicate of the first one, containing an opening for the lower branch of the smaller cylinder.

To find the outline of the opening, draw the center line C M′ M for both halves, and the line HD at right angles to CM in the middle of the first half of the cylinder.

On the line VW below the point H set off the distances HG, GF and FE equal to the distances hg, gf, and fe in Fig. 285; the same distances are laid off above the point H, on the same line, so that HG′=HG, G′F′=GF and F′E′=FE.

Draw lines parallel to HD through the point E, F, G, G′, F′, and E′ and on these lines set forth the distance H S equal to h′s (in Fig. 285) GK and G′K′ each equal to g′k in Fig. 285; FL and F′L′ each equal to f′l in Fig. 285 and the distances EM and E′M′ each equal to e′m in Fig. 285. Thus one-half, MLKSK′L′M′ of the opening is obtained.

The other half of the opening is exactly the same as the first, and is laid off in the same way on the other side of the line M′M. The curve MLKSK′L′M′PRDQO is the complete opening for one branch of the smaller cylinder. In the other half of the same figure a similar opening NN′ is laid out for the other branch of the smaller pipe.

The rectangular piece, VWTU, with the two openings. MM′ and NN′, is the required pattern of the larger cylinder.

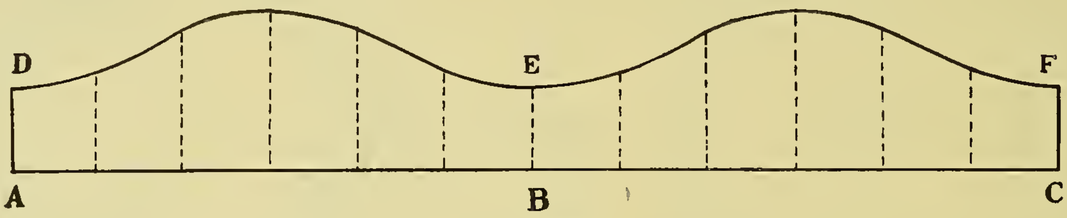


FIG. 287.

To draw the development of a four-part elbow.

A four-part elbow is a pipe joint made up of four parts, such as is used for stove-pipes; in Fig. 288, the four parts forming the elbow are AKSI, KXTS, XYZT and YZfd; of these four parts the

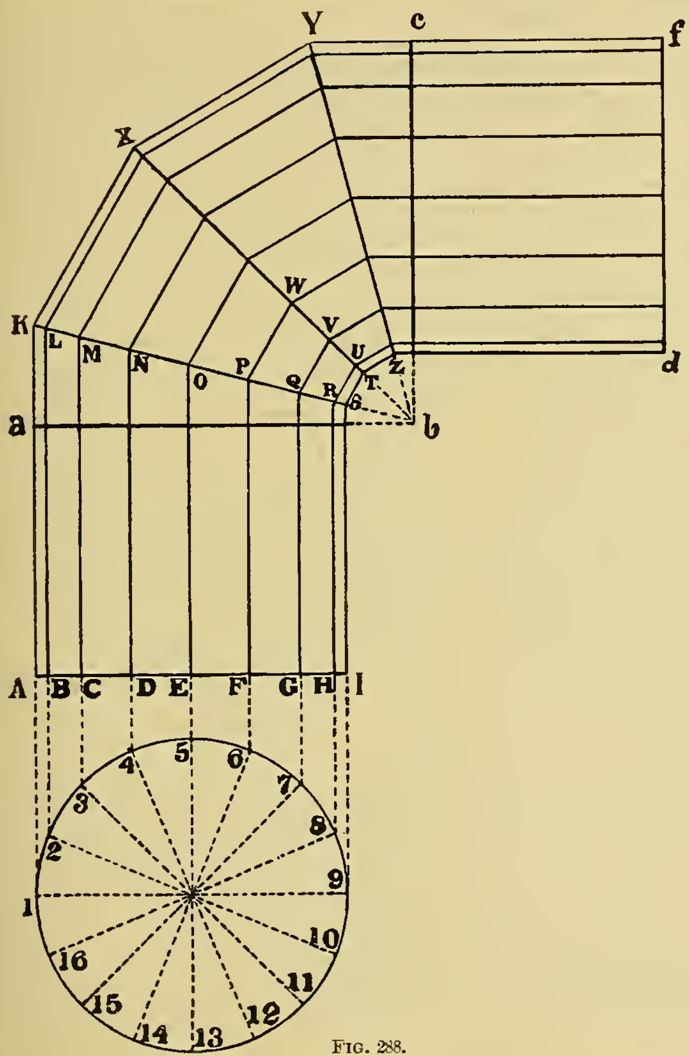


Fig. 288.

two larger parts, AKSI and YZfd are equal. The same is true of the two remaining smaller parts, KXTS and XYZT.

To lay out these parts in the elevation a right angle abc is drawn. the sides of which intersect at right angles, the two largest branches of the joint. It is evident that the point b must be equidistant from both pipes.

The right angle abc is divided first into three equal parts and then each one of these parts is divided in turn into two equal parts; the right angle is thus divided into six equal parts, of which Kba is one part, KbX equals two parts, XbY equals two parts and Ybc one part. It will be noticed that this construction does not depend on the diameter of the pipe.

The problem of developing the four-part elbow resolves itself into developing two only of its parts, one large branch and one smaller part of the elbow, the remaining parts being correspondingly equal to these.

The circumference of the pipe, Fig. 288, is divided into sixteen equal parts by the points 1, 2, 3, 4, 5, etc.

Through these points are drawn lines parallel to the center line of the pipe which is to be developed.

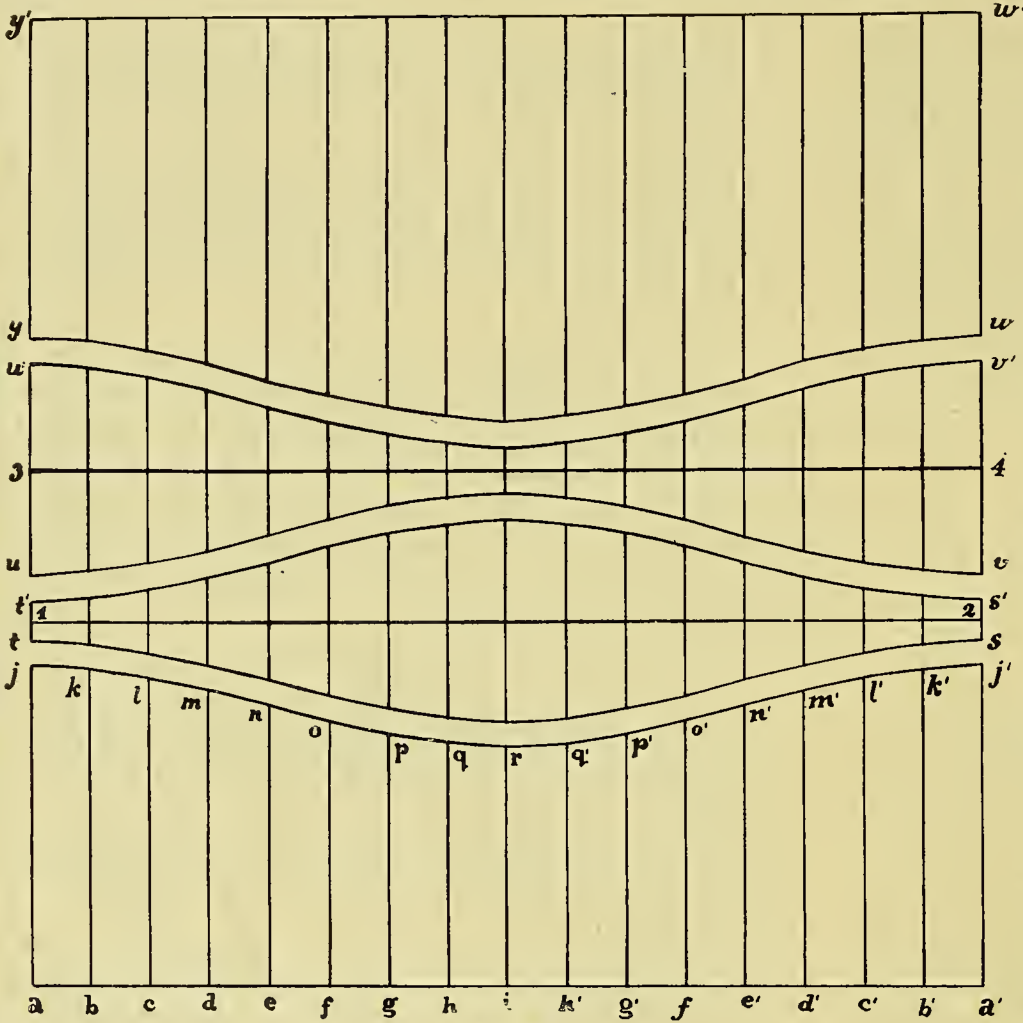


Fig. 289.

In Fig. 289 the vertical branch of the elbow, AKSI, will be taken up for the purpose. The parallels upon the surface of this branch are AK, BL, CM, DN, EO, FP, GQ, HR and IS. Through the points K, L, M, N, O, P, Q, R and S draw parallels for the part KXTS, which will be next developed; some of these parallels are ST, RU, QV, PW.

To develop the vertical branch of the four-part elbow set off, upon a straight line aa', Fig. 289, sixteen equal parts, which altogether are equal to the circumference of the cylinder, which is to be developed.

Let the division points, a, b, c, d, e, f, etc., correspond to the division points, 1, 2, 3, 4, etc., upon the circle, Fig. 288. Through the points, a, c, b, d, e, etc., draw vertical lines equal to the parallel lines drawn upon the surface of the vertical branch of the joint; thus aj is made equal to AK (Fig. 288) bk equal to BL; cl equal to CM and so on until ri is made equal to SI (Fig. 288).

The part laid out so far is ajklmnopgri. This is one-half of the development; the other half, irj'a' being exactly the same as the first one, may be laid out in the same way.

The part tt'ss' is the development of the small part of the elbow. It is evident that its length, ts, must be equal to the circumference of the pipe in the elbow. The lines in the pattern, tt'ss' drawn at right angles to the center line of it, and bisected by it, are made equal to the parallel lines, ST, RU, QV, PW, etc., drawn upon the surface of the part, KXTS, Fig. 288.

It is plain that the part, uu'vv' is equal to the part tt'ss', with the difference that the small parallels in it are laid out above the large parallels in the other part; in the same manner, the part yy'ww' is equal to the part aja'j'.

Laying out the pattern in this manner makes it possible to cut out the complete elbow from one square piece of metal, aya'y'. The spaces between the patterns are left for laps, which are necessary for joining all parts.

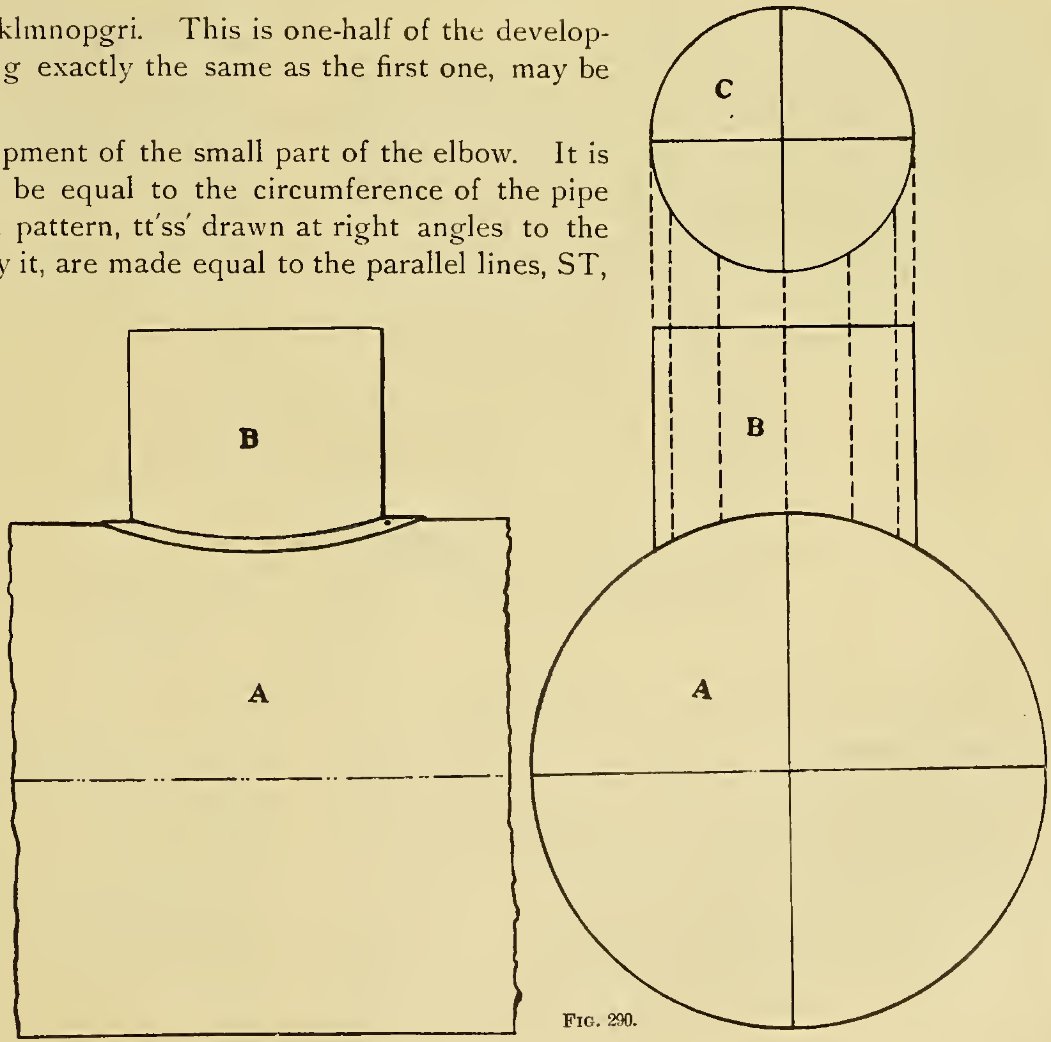


Fig. 290.

To develop the dome of a boiler.

A part of the boiler is shown by A, Fig. 290, to this the dome, B, is fastened by riveting. The illustration shows also the side view of the boiler and dome; the top view of the dome C is drawn above the dome in the side view.

This problem is exactly the same as the one explained on page 170, where the intersection of two cylinders, of different diameters, was considered; the method employed for the development in this case is, consequently, the same as in the previous problem.

The circle C is divided into any number of equal parts, through the divisions of which parallel lines are drawn on the surface of the dome.

The development is shown in Fig. 291; its length is equal to the circumference of the dome. The parallel lines in the development are made equal respectively to the parallel lines drawn upon the surface of the dome, Fig. 290.

The dotted lines around the development show the lap which must be allowed for fastening the dome to the boiler by riveting.

To develop the slope sheet of a boiler, shown in Figs. 292 and 293.

The slope sheet which is to be developed is shown in Fig. 293 by ABCD. This sheet is of an irregular shape. The side view is shown drawn to a larger scale by EF4′G in Fig. 294; the same figure shows one-half of the end view of the same slope sheet UW4.

To prepare for the development divide the arc U4 into any number of equal parts, say four; horizontal lines drawn through the divisions, 1, 2, 3 will cut the line F4′ at the points 1′, 2′, 3′; through these points draw lines parallel to G4′—these lines

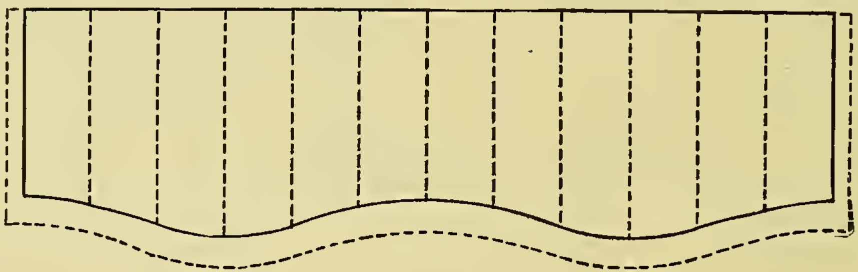


FIG. 291.

are 3'M, 2'N and 1'O—draw the line FP, parallel to these lines. Through point L on this line draw the line LH perpendicular to PF and perpendicular to all the slanting parallel lines just drawn; these lines are cut by the perpendicular at the points H, I, J, K and L.

From the point I on the line M3' lay off the distance IQ equal to 3Z; from the point J on the line N2' lay off the distance JR equal to 2X. From the point K, on the line O1' lay off the distance KS equal to V1 and from the point L on the line PF lay off the distance LT equal to UW; through the points thus obtained draw the curve HQRST. It is now possible to draw the development of the slope sheet.

Draw a horizontal line aa', Fig. 295; through the point j near the center of this line draw kl perpendicular to it. On each side of j, on the line aa' lay off the distance ij and ji' each equal to HQ, Fig. 294. Then lay off the distances if and i'f' on the same line, each equal to QR, Fig. 294.

Next lay off fe and f'e', each equal to RS, Fig. 294, and lay off the distances eb and e'b' each equal to ST, Fig. 294; through the points, b, e, f, i, j, i', f', e', and b' draw lines perpendicular to the line aa'.

Lay off the distances jk and jl, equal to GH and H4' respectively, Fig. 294; then lay off the distances ih equal to h'i' and iq equal to i'q'—the distances hi and iq being equal respectively to the distances MI and I3', in Fig. 294.

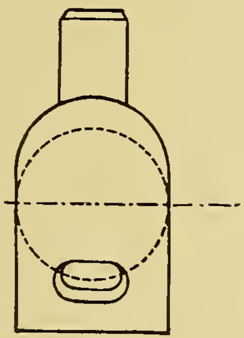


Fig. 292.

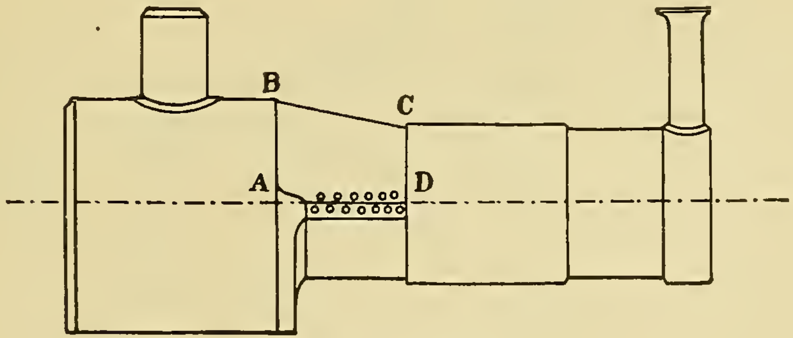


Fig. 293.

In the same manner the distances NJ and J2′, Fig. 294, are laid off on the lines gfp and g′f′p′; the distances OK and K1′, Fig. 294, are laid off on the lines deo and d′e′o′ and the distances PL and LF, Fig. 294, are laid off in the same way, on the lines cbn and c′b′n′.

and m′ by two other arcs, drawn from the points c and c′ as centers, with a radius equal to the distance EP, Fig. 294.

Join the points m and c, m and n, do the same at c′m′ and n′m′ and in this manner the pattern or templet of the slope sheet is obtained.

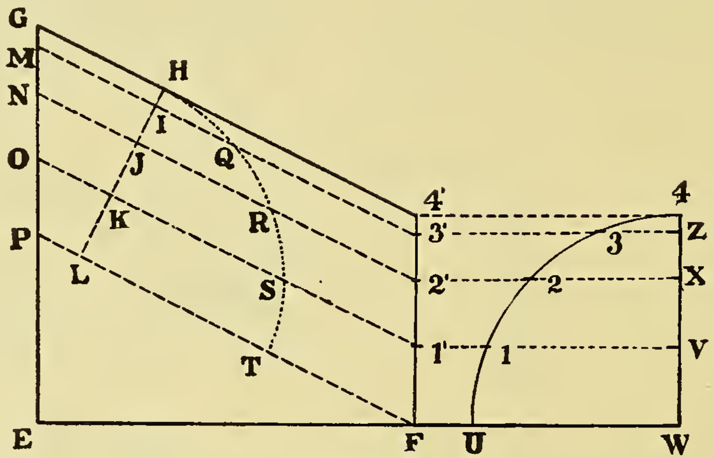


Fig. 294.

Now trace a curve through the points c, d, g, h, k, h′, g′, d′ and c′ and another curve through the points, n, o, p, q, l, q′, p′ o′ and n′.

From the points n and n′ as centers, describe arcs with a radius nm equal to n′m′ each equal to EF, in Fig. 294 and intersect these arcs in the points m

The dotted lines around the templet show the lap which must be allowed for riveting.

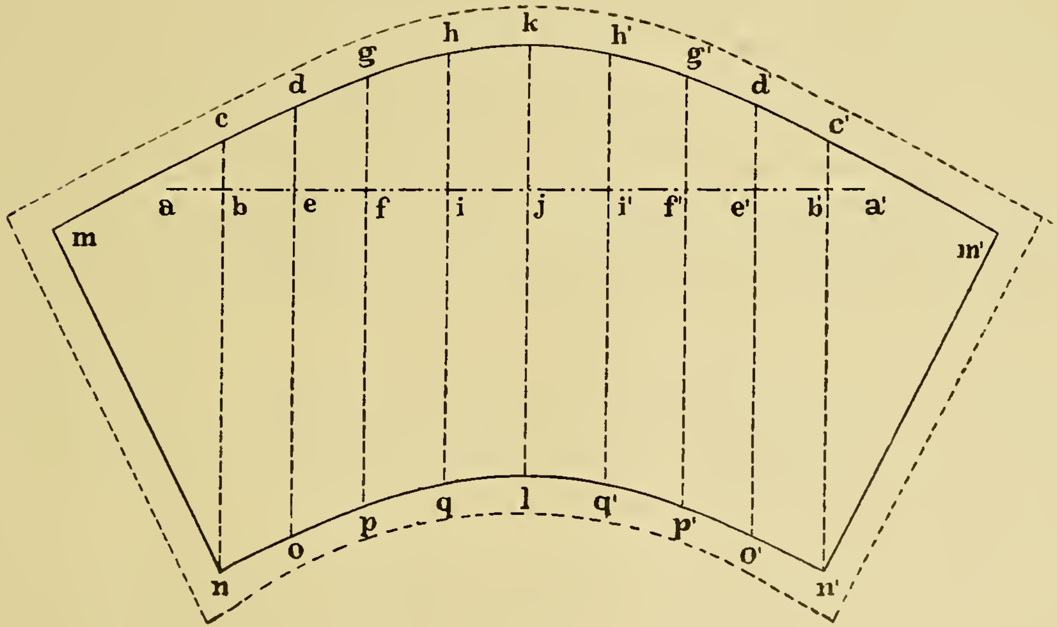


FIG. 295.

WORKING DRAWINGS.

The purpose of a working drawing is to give the shopman information necessary to be known in order to construct the object or mechanism which is represented in the drawing.

The drawings of the different parts of the machine are called "detailed drawings;" in these each detail is represented in the most unmistakable manner, with all the dimensions of the parts written in, containing also, all further information concerning the part in question, that may be important for the purpose of making the patterns or forgings.

The drawings of the complete machine are called general drawings, or general plans, or "assembled drawings;" they show the whole arrangement of the machine, indicating the relative position of its parts; they may also be made to show the motions of the movable parts.

In preparing a detail drawing the first point is to decide the number of views required to illustrate the shape of the object and its parts in a complete and at the same time in a simple and easily understood manner.

After deciding on the manner of views, the selection is decided upon of such a scale that will enable the placing of all the required views of the object within the space of the paper.

As to the number of views required for an object no definite rule can be laid down; it is dependent upon the form and character of the figure and must be decided by the best judgment of the draughtsman.

After ascertaining the most important dimensions of the mechanism a general drawing of the whole should be executed, omitting the smaller parts; after this particular drawings are made. The larger and more important parts are first produced, next, the smaller parts which are to be attached to the larger parts.

The materials of which the parts are to be made should be shown either by sections or by special remarks, notes, etc.; the methods of work which are to be followed by the workman should be indicated, sometimes to the extent of pointing out what machine tool is to be used for the work.

DIMENSIONING DRAWINGS.

This interesting subject has been referred to and illustrated upon pages 132–134; in these the student will find much valuable matter relating to the subject.

Putting the dimensions on a drawing correctly is not only one of the most important but also most difficult parts of the work of a draughtsman; the latter will put in those dimensions only which will be required by the shopman; the manner in which this is done must depend upon the method to be used by the workman in constructing the part to which the dimensions refer; for this reason, an acquaintance with the methods adopted in shop practice as well as with the tools to be used is essential.

Every dimension necessary to the execution of the work should be clearly stated by figures on the drawing, *so that no measurements need to be taken in the shop by scale.* All measurements should be given with reference to the base or starting point from which the work is laid out, and also *with reference to center lines.*

All figured dimensions on drawings must be in plain, round vertical figures, not less than one-eighth inch high, and formed by a line of uniform width and sufficiently heavy to insure printing well, omitting all thin, sloping or doubtful figures. All figured dimensions below two feet are best expressed in inches.

It may be put down as a rule that the draughtsman must anticipate the measurements which will be looked for by the workman in doing the work, and these dimensions only must be put on the drawing.

Surfaces which are to be finished should be plainly marked "finished." When a particular tool or machine which is to be employed in finishing is mentioned, by putting the name of the tool, in small letters, near the surface which is to be finished, the word "finished" need not be added.

When an object is to be turned in a lathe, the dimensions of the turned surfaces must be given by their diameters. Near the outline of the surface the word "turned" should be plainly marked. For some purposes it may be desirable to put in the radius for turned work; if such a case may be foreseen by the draughtsman, the dimension should be inserted.

NOTE.—It must be understood that the scale on a drawing is not given for a shopman to take his dimensions from; such dimensions must all be taken from the dimension figures; the scale is given for the chief draughtsman's use, or whoever may check the drawing, and also for the use of other draughtsmen who may make at some future time alterations or additions to the drawing.

Wherever the ends of a piece of work in the lathe are to be finished, as, for instance, the two ends of a hub on a pulley, the word "face" should be plainly marked near the surface which is to be finished in this manner.

The dimensions written on the drawing should always give the actual finished sizes of the object, no matter to what scale the object may be drawn.

All dimensions which a shopman may require should be put on a drawing, so that no calculation be required on his part.

For instance, it is not enough to give the lengths of the different parts of the object, but the length over all, which is the sum of all these lengths, should also be marked as shown in Fig. 296.

The figures giving the dimensions should be placed on the dimension lines, and not on the outline of the object.

The dimension lines should have arrow heads at each end and the points of these arrow heads should always touch exactly the lines, the distance between which is indicated by the dimension as illustrated in Fig. 297.

The figure should be placed in the middle of the dimension line at right angles to that line, and so as to read either from the bottom, or from the right hand side of the drawing. The arrow heads should be put inside of the lines, from which the distance, as given in the dimension, is reckoned.

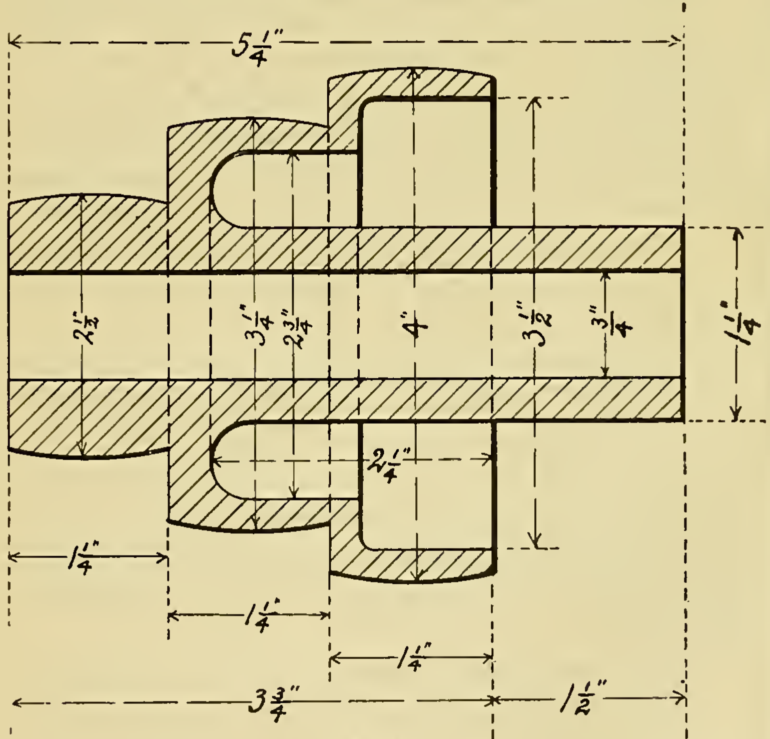


Fig. 296.

When the space between these lines is too small for the figures, the lines being very close together, as shown in Fig. 298, the arrow heads may be placed outside and the figures also be put outside, in which case an arrow should be put in to indicate the proper position of the figures.

The dimension lines should also be put in the drawing, very near to the spaces or lines, to which they refer.

When "the view" is complicated, dimension lines drawn within it, might tend to make it still more obscure and difficult to understand; in such a case

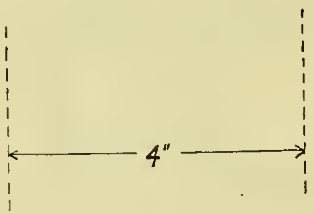


Fig. 297.

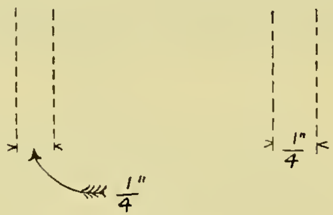


Fig. 298.

the dimension lines should be carried outside of the view and extension lines drawn from the arrow heads to the points, between which the dimension is given.

When the dimension includes a fraction, the numerator should be separated from the denominator by a horizontal line and not by an inclined line; care should also be taken to write the figures in a very clear and legible manner and crowding should be avoided.

When a dimension is given in one view, it need not be repeated in another view, except when such a repetition is essential to locate the size in question.

For most shop drawings blueprints are used; the beginner will find that the dimensions on the print do not correspond with the scale; this is due to the shrinking of the blueprint paper after it has been washed; as the dimensions on a blueprint are generally shorter than the scale by which they have been measured.

In many shops there exists a rule; that every draughtsman must mark plainly on his drawing in some place where it is easily seen by the workman, "*do not scale drawing.*"

When a drill is to be used, it is advisable to write near the hole in question the word "drill." Should the hole be provided with a thread to be produced by a tap, write "tap," adding to this one word, its size or number.

When the hole is of a comparatively large diameter, so that it can be finished only in the lathe by turning, or in the boring mill by boring, the words "turn" or "bore" respectively should be put in near the circumference of the hole. In this case, also, the diameter of the hole, and not the radius, should be given.

When a number of holes are to be laid out in one piece of work, the distance from center to center should be given, and not the distances between the circumferences of the holes.

When a number of holes are at equal distances from a central point, or when their centers are located in the circumference of a circle, this circumference should be drawn through the centers of the holes, and the diameter should be given as a dimension. The distances between the centers of the holes measured on a straight line, or measured as a part of the circumference, on which their centers are located, should also be noted.

In practice, at times, instead of dimensions reference letters are used, thus:

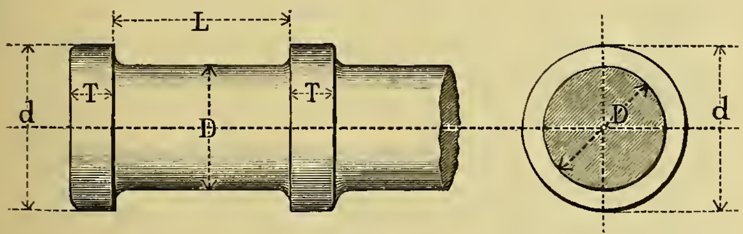


FIG. 299.

D=diam. of shaft, 2½ inches.
L=length of bearing, 3¾ inches.
T=thickness of collar, ⅞ inch.
d=diam. of collar, 3½ inches.

It is preferable to give the diameters of turned and bored work on a section, instead of an end drawn separately; confusion is sometimes caused by a number of radial dimensions.

The following are quoted from A. W. Robinson's admirable Office Rules:

"Every drawing, whether whole or half-sheet, shall have the title, date, scale and number of the sheet stamped in lower right-hand corner, and the quarter and eighth sheets printed on top.

"The name of the drawing, as given in the title, is invariably to consist of two divisions in one line separated by a hyphen. The first division is to state the general name of the thing or machine, and the second name is to clearly designate the part or parts represented (or if a general view should so state). The wording of titles should be submitted to the chief engineer or head draughtsman for approval.

"Each drawing shall bear the name of the draughtsman and examiner, the surname being used without initials.

"Drawings of piping details should be made in diagram form, using standard symbols.

"All detail parts for standard or repetition work shall be shown unassembled as far as possible."

TINTS AND COLORS.

It is sometimes found necessary to prepare a highly finished and shaded drawing of the work in hand, and for special purposes, they are also tinted and colored; such elaborations, in fact, are much admired by the uninitiated, although no criterion as to the scientific value of the object is represented.

Mechanical drawings are seldom tinted, but are mainly produced in India ink. Where, however, a fine effect is desired, working drawings are colored, so as to show at a glance the material of which the different parts are to be made.

The colors required are few but should be of the best quality. Besides India ink the following water-colors are generally used:

1, Neutral-tint; 2, Prussian Blue; 3, Chrome Yellow; 4, Gamboge; 5, Raw Sienna; 6, Carmine; 7, Vermilion; 8, Vermilion Red; 9, Sepia; 10, Indigo. These come in hard cakes.

Certain colors and tints represent different metals and materials as follows:

Wrought Iron—Prussian Blue.

Steel—Carmine and Prussian Blue, mixed to give a purple shade.

Steel Casting—Same as the above darkened by Venetian Red.

Cast Iron—Neutral-tint made of India Ink, Indigo, mixed with a little Carmine.

Brass—Gamboge or Chrome Yellow.

Babbitt—Emerald Green · sometimes light mixture of India Ink.

Copper—Purple Lake.

In applying the tints, the paper must be expanded and stretched evenly all over its surface; otherwise when the moist tint is applied the paper will wrinkle and get out of shape; to do this cut the paper at least half an inch less in size than the drawing board; lay the paper face down, turn up a margin or edge of about three-fourths of an inch all round, then dampen the paper with a sponge and clean water; allow it to soak for a few minutes until it is evenly and thoroughly dampened; next turn the paper upside down (face up).

Apply strong paste to the under side of the margin all round; rub down, on the drawing-board, working from the center of the board outwards so as to exclude the air and prevent creases or furrows. The board is then inclined and left to dry slowly; make sure that the paper is all well pasted and every part of the edges attached to the board.

If tracings are required to be tinted or shaded, the color may be applied before the tracing is cut off, or what is more usual, the color may be applied on the back of the tracing; then there is no liability to wash out the lines.

TRACING AND BLUE PRINTING.

Whenever it is desired to have more than one copy of a drawing, a "tracing" is made of it and from this as many blueprints can be obtained as are required.

When a tracing is needed for making blueprints a piece of tracing paper or tracing cloth of the same size as the drawing is placed over the original drawing and fastened to the board. This tracing paper or cloth is almost transparent; the tracing is a mechanical copy of a drawing made by reproducing its lines as seen through a transparent medium such as has been described and the lines of the drawing can be seen through it.

The surfaces of the tracing cloth are called the "glazed side" and the "dull side," or "front" and "back;" the glazed side has a smooth polished surface and the dull side is like a piece of ordinary linen cloth.

NOTE.—Many concerns have rules of their own, directing their draughtsmen to use either the smooth or the rough side for all purposes; if there are no such rules, it is left to the judgment of the draughtsman.

While it is immaterial which side of the cloth is used in tracing, however, if any mistakes are made and have to be corrected this can be done easier on the glazed side; on the contrary, if any *additions* must be made to the tracing, which have to be drawn in pencil first, the dull side will be found most convenient, as the pencil marks show plainer on the dull side.

Drawing on tracing paper or cloth is effected by pencil and drawing pen as in ordinary work.

The tracing cloth must be fastened to the board, over the drawing, by pins or thumb tacks; moisture or dampness should be carefully avoided and the drawing done, preferably, on the smooth side of the cloth.

When tracing cloth will not take ink readily a small quantity of pounce may be applied to the surface of the cloth and distributed evenly with a piece of cotton waste, chamois, or similar material, but the pounce should be thoroughly removed before applying the ink.

In making tracings the order to be followed is as follows: 1, ink in the small circles and curves; 2, ink in the larger circles and curves; 3, then all the horizontal lines, beginning at the top of the drawing and working downward; 4, next ink in all the vertical lines, commencing at the left and moving back to the right; 5, draw in the oblique lines; 6, in finishing the figuring and lettering should be done with India ink, thoroughly black.

"Erasing," in case of mistakes or errors, should be done with an ink-eraser or a sharp, round erasing knife; the surface of the tracing cloth must be made smooth in those places where lines have been erased; this is accomplished by rubbing the cloth with soapstone or powdered pumice stone, applied with a soft cloth or with the finger. When a mistake made is so serious that it cannot be corrected by erasing, a piece of the tracing cloth may be cut out and a new one inserted in its place.

A finished tracing should be provided with the title of the drawing, the date, scale and the initials

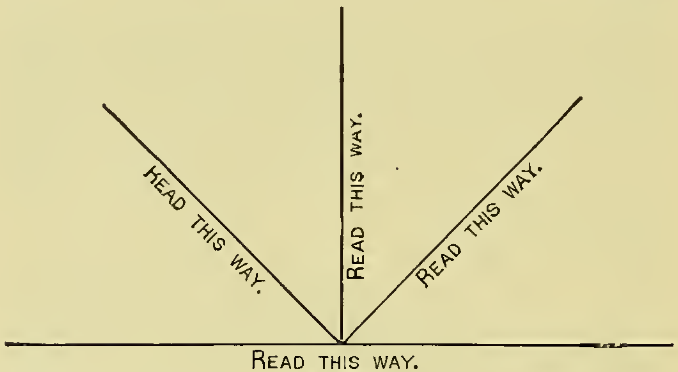


FIG. 300.

of the draughtsman as shown in Fig. 302 which is a representation of a blueprint taken from a tracing.

The letters on a drawing should be placed, as near as possible, as shown in Fig. 300; when a part to which a note refers is at an angle to the base line, the letters should be placed parallel to the part mentioned. All the letters should be so placed that the drawing can be "read" without turning the drawing completely around.

BLUE PRINTS.

As many copies as may be desired of a tracing can be made from it by the process known as "blue printing."

In order to make serviceable blue prints three things are essential: 1, good paper; 2, proper

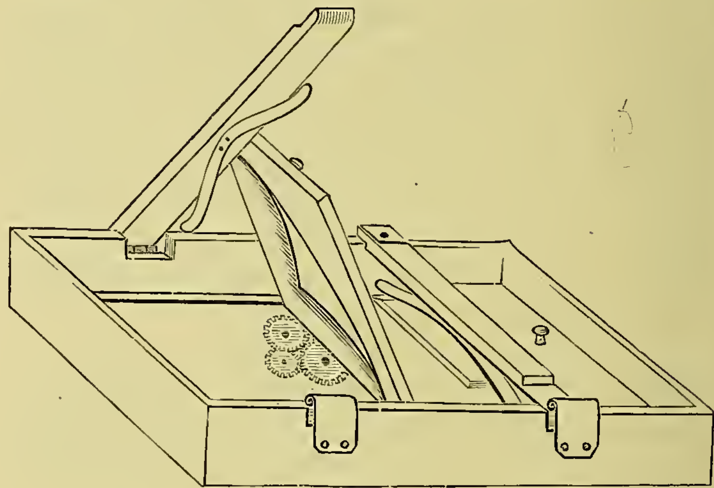


FIG. 301.

chemicals for coating the paper, and 3, a good printing frame. One form of the latter is shown in Fig. 301, with half of the back raised; the back is made in two sections and hinged together, this being done in order to enable the operator to lift one-half of the back and inspect the prepared paper, so as to ascertain if the print is of the right color.

The springs shown in the figure are intended to keep the hinged back pressed close against the prepared paper, tracing and *glass*,—the latter, of course being invisible in the cut, but which should consist of good clear, double thick glass of a size to fit the frame.

The inside surface of the back or that side which presses against the prepared paper is always covered by felt or three or four layers of Canton cotton, which are glued to it.

The "printing" is very simple, as the only apparatus necessary is a blue printing frame one form of which is shown in Fig. 301, and a trough containing water for washing the prints; in brief, this is the method of procedure: 1, the tracing is fixed in the frame, with the surface on which the drawing is made, *i. e.*, the inked side, *next to the glass*; 2, the "sensitized" side of the paper is next laid against the back of the tracing; 3, replace the wooden cover and fasten down the springs so that both paper and tracing are compressed firmly against the glass, permitting no creases or air spaces between them. This should be done in a darkened room; 4, expose for three to six minutes, according to the intensity of the sun; 5, the sensitized paper is to be taken out of the frame and quickly washed in clean cool water: the drawing will appear in white lines on blue ground; 6, the print finally hung up by one edge so that the water will run off and the print allowed to dry.

NOTE.—Large printing frames are generally mounted on a frame, which are provided with wheels running on rails; by means of this arrangement the frame can be pushed out through a window for exposure.

The sun rays or a strong electric light act upon those parts of the sensitized paper not covered by ink lines in the drawing and change their yellowish color gradually to a dull gray. When taken out of the frame and washed, as explained already, the paper turns dark blue leaving the lines of the drawing in plain white.

TEST PIECES.

To make good blueprints, 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.

Now simply take a small test-piece of the same paper (say 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, we can find a place 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.

HELIOGRAPHIC PRINTING.

To obtain sharp lines on a blueprint all lines on the tracing should be made heavier than on ordinary drawing paper and a sharp inking pen should be used.

Paper which has a glossy or starched appearance should never be used, as the blueprint solution when applied to the paper will intermix with the starch and the result will be poor prints. Drawing paper or blueprint paper (unprepared) which may be obtained of any dealer will give the best results.

The sensitized paper is sold ready for use, but it can be prepared by dissolving two ounces of citrate of iron and ammonia in eight ounces of soft water; keep in a dark bottle; also, one and one-third ounces of red prussiate of potash in eight ounces of water; keep in another dark bottle; when about to use mix an equal quantity of each in a cup and apply in a dark room with a soft brush or sponge to one side of white rag paper, similar to envelop paper. To complete the process let it dry and put away in a dark place until required for use.

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 blueprint a special chemical preparation must be used to make white lines. A solution of quicklime 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.

BLACK PROCESS COPYING.

This is accomplished by specially sensitized paper by which a fac-simile of the original drawing can be made; that is, black lines upon white ground; this method of printing avoids the objection to the blue-print paper of shaded drawings which show light and shade reversed.

The prints made by this process are said to be permanent and can be altered, added to or colored the same as original drawings.

SENSITIZING.

This term is much used in photography and means to make "sensitive" to the action of light derived from the sun or from electricity. To sensitize blue printing paper proceed as follows: The paper should be white, smooth and of good quality, it is best to purchase such paper as is purposely made for sensitizing.

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

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

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

Keep the solutions 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 prints 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 said 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.

In place of blue printing paper *brown printing paper* may be substituted. After an exposure of five minutes in bright sunlight, the margin protruding beyond the tracing cloth changes its original light yellow color to a dull reddish brown. The print is then immersed in the water-bath and thoroughly soaked and rinsed on both sides; the back ground immediately changes to a brown color the lines coming out in perfect white. The prints are then placed in a fixing solution and washed again during fifteen or twenty minutes.

NOTE.—There is a method of copying drawings on thick paper and even on cardboard; it consists of using a kind of sensitive paper known as "gelatine" or "bromide"; this is covered with a sensitizing compound made chiefly from the bromide of silver put on in a layer of gelatine.

TO SENSITIZE PAPER FOR BLUE LINES ON A WHITE GROUND.

The following process, credited to Captain Abney, yields a photographic paper giving blue lines on a white ground:

Common salt...........	3 ounces.
Ferric chloride..........	8 ounces.
Tartaric acid...........	3¼ ounces.
Acacia..................	25 ounces.
Water.................	100 ounces.

Dissolve the acacia in half the water, and dissolve the other ingredients in the other half; then mix.

The liquid is applied with a brush to strongly-sized and well-rolled paper in a subdued light. The coating should be as even as possible. The paper should be dried rapidly to prevent the solution sinking into its pores. When dry, the paper is ready for exposure.

In sunlight, one or two minutes is generally sufficient to give an image, while in a dull light, an hour is necessary.

To develop the print, it is floated immediately after leaving the printing frame upon a very weak solution of potassium *ferrocyanide.* None of the developing solution should be allowed to reach the back. The development is usually complete in less than a minute. The paper may be lifted off the solution when the face is wetted, the development proceeding with that which adheres to the print. A blue coloration of the background shows insufficient exposure, and pale-blue over-exposure.

When the development is complete, the print is floated on clean water, and after two or three minutes is placed in a bath, made as follows:

Sulphuric acid..........	3 ounces.
Hydrochloric acid.......	8 ounces.
Water.........	100 ounces.

In about ten minutes the acid will have removed all iron salts not turned into the blue compound. It is next thoroughly washed and dried. Blue spots may be removed by a 4 per cent. solution of caustic potash.

The back of the tracing must be placed in contact with the sensitive surface.

NOTE.—The sensitized paper, when not in use, should be kept in a dark, dry and air-tight place, as with age and exposure the paper becomes deficient in quality; the best way to preserve the sensitized paper is to have made a tin cylinder about 3½ inches in diameter and an inch or two longer than the paper it is desired to keep and with a tight cover to fit over the outside at one end.

MOUNTING BLUE PRINTS FOR THE SHOP.

The shop foreman is often put to a great deal of inconvenience because of the rapid destruction, either through becoming soiled or torn, of blueprints which are used at the machines. Some damage is undoubtedly due to careless handling of the prints, but the greater part of the wear and tear cannot be avoided, even with the greatest care, and the spotting and creasing soon make the print unusable.

To obviate this the blueprints can be fastened on common sheets of pasteboard, but in time the pasteboard itself becomes broken and oil-spotted, hence the frequent adoption of the idea of using thin sheet iron as a backing.

The prints in common use in the shop are first pasted on pieces of sheet iron, then both sides are varnished over, so as to make the paper oil and waterproof. After being subjected to this treatment, the prints can be hung up near the machines. By thus mounting the prints they are clean and clear, and can be filed away in a small space when not in use; moreover, they are practically indestructible, because when soiled they can be put under the hose and washed off.

Sheets that are likely to be removed and replaced, for any purpose, as working drawings generally are, can be fastened very well by small copper tacks, or the ordinary thumb-tacks, driven in along the edges at intervals of 2 inches or less.

The paper can be very slightly dampened before fastening in this manner, and if the operation is carefully performed the paper will be quite as smooth and convenient to work upon as though it were pasted down; the tacks can be driven down so as to be flush with, or below the surface of, the paper, and will offer no obstruction to squares. If a drawing is to be elaborate, or to remain long upon a board, the paper should be pasted down.

To do this, first prepare thick mucilage, and have it ready at hand, with some slips of absorbent paper 1 in. or so, wide. Dampen the sheet on both sides with a sponge, and then apply the mucilage along the edge, for a width of ¼-⅜ in. It is a matter of some difficulty to place a sheet upon a board; but if the board is set on its edge, the paper can be applied without assistance. Then, by putting the strips of paper along the edge, and rubbing over them with some smooth hard instrument, the edges of the sheet can be pasted firmly to the board, the paper slips taking up a part of the moisture from the edges, which are longest in drying.

TO MAKE DRAWINGS FROM THE PRINTS.

To accomplish this, the blueprints may be inked over with "waterproof ink" and when thoroughly dry washed with a solution of oxalate of potash, treated thus the ink lines will remain, and the blue ground will fade and become white and appear similar to an original drawing; the prints can be bleached by washing them in a saturated solution of oxalate of potash, as above.

MECHANICAL DRAWING AND ITS RELATION TO PRACTICAL SHOP WORK.*

The relation of the drafting room to practical shop work is a vital subject that is constantly forced upon the attention of all by the occurrences of daily work, but each department, the drafting room and the shop, has its well-defined place.

In mechanical work we must have first the *idea*, or conception of what is wanted, whether the idea comes from the inventor, the draughtsman or the machinist; the draughtsman, by means of the drawing, becomes the interpreter of the idea to the shop.

*NOTE.—From an address delivered by L. D. Burlingame, Chief Draughtsman at the Brown & Sharpe Manufacturing Company, before the Eastern Manual Training Association, at the convention held at Boston.

The three important relations hereafter dwelt upon can be stated briefly thus:

First—The drafting department as the interpreter *to* the shop—the drawing making plain the meaning and requirements of the designer to the workman.

Second—The drafting department as the interpreter *of* the shop—the draughtsman, through consultation and discussion, making available the practical experience and suggestions of the shop man.

Third—The drafting department as the recorder *for* the shop—the records of all data and information being so compiled and kept as to be reliable, and quickly available when needed.

First. Let us consider the drafting room as an interpreter *to* the shop:

In preparing drawings each piece must be fully and separately detailed, and in many shops, each on a sheet by itself; all particulars of oiling and venting oil holes must be shown, grinding limits given, the depths of tapped holes figured. There must be an indication of when stock is to be allowed for fitting, and of the special kinds of finish on machined surfaces. All special tools used in manufacturing the piece must be listed below its name, and perhaps a list of operations given either on the drawing or in a separate list.

Second. I would earnestly recommend that there be instilled into the minds of technical students the importance of taking advantage of the great mass of mechanical knowledge and the ideas stored up in the minds of the mechanics of the country, in the minds of the men that are actually doing the work, and that the students have it impressed upon them that if they become draughtsmen, one of their important duties will be so to get in touch with the shop as to make this knowledge available, even though it may come to them in crude form from a mind not trained to analyze, to classify and to put ideas upon paper—in other words, that they learn to be the *interpreters of the shop.*

Third. Briefly the office of the drafting room is the *recorder for the shop;* here we touch upon the important work of tabulating, listing and classifying; for example: thousands of special tools accumulate in a large shop; prominent among these are taps, reamers, drills and counterbores, cutters, gauges, etc.; there are many things to be preserved for reference that naturally find their way to the drafting room, such as trade catalogues, photographs, copies of patents and technical journals. The treatment of these in indexing makes all the difference whether they are valuable—of growing value as time goes on—or nearly as worthless.

The importance of the shop side has perhaps been emphasized in what has been said, but I certainly would not belittle the draughtsman, even aside from the high position he often holds as designer and constructor. I agree with the statements made by Prof. Charles L. Griffin; he says: "The workman of to-day is not permitted to assume dimensions or shapes; it is his business to execute the draughtsman's orders; it is, however, often his privilege to choose his own way of doing it, but further than this modern practice does not allow him to go. . . . The drawing is supreme, it is official; it must be plain, direct and all sufficient." It might be added that to make it so the draughtsman must mentally put himself in the place of the shopman, and anticipate his needs. The workman will then respect the draughtsman and his work, and will be willing to follow implicitly the instructions given on his drawings.

TO READ WORKING DRAWINGS.

A working drawing should be made, primarily, as plain as possible by the draughtsman; second, the workman should patiently and carefully study it, so that it is thoroughly understood.

In studying a drawing, the object it is intended to represent should be made as familiar as possible to the mind of the student, so that he may fill out in imagination the parts designedly left incomplete—as in a gear wheel where only two or three teeth are drawn in, that he may see, mentally, the whole.

Drawings are almost always made "finished size," that is, the dimensions are for the work when it is completed. Consequently all the figures written on the different parts indicate the exact size of the work when finished, without any regard to the size of the drawing itself, which may be made to any reduced and convenient scale.

Even in full size drawings this system of figuring is not objectionable. It is a system which should be followed whenever a drawing is made "to work to," for it allows the workman to comprehend at a glance the size of his work and the pieces he has to get made. Figuring makes a drawing comprehensible even to those who cannot make drawings.

In some figures it is necessary to show end views, also section views, to enable all measurements to be read from the drawing.

Fig. 302 represents a blueprint of a *bracket-bearing*, constructed from the drawing, for the Raabe compound oil engine; the front, end view and plan, with dimensions, are shown; the scale is *full size* 12″=1 ft.

MACHINE DESIGN.

The study of mechanical drawing not only consists in copying drawings of machinery and diagrams by accurate measurements and fine finished lines, but it includes the purpose and practical operation of the mechanism designed; *i. e.*, drawing as a means to an end.

The designing of machines requires an extended acquaintance of parts and of similar mechanisms which have been found suitable for the work required and thus have become standard elements of construction; to utilize this knowledge is often the life task of the draughtsman and designer of machinery.

It is a matter of common acceptance that machine design depends more upon an acquaintance with mechanism and shop practice than upon a knowledge of the strength of materials and other kindred subjects making up the science of mechanics; this is the reliance, however unscientific it may be, that is depended upon in perfecting the designs for the machinery that is being produced to-day, and there will probably never be another system that, on the whole, will be more satisfactory.

It is, however, not sufficient to limit our education to observation of completed working machines; it is just as necessary to know the theoretical principles and laws of mechanical construction; these have been classified as Theoretical Mechanics or Theory of Mechanism; a few necessary definitions and general considerations will be found on the succeeding pages

NOTE.—"The correct forms to be given to the materials employed in the construction of tools or machinery depend entirely upon natural principles. Natural form consists in giving each part the exact proportion that will enable it to fulfill its assigned duty with the smallest expenditure of material, and in placing each portion of the materials under the most favorable conditions of position that circumstances will admit of.

"Such natural form is not only the most economical but, strange to say, it is always correct in every respect, and *is invariably beautiful and lovely in its outlines.*"—ANDREWS.

The most successful designer is no doubt born with a love for mechanics and a measure of inventive ability; if to these inherent qualities be added a retentive memory, a mind trained to observe closely, deliberate carefully and decide wisely, he should be a success. Technical education in itself is of little avail; but if allied to these other qualities, perfect and round them out, smoothing the way over places that would be otherwise well nigh insurmountable.

The cost and results of special machinery depend so much on the ability of the designer that it may be well to consider what his attainments should be; he should be able to clearly illustrate his ideas—not necessarily a finished draughtsman—and he should have a practical experience in machine shop practice so that to know that the elements of his design can readily be machined, and that no unnecessary trouble be had with the patterns or in making castings from them.

He should also know enough of machine design that no illy-proportioned parts disfigure or weaken the structure, and sufficient taste to realize that true art in machinery does not consist of imitating architectural embellishments; for beauty, as well as for strength and cheapness, castings should be of the simplest shape possible; rounded corners, especially interiors, straight lines where permissible, with all projections provided for originally, rather than to appear as afterthoughts, are the principal elements of mechanical beauty.

In reference to the particular case in hand, the designer ought to familiarize himself with the methods before employed, if the product has been previously made; quantities of product expected from the machine, space to be occupied, size, weight, speed, power required, and number likely to be made, should be carefully considered.

All notes, deductions, sketches and the like should be carefully preserved, at least until the machine is completed; that is, actually built, for these sketches may prove to be proof of the most convincing character should questions arise as to mechanical elements considered, even at the time unapproved.

It is inconceivable that without shop experience a designer can be highly successful; the more experience the better, not in one shop alone but several. To succeed requires determination and painstaking hard work; a mistaken figure, a wrong calculation or blunder of any kind is sure to bring vexation for some one, and possibly a serious loss.

Finally, always study simplicity of construction, avoiding as far as possible all special shaped wrenches, etc., and using "more than enough" of iron and steel in all designs, to assure strength and durability.

DEFINITIONS AND GENERAL CONSIDERATIONS.

Attraction. This is an invisible power in a body by which it draws anything to itself; the power in nature acting naturally between bodies, or particles, tending to draw them together; the *attraction of gravitation* acts at all distances throughout the universe; *adhesive attraction* unites bodies by their adjacent surfaces; *chemical attraction*, or chemical affinity, is that peculiar force which causes elementary atoms or molecules to unite.

Co-efficient is a number expressing the amount of some change or effect under certain fixed condition as the *co-efficient of expansion;* the *co-efficient of friction;* the word generally means, "*that which unites in action with something else to produce the same effect.*"

Cohesion is that force which binds two or more bodies together. It is that force which the neighboring particles of a body exert to keep each other together.

Ductility is that property by which some metals can be drawn out into wire or tubes.

Effort is a force which acts on a body in the direction of its motion.

Elasticity is the property possessed by most solid bodies, of regaining their original form or shape, after the removal of a force which caused a change of form.

Energy is the capacity for performing work; the *kinetic energy* of a body is the energy it has in virtue of being in motion; kinetic energy is sometimes called *actual energy; potential energy* is energy stored up as that existing in a spring or a bent bow, or a body suspended at a given distance above the earth and acted upon by gravity.

The ***efficiency of a machine*** is a fraction expressing the ratio of the useful work to the whole work performed, which is equal to that expended.

A ***Factor*** is one of the elements or quantities which when multiplied together form a product.

Force is that which tends to produce or to destroy motion; if a body is at rest anything which tends to put it in motion is a force; *centrifugal force* is that by which all bodies moving around another body in a curve, tend to fly off from the axis of their motion; *centripetal* is that which draws, or impels a body toward some point as a center; *force* is equivalent to *push* or pull.

Fatigue of Metals. In many cases materials are subject to impulsive loads and a gradual diminution of strength is observed; in part this deterioration of strength may be due to the ordinary action of a live or repeated load, but it appears to be more often due directly to the gradual loss of the power of elongation in consequence of the slow accumulation of the *permanent set;* the latter may be defined as the *fatigue of metals.*

Friction is that force which acts between two bodies at their surface of contact so as to resist their sliding on each other, and which depends on the force with which they are pressed together.

Gravity. We can not say what gravity *is*, but what it *does*,—namely, that it is something which gives to every particle of matter a tendency toward every other particle. This influence is conveyed from one body to another without any perceptible interval of time. We weigh a body by ascertaining the force required *to hold it back*, or to keep it from descending; hence, also, weights are nothing more than *measures of the force of gravity* in different bodies.

Inertia is that property of a body by virtue of which it tends to continue in the state of rest or motion in which it may be placed until acted on by some force.

Kinematics. The science that treats of motions, considered in themselves, or apart from their causes; "Kinematics forms properly an introduction to mechanics as involving the mathematical principles which are to be applied to its more practical problems."

Load. By the load on any member of a machine is meant the aggregate of all the external forces in action upon it. These may be distinguished as (1) the *useful load*, or the forces arising out of the useful power transmitted, and (2) the *prejudicial resistances* due to friction, to work uselessly expended, to weight of members of the machine, to inertia due to changes in velocity of motion, and to special stresses caused in the apparatus by changes in its parts through variations of temperature.

NOTE.—It appears that in some if not all materials a limited amount of stress variation may be repeated time after time without apparent reduction in the strength of the piece; on the balance wheel of a watch for instance, tension and compression succeed each other for some 150 millions of times in a year, and the spring works for years without showing signs of deterioration. In such cases the stresses lie well within the elastic limits; on the other hand the toughest bar breaks after a small number of bendings to and fro when these pass the elastic limits.

There are two kinds of load: first, a *dead load* which produces a permanent and unvarying amount of straining action, and is invariable during the life of the machine—such, for example, as its weight; and, second, variable or *live load*, which is alternately imposed and removed, and which produces a constantly varying amount of straining action. Every load which acts on a structure produces a change of form, which is termed the strain due to the load. The strain may be either a vanishing or elastic deformation, that is, one which disappears when the load is removed; or a permanent deformation or set, which remains after the load is removed. In general, machine parts must be so designed that, under the maximum straining action, there is no sensible permanent deformation.

The *Breaking Load* is that load which causes in those fibres which are subjected to the greatest strain, a tension equal to the Modulus of Rupture; in every case this is equal to the force necessary to tear, crush, shear, twist, break, or otherwise deform a body.

Modulus. The primary signification of the *Modulus* is a measure; the modulus of a machine means the same as the *efficiency* of it. "The modulus of a machine is a formula (or measure) expressing the work a given machine can perform under the condition under which it has been constructed"; the words *mode*, *model*, *mold* are kindred terms all formed from the same root-word and meaning somewhat the same.

Modulus of Resistance is the strain which corresponds to the limit of elasticity, compression and expansion each having a corresponding modulus. *Modulus of Rupture* is the strain at which the molecular fibres cease to hold together. *Modulus of Elasticity* is the measure of the elastic extension of a material, and is the force by which a prismatic body would be extended to its own length, supposing such extension were possible. The *Modulus of a Machine* is the amount of work actually obtained, divided by the work that should be obtained theoretically.

Momentum means impetus or push; it is the quantity of motion in a moving body; it is always proportioned to the quantity of matter multiplied into the velocity.

Moment is the tendency, or measure of tendency, *to produce motion*, especially motion about a fixed point or axis.

Motion signifies movement; in mechanics it may be either simple or compound, the latter consists of combinations of any of the simple motions. The *acceleration of motion* is the rate of change of the velocity of a moving body, in either an increasing or a decreasing rate.

Power is the rate at which mechanical energy is exerted or mechanical work performed, as by a steam engine, an electric motor, etc.

Theoretical Resistance is the force which, when applied to any body, either as tension, compression, torsion or flexture, will produce in those fibres which are strained to the greatest extent, a tension equal to the modulus of resistance; or, in other words, it is a load which strains a load to its limit of elasticity. The *Practical Resistance* often improperly termed merely resistance, is a definite but arbitrary working strain to which a body may be subjected within the limits of elasticity.

Ultimate Strength. If the straining action on a bar is gradually increased till the bar breaks, the load which produces fracture is called the ultimate or breaking strength of the bar. That ultimate strength is for different materials more or less roughly proportional to the elastic strength. We may insure the safety of a structure by taking care to multiply the actual straining action by a factor sufficiently large to allow, not only for unforeseen contingencies and the neglected causes of straining, but also for the difference between the elastic and ultimate strength. The actual straining action multiplied by this factor is still termed a *factor of safety*, and is then equated to the ultimate strength of the structure; the value of the factor of safety must be determined by practical experience.

The *Co-efficient of Safety* is the ratio between the theoretical resistance and the actual load, or, what amounts to the same thing, the ratio between the elastic limit and the actual tension of the fibres. The *Factor of Safety* is the ratio between the breaking load and the actual load.

As a general rule, for machine construction, the Co-efficient of Safety may be taken as double that which is used for construction subjected to statical forces.

The ***Strength of Materials*** entering into machine construction is measured by the resistance which they oppose to alteration of form, and ultimately to rupture, when subjected to force, pressure, load, stress or strain.

Stress is the re-action or resistance of a body due to the load.

Strain is the alteration in shape, as the result of the stress.

Tenacity is the resistance which a body offers to being pulled asunder, and is measured by the tensile strength in lbs. per square inch of the cross section of the body.

Tensile Strength is the resistance per unit of surface, which the molecular fibres oppose to separation.

Velocity is the rate of motion; in kinematics, *speed* is sometimes used to denote the amount of velocity without regard to direction of motion, while *velocity* is not regarded as known unless both the direction and the amount are known.—(W. I. D.)

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 hours. *Circular velocity* is the rate at which a body describes an angle about a given point, and is measured in feet per second or per minute, or in number of revolutions per minute, as is a pulley or shaft. *Uniform velocity* takes place when the body moves over equal distances in equal times. *Variable velocity* takes place when a body moves with a constantly increasing or decreasing speed. *Velocity ratio* is the proportion between the movement of the power and the resistance, in the same interval of time.

Vis-viva, or living force, is a term formerly used to denote the energy stored in a moving body; the term is now practically obsolete, its place being taken by the word energy.

Work is the overcoming of a resistance through a certain space, and is measured by the amount of the resistance multiplied by the length of space through which it is overcome; the *Principle of Work:* The foot-pounds of work applied to a machine must equal the number of foot-pounds of work given up by the machine plus the number absorbed by friction.

NOTE.—The simplest possible example of doing work is to raise a weight through a space against the resistance of the earth's attraction, that is to say, against the force of gravity. For instance, if a hundred pounds be raised vertically upwards, through a space of three feet, work is done, and, according to the above, the amount of work done is measured by the resistance due to the attraction of the earth or gravity, *i.e.*, one hundred pounds, multiplied by the space of three feet, through which it is lifted. The product formed by multiplying a pound by a foot is called a foot-pound. Thus, in the above instance, the amount of work done is 300 foot-pounds. Had the weight been only three pounds, but the height to which it was raised been 100 feet, the quantity of work done would have been precisely the same, *i.e.*, 300 foot-pounds.

PHYSICS.

Physics is that branch of science which treats of the laws and properties of matter and the forces acting upon it; especially that department of science (known, formerly, as Natural Philosophy) which treats of the causes that modify the general properties of the bodies.

The object of *physics* is the study of phenomena presented to us by bodies; it should, however, be added that changes in the nature of the body itself, such as the decomposition of one body into others, are phenomena, whose study forms the more immediate object of *chemistry*.

MECHANICS.

Mechanics is that section of natural philosophy or physics which treats of the action of forces on bodies.

That part of mechanics which considers the action of forces in producing rest or equilibrium is called *statics*; that which relates to such action in producing motion is called *dynamics*. The term *mechanics* includes the action of forces on all bodies, whether solid, liquid, or gaseous. It is usually, however, used of *solid bodies* only. *Applied mechanics* is the practical use of the laws of matter and motion in the construction of machines and structures of all kinds.

NOTE.—"The mechanics of *liquid bodies* is also called *hydrostatics* or *hydrodynamics*, according as the law of rest or of motion are considered. The mechanics of *gaseous bodies* is called also pneumatics. The mechanics of *fluids in motion* with special reference to the methods of obtaining from them useful results constitutes *hydraulics*."

—WEBSTER'S INTERNATIONAL DICTIONARY.

PROPERTIES OF MATTER.

The two *essential* properties of matter, both of which are inseparable from it, are *extension* and *impenetrability*. Extension, in the three dimensions of length, breadth, and thickness, belongs to matter under all circumstances; and impenetrability, or *the property of excluding all other matter from the space which it occupies*, appertains alike to the largest body and the smallest particle.

The limits of useful knowledge relating to the properties of matter may be found in the three following definitions:

(a) "An atom is an ultimate indivisible particle of matter."

(b) "An atom is an ultimate particle of matter not necessarily indivisible; a molecule."

(c) "An atom is a constituent particle of matter, or a molecule supposed to be made up of subordinate particles."—W. I. D.

As no one really knows what matter is in the abstract, not even the most powerful microscope having shown it, it were wise to rest here.

The quantity of matter which a body contains is called its *Mass;* the space it occupies, its *Volume;* its relative quantity of matter under a given volume, its *Density.* All bodies have empty spaces denominated *Pores.*

In solids, we may often see the pores with the naked eye, and almost always by the microscope; in fluids, their existence can be proven by experiment; there are reasons for believing that even in the densest bodies, the amount of solid matter is small compared with the empty spaces, hence it is inferred that the particles of matter touch each other only in a few points.

There are also several other properties which are known by experience to belong to all matter, as *gravity, inertia,* and *divisibility;* and others still which belong not to matter universally, but only to certain classes of bodies, as *elasticity, malleability,* or the power of being extended into leaves or plates; and *ductility,* or the power of being extended in length, as when drawn into wire.

The *mass* of a body, or the quantity it contains is a constant quality, while the *weight* varies according to the variation in the force of gravity at different places.

NOTE.—The distinction between *weight* and *moment* is one important to have in mind. Weight, in mechanics, is the resistance against which a machine acts as opposed to the power which moves it; moment, in mechanics, is the tendency or measure of tendency to produce motion, especially motion about a fixed point or axis.

THE THREE STATES OF MATTER.

Matter is any collection of substance existing by itself in a separate form; matter appears to us in separate forms which however can all be reduced to three classes, namely, *solids, liquids, gaseous;* a *solid* offers resistance to change of shape or shape of bulk, always keeping the same size or volume and the same shape; a *liquid* is a body which offers no resistance to a change in shape and a *gas* or *vapor* is any substance in the elastic or air-like shape.

NOTE.—The difference between a *gas* and a *vapor* is one less of kind than of degree. It is important to note that experiment proves that every vapor becomes a gas at a sufficiently high temperature and low pressure, and, on the other hand, every gas becomes a vapor, at sufficiently low temperature and high pressure.

THREE LAWS OF MOTION.

As there are three states of matter already described, *i. e.*, solids, liquids, gaseous, so there are three laws of motion. These are as follows:

LAW 1. "Everybody continues in its state of rest, or of uniform motion in a straight line, except in so far as it is compelled by force to change that state."

LAW 2. "Change of (quantity of) motion is proportional to force, and takes place in the straight line in which the force acts."

LAW 3. "To every action there is always an equal and contrary reaction; or the mutual actions of any two bodies are always equal and oppositely directed."

The above are "Newton's Laws."

Law one tells us what happens to a piece of matter left to itself, *i. e.*, not acted on by forces; it preserves its "state," whether of rest or of uniform motion in a straight line. The first law gives us also a physical definition of "time," and physical modes of measuring it.

Law two tells us—among other things, how to find the one force which is equivalent, in its action, to any given set of forces. For, however many change of motion may be produced by the separate forces, they must obviously be capable of being compounded into a single change and we can calculate what force would produce that.

Law three furnishes us with the means of studying directly the transference of energy from one body or system to another. Experiment, however, was required to complete the application of the law.

MATERIALS USED IN MACHINE CONSTRUCTION.

The designer should not only know what provisions are to be made for strength, wear and tear, but he should also be familiar with the various materials used in machine construction; he should know what parts of the design are to be cast, forged, cast in one piece or framed or put together of many pieces and also how the work is done.

The principal metals used in machine construction are: Cast iron, wrought iron and steel.

Cast iron is a mixture and combination of iron and carbon, with other substances in different proportions. The first smelting of the iron ore produces pig iron. Pig iron is very seldom used in construction; as a rule it is remelted and made into the kind of iron required for construction. The qualities of cast iron depend upon the proportion of carbon contained therein.

There are different grades of cast iron:

1st. White cast iron contains only a very small proportion of carbon; it is very hard and brittle, it is mostly used for manufacturing wrought iron and steel.

2nd. Gray cast iron contains part of the carbon in chemical combination and the rest is mechanically mixed with the iron in the form of graphite. Gray cast iron is divided into several kinds (mainly three), according to the quantity of carbon in the shape of graphite it contains; these are Nos. 1, 2 and 3. No. 1 contains the largest and No. 3 the smallest percentage of graphite. The first kind has a great fluidity when melted and casts well; it has but little strength. The last kind has considerable strength and makes the most rigid and massive castings.

The great facility of casting this iron into any desired mold is the principal reason for its unlimited application and its great utility in machine construction.

It cannot be welded or riveted, it is very brittle and it has but little elasticity.

These disadvantages cause the designer oftentimes to select more expensive materials. This iron is mostly used where rigidity and weight are of the utmost importance, as for instance in bed plates, frames, hangers, gears, pipes, etc.

Wrought iron is produced by decreasing the quantity of carbon contained in cast iron; it cannot be cast but can be worked into form by rolling or forging; it can be welded, punched, riveted, etc., it is flexible and malleable. For shafts it is "cold rolled," thus adding to its strength and elasticity.

Steel is refined or nearly pure iron, chemically combined with a certain per cent. of added carbon. Its great elasticity and strength make it the most suitable material for machine construction. Steel is divided into different varieties, according to the amount of carbon contained in it. Steel can be forged like wrought iron and it is fusible. Its hardness depends entirely upon the per cent. of carbon contained therein. According to its quality it may be used for cutlery, tools, springs and so forth.

In selecting materials for machine construction, the most important properties that must be considered, are: *strength*, *stiffness*, *elasticity*, *weight*, *durability*, *ease of manufacture and cost.*

MACHINES.

Machines are divided into *simple* and *compound*; and machines when they act with great power, take the name, generally of *engines*, as the pumping engine.

The simple machines are six in number, viz.:

The lever. The wheel and axle. The pulley. The inclined plane. The screw. The wedge.

These can in turn be reduced to three classes: 1. A solid body turning on an axis. 2. A flexible cord. 3. A hard and smooth inclined surface.

For the mechanism of the wheel and axle and of the pulley, merely combines the principle of the *lever* with the tension of the cords; the properties of the screw depend entirely on those of the lever and the inclined plane; and the case of the wedge is analogous to that of a body sustained between two inclined planes.

All machines, however complicated they may be, are combinations of simple mechanical devices; the object in combining them is to give such a direction and velocity to the motion as will enable the machine to do the required work.

The study of machines is divided by Reuleaux into the following parts:

1. The study of machinery in general, looked at in connection with the work to be performed; this teaches what machines exist and how they are constituted.

2. The theory of machines, which concerns itself with the nature of the various arrangements by means of which natural forces can best be applied to machinery.

3. The study of machine design, the province of which is to teach how to give the bodies constituting the machine the capacity to resist alterations of form.

4. The study of pure mechanism, or of kinematics, which relates to the arrangements of the machine by which the mutual motions of its parts, considered as changes of position, are determined.

Upon these foundation principles have been constructed many thousands of machines; instances are on record where the number of tools and machines have run into the tens of thousands used in a single shop, in another more than three thousand "jigs" were in use; from this may be perceived the possibility of describing but few of the many examples.

NOTE.—*Man as a Machine.*—"The human body forms an example of a machine. Physiologists calculate the work done by the body in foot tons, a foot ton of work being represented by the energy required to raise one ton weight one foot high. A hard-working man in his day's labor will develop power equal to about 3,000 foot tons, this amount representing both the innate work of his frame involved in the acts of living and his external muscular labor as a hewer of wood and a drawer of water.

"A man's heart, in twenty-four hours, shows a return equal to 120 foot tons; that is, supposing he could concentrate all the work of the organ in that period into one big lift, it would be capable of raising 120 tons weight one foot high. The breathing muscles, in twenty-four hours, develop energy equal to about 21 foot tons, and when are added the actual work of the muscles and that expended in heat production 3,000 foot tons are arrived at as the approximate daily expenditure of energy.

"All this power, moreover, is developed on about eight and one-third pounds of food a day, the supply including solid food, water and oxygen. No machine of man's invention approaches near to his own body, therefore, as an economical energy producer; and this for the practical reason that the human engine gets at its work directly and without loss of power entailed in other appliances that have to transmit energy through ways and means involving friction and other untoward conditions."

STRESSES, STRAINS AND LOADS.

The great variety of materials employed in machine construction precludes a complete table of factors of safety for use in practice for various materials under dead and live loads and for machines subjected to sudden and frequent strains of short duration, known as shocks.

We give here only a few of the most important materials showing the factors allowed in general practice :

FACTORS OF SAFETY.

MATERIALS.	Dead Load.	Varying Load.	Material subject to shocks.
Cast Iron	6	10–15	15–20
Wrought Iron	4	6	12
Steel................	4	7	15
Copper...............	5	8–10	10–15
Timber...............	8	10	15
Masonry and Brickwork	15	25	30

The stresses to which constructions and parts of constructions may be subjected are of three kinds, mainly :

1. Tensile strain or stress, which has a tendency to lengthen the body in the direction of the load.

2. Compressive or crushing strain or stress, which produces a tendency to shorten or crush the body in the direction of the load.

3. Shearing strain or stress produced in a piece of material which is distorted by a load, tending to cut it across.

Various metals have a different strength to resist compressive and tensional stresses. Stress is usually measured in pounds per square inch.

As mentioned above, when a part is not loaded beyond its limit of elasticity, the stress produced is directly proportional to the strain, so that the stress divided by the strain is a constant quantity for the same material. This constant quantity is called the modulus of elasticity. The modulus of elasticity is found by dividing the stress by the strain.

The modulus of elasticity is also called the coefficient of elasticity.

If a cross section of a given bar is equal to A square inches and if this bar is subjected to a load of W pounds which may result in tensile or compressive stresses, and if the modulus of elasticity of the material in the given bar is equal to E pounds per square inch, then the strain produced is determined by the formula :

$$\text{Strain} = \frac{W}{E \times A}$$

MODULUS OF ELASTICITY.

Materials.	Pounds per sq. in.
Cast Iron	18,000,000
Wrought Iron (in bars)	29,000,000
" " (in plates)	26,000,000
Steel	30,000,000
Brass (cast)	9,000,000
" (wire)	14,000,000
Copper (in sheets)	15,000,000
" (wire)	17,500,000

The stress or load per sq. in. of section is called the unit stress. For instance, if a bar is subjected to a load of 2,000 lbs. and the cross section of the bar is equal to 4 sq. in., the unit stress of the bar would be $2000 \div 4 = 500$ lbs.

As has been said before, strain is the amount of alteration in form of a piece of material produced by a stress to which the piece is subjected. If a wrought iron bar is subjected to pulling stress and is, as a result of this, lengthened $\frac{1}{1000}$ of an inch, this change in its form in length or area, as may be the case, is called the strain.

The unit strain is the amount of alteration of form per unit of form. It is usually taken per unit of length, and then it is called the elongation per unit of length.

We may express this in the following formula:

$$\text{Strain} = \frac{\text{increase in length of bar}}{\text{original length of bar}}$$

For instance if a bar 8 ft. long is elongated by $\frac{1}{16}$ of an inch when subjected to a load, the strain is equal to $\frac{1}{16}$ divided by $96 = \frac{1}{1536}$.

It is to be remembered that the relation of the proportion between the stress and the strain is true only within the elastic limit.

The smallest load which will cause the rupture of a piece of material is called the ultimate strength of that piece, that is the stress in lbs. per sq. in. which the piece can sustain just before rupture takes place.

The following is a table of ultimate strengths:

ULTIMATE STRENGTH IN POUNDS PER SQUARE INCH.

Material.	Tensile.	Compressive.	Shearing.
Cast Iron	19,000	90,000	20,000
Wrought Iron	52,000	52,000	50,000
Steel	100,000	150,000	70,000
Wood	10,000	8,000	600 to 3,000

EXAMPLE 1, Fig. 303.

A wrought iron bar 2" by 2" in section is subjected to tension by the action of a load; it is required to find the weight which will cause its rupture.

The foregoing table of ultimate strengths shows 52,000 lbs. per sq. in. as the tensile stress, and as the given bar measures 4 sq. in., in section, the load required is $52{,}000 \times 4 = 208{,}000$ lbs

FIG. 303.

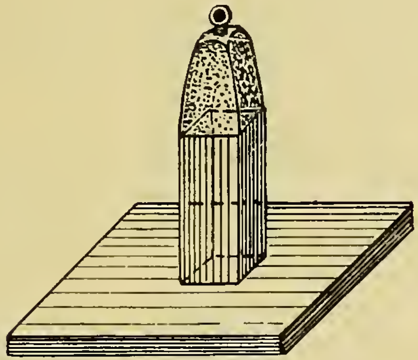


FIG. 304.

EXAMPLE 2, Fig. 304.

A square cast iron block is required to sustain a load of 80,000 lbs. What must be the length of a side of this block?

Let us employ a factor of safety, say 5 for cast iron. That is, we will suppose that the load which is to be sustained will be 5 times greater than 80,000, *i. e.*, 400,000 lbs. As the piece of material in question is subject to a compressive stress, we find the ultimate strength of cast iron in compression, 90,000 per sq. in. of section. To find the required area of a section, divide the load, 400,000, by the ultimate strength, 90,000, $\frac{400000}{90000} = 4.444$ square inches. This is the square section required for the block; so to find the length of a side, take the square root of 4.444 which is 2.1081 inches, or about $2\frac{7}{64}$ inches.

From this example, as well as from what has been said above, we draw the following conclusions:

The resistance to compression, of a piece which is short, compared with its cross section, is calculated by the following formula:

Load = Area of Section × Compressive Stress.

The compressive strength of materials is generally much more difficult to determine when the material is of a soft and plastic character which causes them to spread out when under compression.

The method here described for the calculation of the compressive strength of materials is true only in the case where the given piece is comparatively short. Longer pieces of material, subjected to compressive stresses are much more difficult to calculate because of other strains arising from the action of the load.

The resistance to tension is calculated as in the first example. If a piece having a cross section of A square inches is subjected to a tensile stress by the action of a load of W pounds, and if the tensile strength in pounds per sq. in., is uniformly distributed over the cross section, and is equal to f, then the load W = A (area) × f $\left(\begin{smallmatrix}\text{tensile}\\\text{strength}\end{smallmatrix}\right)$.

Resistance to shearing is calculated by the same formula as the resistance to tension, namely:

$$W = A \times f.$$

The ultimate shearing strength of metals is usually from 70 to 100 per cent. of their ultimate tensile strength.

Stresses induced by bending.

When a beam is supported at both ends, the load causes the material, in the upper part, to be compressed and that in the lower part to be stretched.

We may imagine a horizontal surface separating the compressed part of the beam from the stretched part. We shall call this surface the neutral surface of the beam. The line in which this surface intersects a transverse section of the beam is called the neutral axis of that section.

It is evident that a beam may have as many neutral axes as there are cross sections taken in the beam. The bending stresses occurring in a beam supported at both ends will depend not only upon the magnitude of the forces acting thereon, but also on the distances of the line of action of the given forces from any section of the beam under consideration.

At any point in the length of the beam, the bending action is equal to the sum of all external forces at that point. This is expressed generally as follows: the bending action must be measured by the moments of the forces acting on the beam relative to the given section.

The moment of a force is equal to the force multiplied by the length of the perpendicular to the direction of the force, from a point in which the beam is supposed to be fixed. In Fig. 305 the moment of the force induced by the weight of 20 lbs. is *equal* to 20 times 10 = 200 ft. pounds.

In Fig. 306, the moment is *equal* to 20 × 9 = 180 ft lbs.

The resultant moment of the forces acting on the beam on one side of a given section, referred to that section, is called the bending moment on the beam at that section. For instance, in a beam fixed at one end and loaded at the other with a

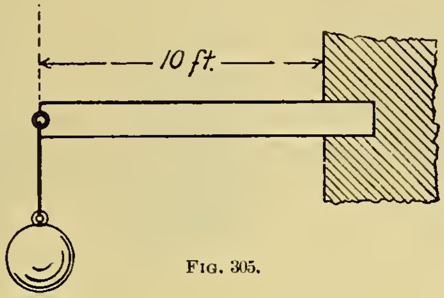


FIG. 305.

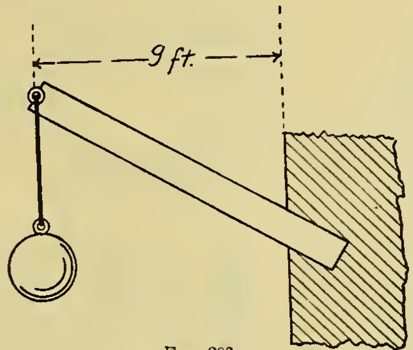


FIG. 306.

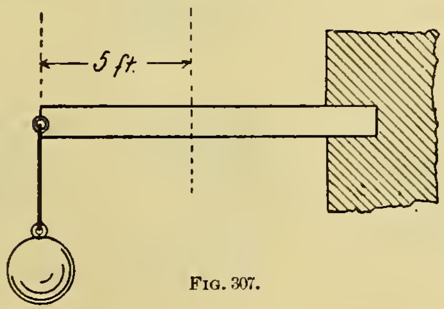


FIG. 307.

weight of 100 pounds, Fig. 307, the bending moment at a cross section at a distance of 5 ft. from the free end of the beam is $100 \times 5 = 500$ ft. lbs.

In Fig. 308, a beam supported at both ends is shown, and where a uniformly distributed load of W pounds per unit of length and a concentrated load of W pounds at a distance *a* from one end is given,

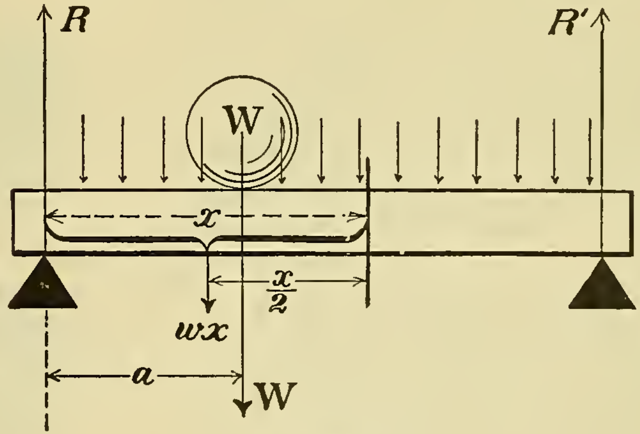


FIG. 308.

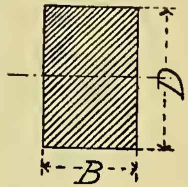
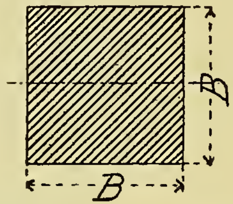
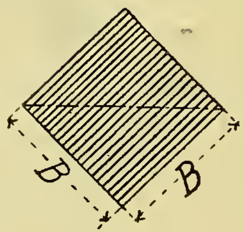
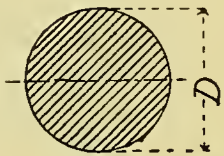
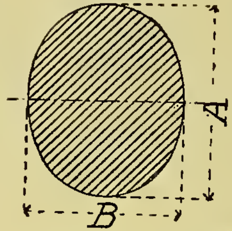
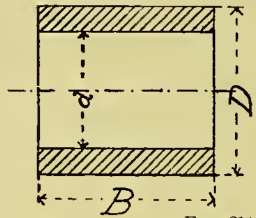
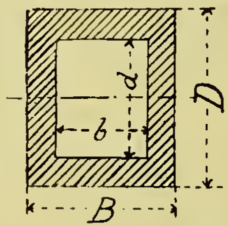
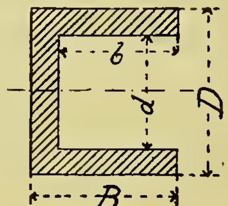
let it be required to find the bending moment at a section, a distance x from one end. First determine by the principle of the lever, the reactions R and R' of the points of support. The forces to the left of the given section are R, W and $w \times x$. The moments of these forces relative to the section are

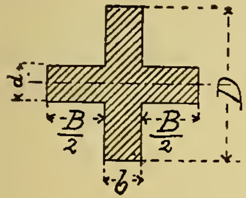
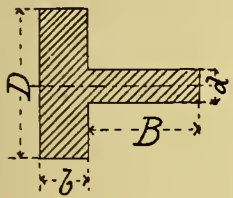
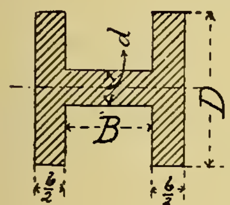
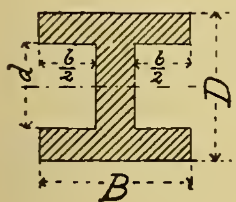
$R \times x$, $W \times (x-a)$ and $\frac{wx^2}{2}$ and the resultant moment $Rx - W \times (x-a) - \frac{wx^2}{2}$ and this is the required bending moment at the given section.

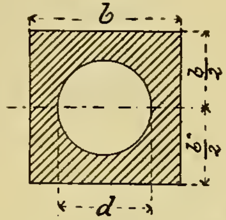
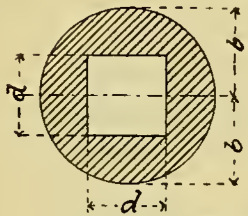
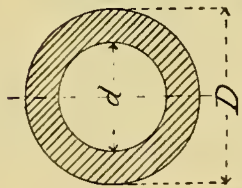
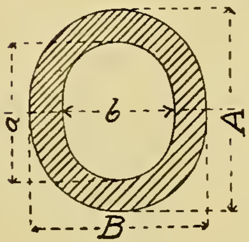
The combined compressive stresses on one side of the neutral axis of any cross section are equal to the combined tensile stresses on the other side of that axis. These two equal and parallel forces form a couple, whose moment is the moment of resistance of the beam to bending of that section. The moment of resistance is equal to the bending moment.

Suppose that the greatest compressive or tensile stress at a given section of a beam is equal to f, then we may express the moment of resistance by the product of fz, where z is a quantity called the modulus of the section, depending upon the form of the section of material in consideration.

The modulus of section or section modulus is sometimes called resisting inches of a section.

FORM OF SECTION.	SECTION MODULUS.
 FIG. 309.	$\frac{1}{6} BD^2$
 FIG. 310.	$\frac{1}{6} B^3$
 FIG. 311.	$0.118\, B^3$
 FIG. 312.	$\frac{3.1416}{32} D^3$
 FIG. 313.	$\frac{3.1416}{32} BA^2$
 FIG. 314.	$\frac{B}{6}\left(\frac{D^3-d^3}{D}\right)$
 FIG. 315.	$\frac{1}{6}\left(\frac{BD^3-bd^3}{D}\right)$
 FIG. 316.	$\frac{1}{6}\left(\frac{BD^3-bd^3}{D}\right)$

Form of Section.	Section Modulus.
 Fig. 317.	$\frac{1}{6}\left(\frac{bD^3+Bd^3}{D}\right)$
 Fig. 318.	$\frac{1}{6}\left(\frac{bD^3+Bd^3}{D}\right)$
 Fig. 319.	$\frac{1}{6}\left(\frac{bD^3+Bd^3}{D}\right)$
 Fig. 320.	$\frac{1}{6}\left(\frac{BD^3-bd^3}{D}\right)$

Form of Section.	Section Modulus.
 Fig. 321.	$\frac{1}{6}\left(\frac{b^4-66d^4}{b}\right)$
 Fig. 322.	$\frac{1}{84}\left(\frac{66d^4-7b^4}{d}\right)$
 Fig. 323.	$\frac{3.1416}{32}\left(\frac{D^4-d^4}{D}\right)$
 Fig. 324.	$\frac{3.1416}{32}\left(\frac{BA^3-ba^3}{A}\right)$

The relation between the bending moment and the moment of resistance may be expressed by the formula M=fz.

It must be remembered that this ratio is only true as long as the elastic limit of the beam has not been reached.

The formula is based on the supposition that the stress being greatest at the top or bottom of a cross section, diminishes gradually to nothing at the neutral axis of the section.

The following illustrations, Figs. 309–324, give the value of the section modulus z for various sections. The horizontal line drawn in each section represents the neutral axis.

The safe resisting moment is equal to the safe stress of the material multiplied by the section modulus.

EXAMPLE 3.

What is the safe resisting moment of a wooden beam, the extreme fibre stress of which is equal to 6,000 lbs. per sq. in., when the beam is 10″ wide and 12″ deep?

Take a factor of safety equal to 6.

The section modulus for the given section is, according to the table $\frac{BD^2}{6} = \frac{10 \times 144}{6} = 240$.

The extreme stress for the given material is equal to 6,000 lbs. As a factor of safety equal to 6 has been taken into account, we divide 6,000 by the factor 6=1,000 lbs.

Then the safe resisting moment of a section of the beam is equal to 240 × 1,000=240,000 inch pounds.

Useful examples of bending moments.

EXAMPLE 4, Fig. 325.

The beam is fixed at one end while the load acts at the other. The greatest bending moment is at B and is equal to W × L, the weight of the load multiplied by the length of the beam.

There also exists a shearing force equal to the magnitude of the load W, which force is to be taken equal from end to end of the beam.

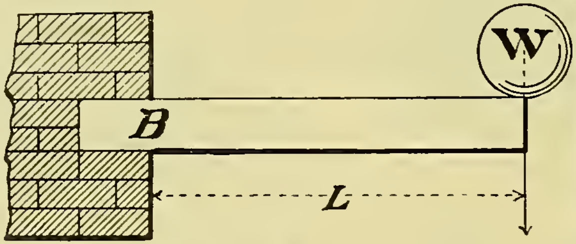


FIG. 325.

EXAMPLE 5.

In Fig. 326 is shown a beam fixed at one end, carrying a load W uniformly distributed. The greatest bending moment is again at B and is equal to ½ WL.

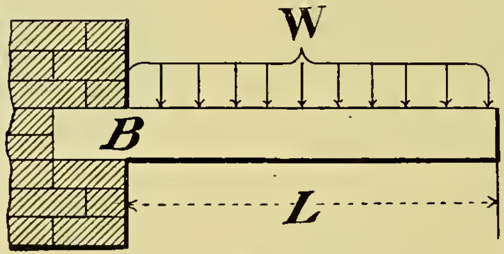


FIG. 326.

EXAMPLE 6.

In Fig. 327 we have a beam supported at each end and loaded exactly in the middle. The greatest bending moment in this case is at B and it is equal to ¼ W × L. There also exists a shearing force equal to ½ W, this force being uniform throughout.

The beam shown in Fig. 328 is supported at each end and is loaded uniformly. The greatest bending moment is at the middle of the beam and is equal to 1/8 W × L. When compared with the bending moment in the preceding example, we see that a beam may carry a load two times greater when the load is distributed uniformly throughout the beam.

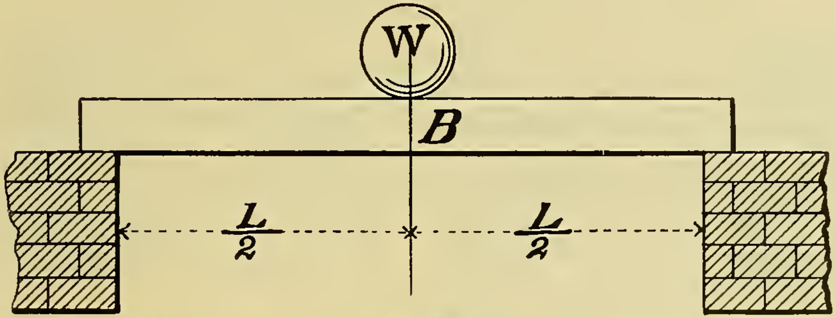


FIG. 327.

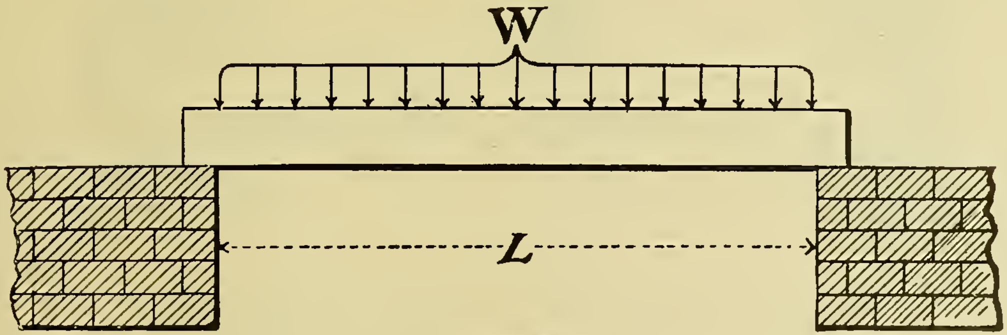


FIG. 328.

The greatest shearing force is at the ends near the supports and is equal to 1/2 W.

EXAMPLE 8.

When the beam is fixed securely at each end, and loaded at the center, as in Fig. 329, the greatest bending moment is at the center and at each end, and is equal to 1/8 W × L. This is based on the supposition that the cross section of the beam is uniform throughout its full length. The bending moments at the ends are contrary to the bending moments at the center, that is, at the center, the bottom of the beam will be subjected to tension, while at the ends the bottom will be subject to compression.

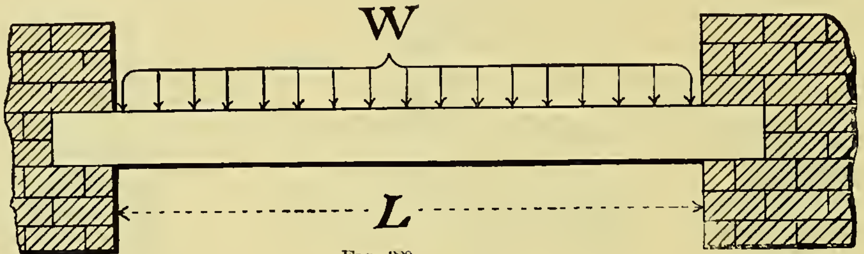


Fig. 329.

EXAMPLE 9, Fig. 330.

When a beam, having a uniform cross section from end to end is fixed securely at both ends, the load which the beam is made to carry, being distributed uniformly, as in Fig. 330, the bending moment is greatest at the ends and is equal to $\frac{1}{12}$ WL. The bending moment at the center is equal to ½ of the moment at the ends, that is, equal to $\frac{1}{24}$ WL, and is contrary to the moments at the ends.

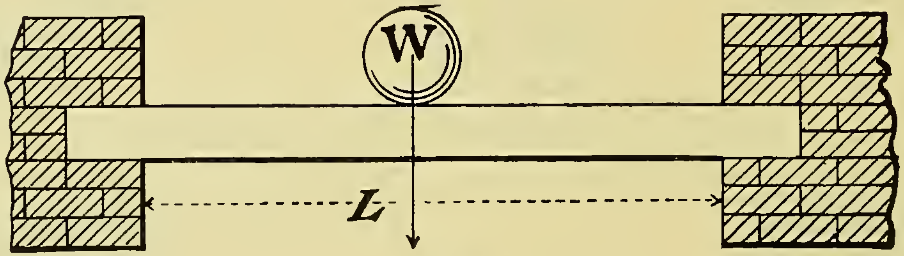


Fig. 330.

If a beam is required to be very stiff, the length should be made as short as possible and the depth as great as circumstances will permit. With the same area of section, the deeper the beam the stronger it will be, provided the breadth of the beam is sufficient to prevent lateral breaking.

Various application of the principles of strength of materials will be discussed in connection with the design of different parts of machines.

Another requisite for successful designing is a knowledge of the properties of materials commonly used for machine construction. In selecting materials for machine parts the designer must consider their properties in regard to the adaptability for the work to which they are to be subjected; the strength, stiffness, durability and convenience of working into the necessary form.

A machine properly constructed, must be able to withstand the stress to which its various parts are to be put, and this depends entirely on their action and endurance, as conditioned by the forms of the parts of the machines. By the word stress we mean a force acting between two bodies or two parts of the same body when subjected to the action of a load. This force is understood to resist the load in preventing it from changing the form of the machine or its parts.

The combination of all external forces acting on a part of a structure calls into existence a new force within the structure itself, and this resisting force we call stress.

All the external forces are called the load of the machine. The effect of the load is the strain produced in the machine; the strain is the tendency to change the form of the machine part under the influence of the load. The resistance which is offered by a material to the change of form resulting from the application of a load, combined with its natural power of returning to its original shape after the load is removed, is called its elasticity.

When a piece of material deformed somewhat when subjected to a load returns exactly to its original form as soon as the load is removed, the piece of material is said to be perfectly elastic within certain limits of a load.

When under the influence of a load the piece of material is permanently deformed—that is, does not return to its original form when the load is removed—we say that the limit of elasticity of the material has been reached.

Up to the limit of elasticity the stress is directly proportional to the strain; beyond the limit of elasticity the strain increases faster than the stress until rupture is produced.

The loads to which material can be subjected may be divided primarily into two classes: a dead load is one which is applied slowly and remains steady and unchangeable; a live load is one which constantly changes, being either alternately imposed and removed, or varying in intensity and direction.

To avoid the danger accompanying an unforeseen intensity of strain, which may produce undesirable deformation or rupture, as may be caused by imperfect workmanship, poor quality of material or other causes, the parts of a machine are usually made to resist a much greater load than will be brought on them in the regular course. The expected load is supposed to be greater, and for this reason is multiplied by a number known as the factor of safety. The factor of safety varies for different materials according to their structure and application, as well as for the same kind of material according to conditions to which it may be subjected.

For materials, the quality of which is liable to change, the factor of safety must be larger than for materials the quality of which is more uniform and less liable to change through atmospheric exposure or varying temperature.

It happens that in some structures the whole load cannot be ascertained with accuracy—in such cases the factor of safety must be increased as a safeguard against unexpected straining action. It may also happen that in some machines the working load may be suddenly increased—for such accidental strains a factor of safety must be allowed.

SCREWS, BOLTS AND NUTS.

In all working drawings consideration should be given to the manner of uniting the different parts of the machine. Screws play a most important part in machine design, particularly as a means for fastening the different parts together. The representation of bolts and screw threads is consequently of such importance that a knowledge of their proportions and the usual method of drawing them, is of great consideration to machine draughtsmen; the exact representation of a screw thread is somewhat difficult; it takes both time and care.

The proper way to draw a screw thread as it actually appears in a finished screw, is by laying out a curve or curves upon the surface of the cylinder, forming the body of the bolt. This curve is called a *helix;* the helix may be defined as a curve generated by progressive rotation of a point around an axis, remaining equidistant from the axis throughout the length of the motion.

When a machinist desires to cut a thread upon a cylinder, he will first change the gears of the lathe to produce the desired number of threads to each inch of length of the screw; this being done, the cylinder is put in place on the centers of the lathe and the thread cutting tool is then set to its proper angle.

Before proceeding to cut the thread, the tool is moved close to the work, so as to trace a fine line upon the surface of the cylinder when the machine is put in motion; the fine spiral produced upon the surface of the cylinder in this manner, is the helix of the screw.

PROBLEM: *To draw a helix, the diameter and height of one turn being given.*

The height of one turn of a helix is called its pitch.

Let the diameter of the cylinder be 3″ and the pitch 2″.

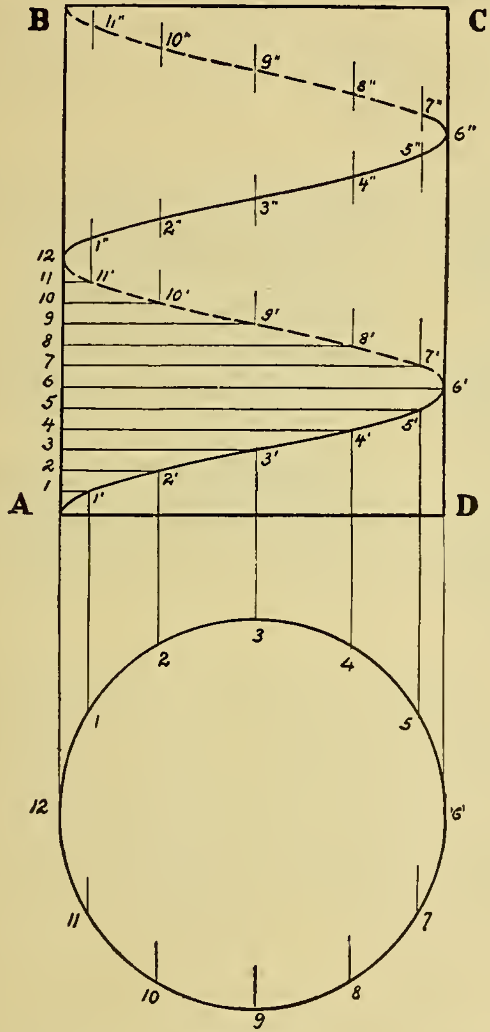


FIG. 331.

Draw the elevation of the cylinder ABCD above its bottom view 1, 2, 3, etc., Fig. 331. The elevation ABCD may be four inches high, that is equal to two complete turns of the helix.

Lay off the pitch from the point A upon the line AB equal to A 12 and 12 B. Divide the pitch A 12 into any number of equal parts, for instance in this case 12. Divide the circle into the same number of equal parts. Through the points of division on the circle, draw lines parallel to the line AB and extend them through the full height of the front view ABCD.

Through the point 1 of the divisions of the pitch, draw 1-1′ parallel to AD, intersecting the vertical line 1 1′ in the point 1′ which is a point in the required helix. Through the point 2 of the pitch divisions, draw the line 2-2′ parallel to AD and intersecting the vertical line 2 2′ at the point 2′, which is another point of the helix. Through the point 3 of the pitch divisions draw the line 3-3′ parallel to AD and cutting the vertical line 3 3′ in the point 3′, which is a third point of the required helix. Proceed in this manner until the sixth point of the helix is found: it will be situated on the line DC. The points A, 1′, 2′, 3′, 4′, 5′ and 6′ determine the position of one-half of a turn of the helix, which may be traced through these points, first in pencil and then inked in.

In the same manner the second half of the first turn may be completed. The accompanying illustration renders a repetition of the above explanation unnecessary. The second half of the turn is drawn dotted, as it is on the other side of the cylinder and cannot be seen. The second turn may be laid out by the aid of the points of the first turn of the helix in the following manner. Set the compasses to a distance equal to the pitch and lay off the points 1″, 2″, 3″, etc., above the corresponding point 1′, 2′, 3′, etc., of the first turn of the helix.

A thorough understanding of the above problem is of considerable use, not only for drawing large sized screws, but especially for drawing a worm for worm gears, which will be explained later.

A screw with a V-thread, drawn with exact helical curves is shown in Fig. 332.

It is made of two helices, one for the top of the thread and the other for the root of it.

Fig. 333 shows a screw with a square thread. An examination of the drawing will show that the thread is drawn with four helices; two helices upon the outside of the cylinder, the top of the thread, and two for the root of the thread. It is evident that the method of drawing screw threads with helices while producing an exact representation of the screw cannot be employed in the shop in drawing machinery, where, as a rule, the number of bolts and screws is very considerable.

The bolts, nuts, etc., are so numerous on some machines, that it is customary to make separate *bolt sheets*, showing all screws necessary for one machine, in all their different sizes and forms.

The square thread shown in Fig. 333, would appear, when drawn by straight lines only, as in Fig. 334, and the V-thread shown before would be drawn as in Fig. 335.

We have so far considered only right-handed screws. *A right-handed screw is one, which passing through a fixed nut and turned in the direction of the motion of the hands of a clock, will advance into the nut.*

A left-handed screw is one, which to pass through a fixed nut, must be turned in a direction opposite to the motion of the hands of a clock. Such a thread is shown in Figs. 336 and 337. Screws may be either single-threaded or double-threaded. If we assume that a screw consists of a cylinder with a coil forming the thread wound around it, we may easily define a double screw as a cylinder with two parallel coils

NOTE.—To avoid the difficult and tedious operation of drawing the helices, screw threads are generally indicated by straight lines only.

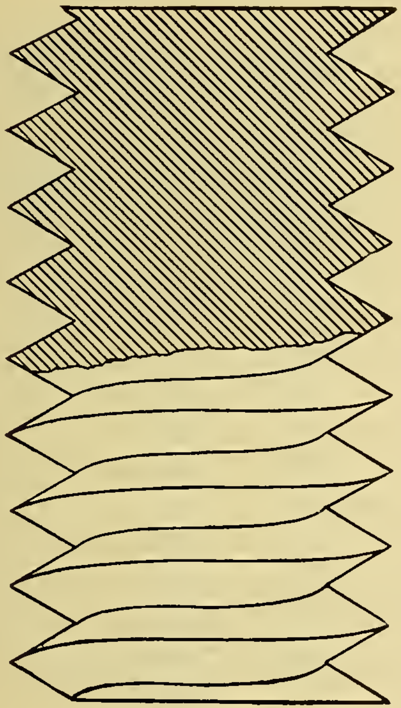


FIG. 332.

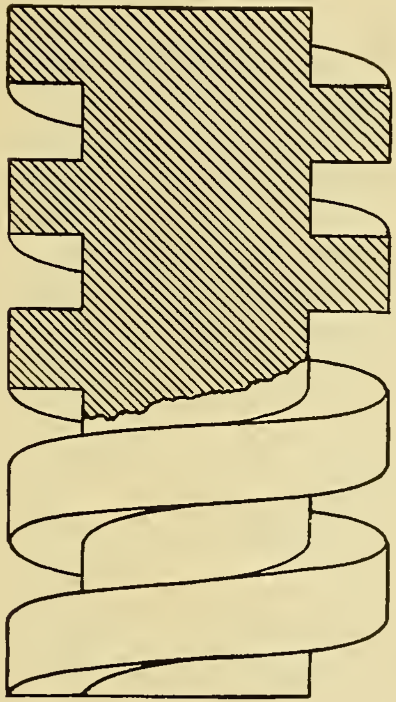


FIG. 333.

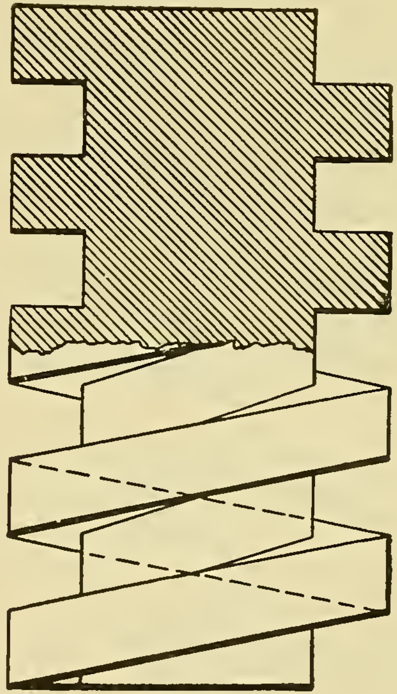


FIG. 334.

of thread wound around it. Generally the double-threaded screw is defined as one having two paralled threads. A screw having three parallel threads is called a triple-threaded screw. Double-threaded screws are shown in Figs. 338 and 339.

The distance between the centers of two successive threads in a single-threaded screw is called the pitch of the screw, Figs. 340 and 341 ; *the pitch is equal to the distance which the screw will advance into a fixed nut during one turn.*

Fig 341 shows the pitch of a square thread. It is equal to twice the pitch of the triangular thread. Screw threads are generally either triangular or square in section, although some other forms are in use.

The triangular thread is called the V-thread. The form of V-thread most commonly used in this country, known as the U. S. Standard thread, is shown in Fig. 342.

The U. S. Standard screw, known also as the Franklin Institute Standard, was presented to that Institute by Mr. Wm. Sellers, in a paper read by him in 1864. As a result of this, the Franklin Institute recommended for general adoption by American engineers the following rules and table of standard threads :

TABLE OF U. S. STANDARD SCREW THREADS.

(Outside) Diameter of Screw.	Threads per Inch.	Diameter at Root of Thread.	Diameter of Tap Drill.
$\frac{1}{4}$	20	0.185	$\frac{3}{16}$
$\frac{5}{16}$	18	0.240	$\frac{1}{4}$
$\frac{3}{8}$	16	0.294	$\frac{5}{16}$
$\frac{7}{16}$	14	0.344	$\frac{23}{64}$
$\frac{1}{2}$	13	0.400	$\frac{13}{32}$
$\frac{9}{16}$	12	0.454	$\frac{15}{32}$
$\frac{5}{8}$	11	0.507	$\frac{17}{32}$
$\frac{3}{4}$	10	0.620	$\frac{5}{8}$
$\frac{7}{8}$	9	0.731	$\frac{3}{4}$
1	8	0.837	$\frac{27}{32}$
$1\frac{1}{8}$	7	0.940	$\frac{31}{32}$
$1\frac{1}{4}$	7	1.065	$1\frac{3}{32}$
$1\frac{3}{8}$	6	1.160	$1\frac{3}{16}$
$1\frac{1}{2}$	6	1.284	$1\frac{9}{32}$
$1\frac{5}{8}$	$5\frac{1}{2}$	1.389	$1\frac{13}{32}$
$1\frac{3}{4}$	5	1.491	$1\frac{1}{2}$
$1\frac{7}{8}$	5	1.616	$1\frac{5}{8}$
2	$4\frac{1}{2}$	1.712	$1\frac{3}{4}$
$2\frac{1}{4}$	$4\frac{1}{2}$	1.962	2
$2\frac{1}{2}$	4	2.176	$2\frac{3}{16}$
$2\frac{3}{4}$	4	2.426	$2\frac{7}{16}$
3	$3\frac{1}{2}$	2.629	$2\frac{21}{32}$
$3\frac{1}{2}$	$3\frac{1}{4}$	3.100	$3\frac{1}{8}$
4	3	3.567	$3\frac{5}{8}$

The proportion of pitch to diameter is

$$P = 0.24\sqrt{D + 0.625} - 0.175$$

The depth of the thread is 0.65 of the pitch.

The table does not give the pitch. To find the pitch, divide one inch by the number of threads. Eight threads to one inch give a pitch of ⅛″.

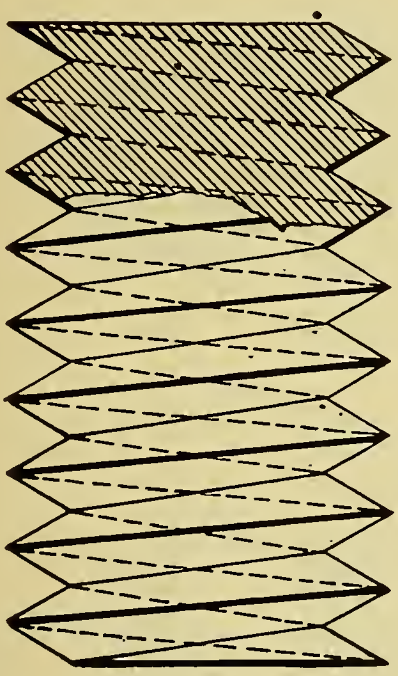


Fig. 335.

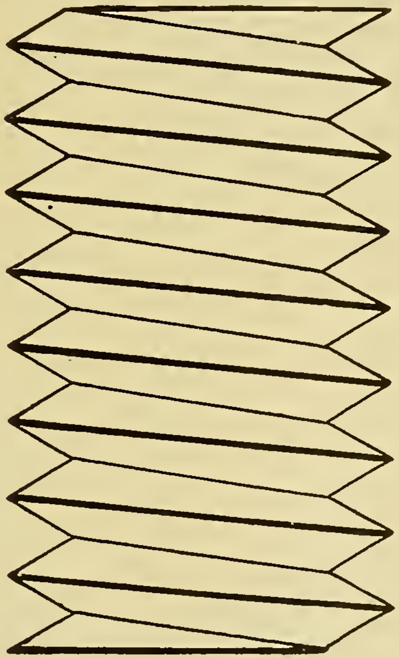


Fig. 336.

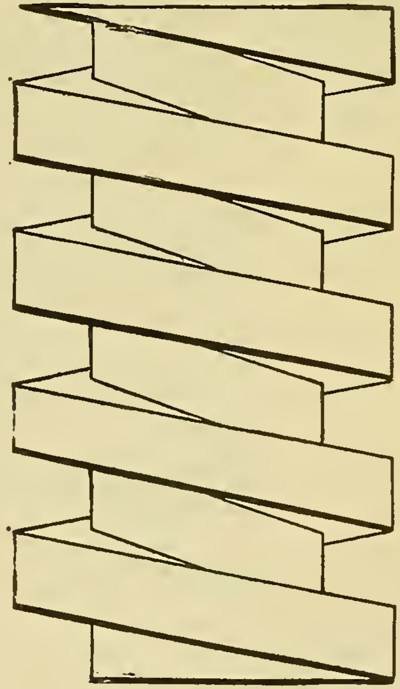


Fig. 337.

By the term diameter of the screw is always meant the outside diameter. The diameter measured at the root of the thread is called the inside diameter.

In the foregoing table of U. S. Standard Screw Threads, the number of threads to one inch of screw is given from ¼″ to 4″ in diameter.

The third column gives the diameter of the screw at the root, or the inside diameter. The next column gives the diameter of drill to be used for any required diameter of tap or thread. They are ordinarily a little larger than the diameter at the root of the thread.

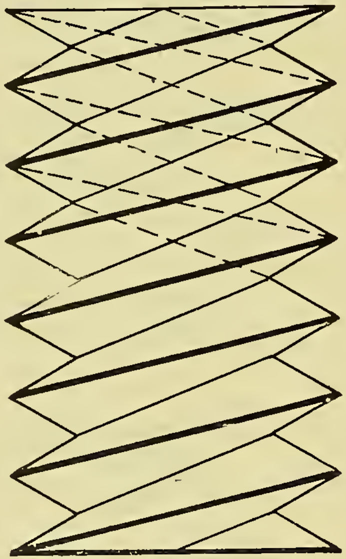


FIG. 338.

The screw thread is formed with straight lines at an angle of 60° to each other. The top and bottom of the thread are flattened, each to a width of ⅛th of the pitch, Fig. 343.

For small diameters of bolts the amount of flattening is not made to any particular measure, and in drawing screw threads it may be neglected entirely.

For a square-threaded screw, the number of threads per inch is equal to one-half the number on a V-threaded screw.

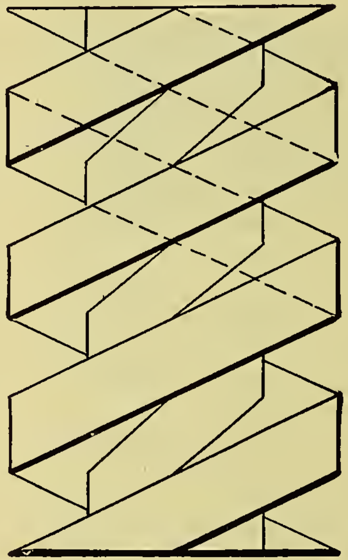
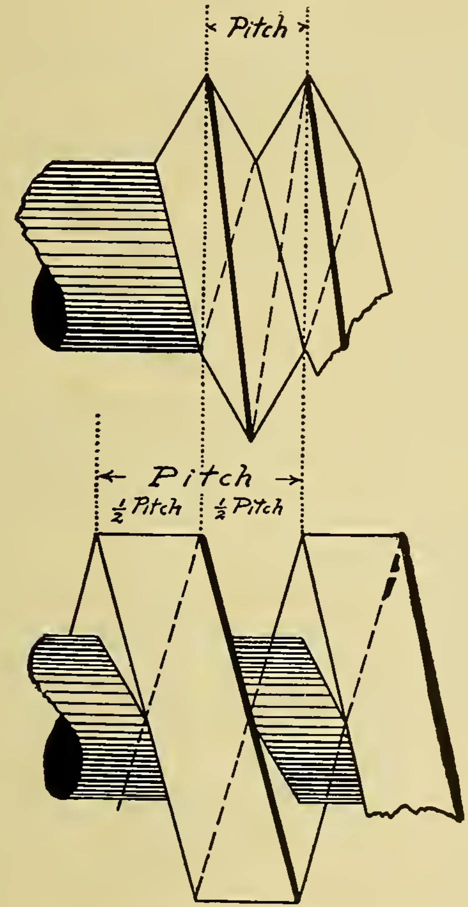


FIG. 339.

In a square-threaded screw of U. S. Standard form, the width of the thread is equal to the width of the groove—each equal to one-half the pitch, Fig. 344.

The depth of the thread is also equal to one-half of the pitch—that is, equal to the width of the groove.

Figs. 345–350 exhibit the conventional methods of showing different threads of a bolt.



FIGS. 340 AND 341.

Fig. 346 represents a single square-thr aded screw. To draw the screw, first draw the cylinder. Lay off distances each equal to one-half the pitch and through the division points draw lines at right angles to the axis of the cylinder, and cutting the other side of the cylinder, the inclination of the parallel lines indicating the thread through the width of the cylinder being equal to one-half the pitch. This method is clearly illustrated in Fig. 346.

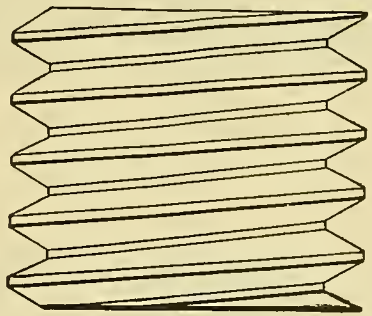


FIG. 342.

Fig. 345 shows a single V-threaded screw. To draw the screw lay out the outlines of the cylinder of the bolt and upon one of its sides set off distances each equal to the pitch. Do the same on the other side of the cylinder beginning at a point one-half the pitch from the end of the cylinder, after which draw the lines for the top of the thread. From the points of division draw lines inclined to each other 60° for

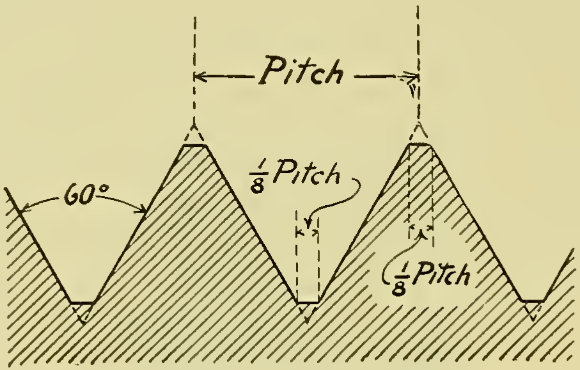


Fig. 343.

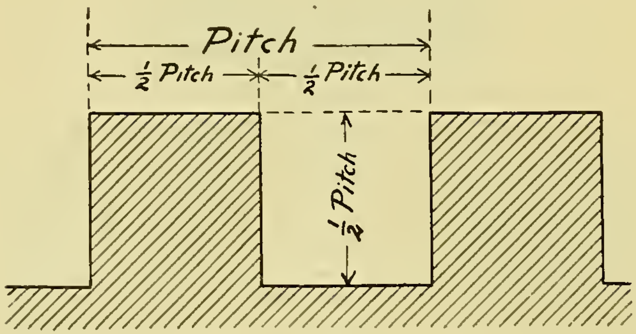


Fig. 344.

the threads, on both sides of the cylinder, then connect the roots by straight lines. It will be noticed that these lines are not parallel to the lines connecting the tops of the thread.

Fig. 347 shows a still simpler method of representing a V-threaded screw. The pitch is laid off as in the preceding example. The heavy lines represent the bottom of the thread.

The method employed in Fig. 348 is still more rapid in delineation and is, therefore, recommended for rapid drawing. Here the heavy lines are used to represent the top of the thread, the fine lines indicating the bottom of the thread.

In Fig. 349 the fine lines are drawn as long as the heavy lines, which makes the drawing of the thread still easier. A method of indicating screw threads when great haste is necessary and for sketching is shown in Fig. 350.

In drawing the thread as illustrated in the last four figures, no particular attention need be given to the number of threads per inch. A note written plainly on the drawing, very near to the representation of the screw, gives the exact number of threads to the inch. Even this may be left out when the diameter of the screw is plainly given, with the note "standard" near it; in this case the workman is expected to determine the number of threads to the inch from the table of U. S. Standard Threads.

The proportions of bolt heads and nuts which have been accepted in this country as a standard are as follows:

The distance between the parallel sides of heads and nuts is equal to 1½ times the diameter of the bolt, plus ⅛ inch = 1½ D + ⅛ inch.

The thickness of heads is equal to one-half of the distance between the parallel sides.

$$\frac{1\frac{1}{2}\text{ D} + \frac{1}{8}\text{ inch.}}{2}$$

The thickness of nuts is equal to the diameter of the bolt = D.

The same proportions are used for square heads and nuts.

In all these formulæ D expresses the diameter of the bolt.

Fig. 351 shows the conventional method of representing a hexagonal nut for a 2″ bolt, The height of the nut is equal to 2″. The two views may be drawn similar to the two views of a hexagonal prism, explained in the chapter on projection.

The curve cde is drawn first, with a radius equal to the height of the nut. When the points c and e are thus determined, a fine straight line is drawn

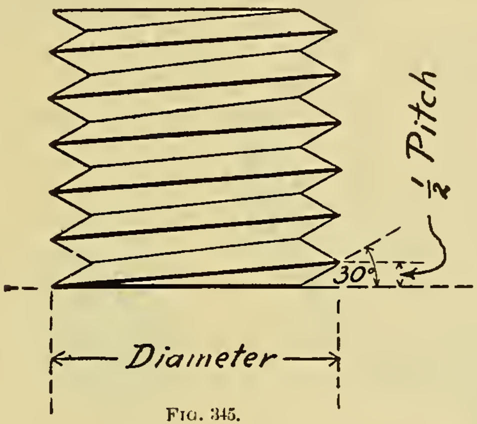


Fig. 345.

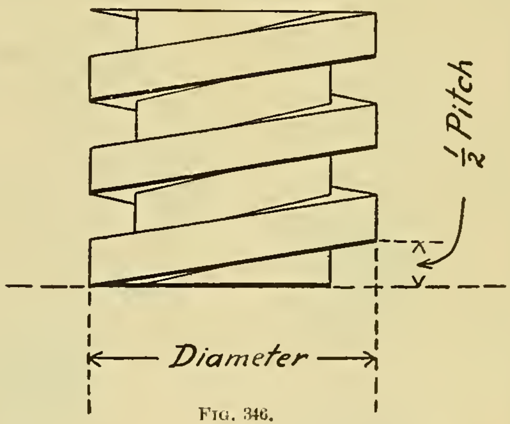


Fig. 346.

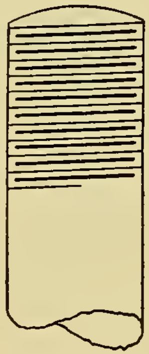


Fig. 347.

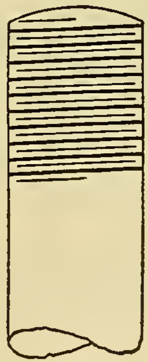


Fig. 348.

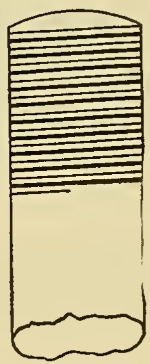


Fig. 349.

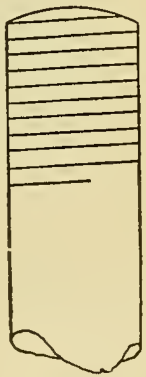


Fig. 350.

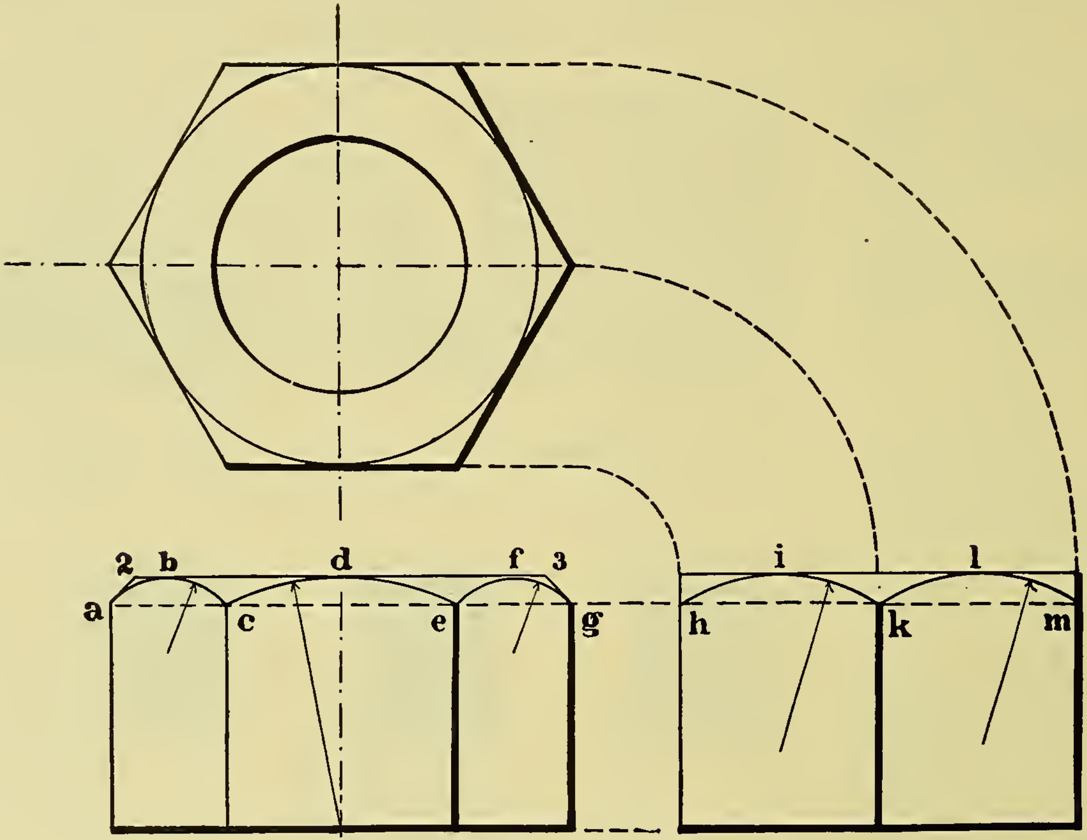


FIG. 351.

through these points and extended in both directions so as to cut all vertical edges of the nut in both views, at the points a, g, h, k and m. Arcs are then

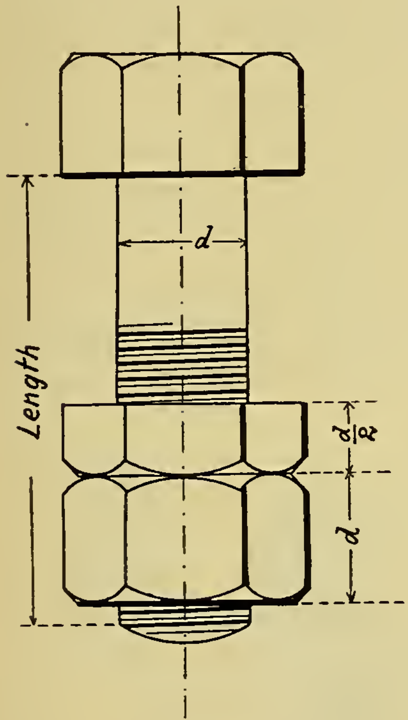


FIG. 352.

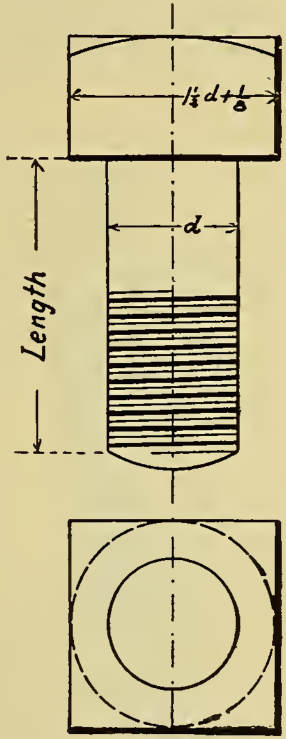


FIG. 353.

drawn through the points a, b, c and through e, f, g. The same is done in the other view in passing arcs through h, i, k and k, l and m. These arcs are struck with compasses, after a centre is found by trial with the compasses. The chamfer at a2 and g3 may be drawn by 45° lines, from the points a and g respectively.

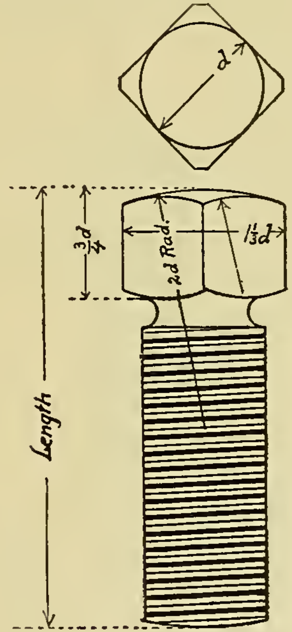


FIG. 354.

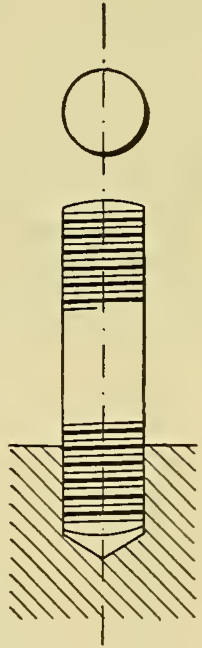


FIG. 355.

This is not the exact construction of the curves as they appear on a hexagonal nut. However, the exact curves are not of any importance on a working drawing, and it will be found that this practical shop method effects a material saving of time and trouble, particularly as the representation of heads and nuts is of very frequent occurrence in machine drawing. In drawing a hexagonal nut or head, it is the general custom to show three faces of each.

A square nut or bolt head is generally shown by drawing one face of each only. Fig. 352 illustrates a bolt with hexagonal check nuts. It is more convenient to make both nuts of standard thickness, that is equal to the diameter of the bolt, although it is often found that the inner nut is made thinner. In the illustration the outer nut is chamfered on both faces.

In Fig. 353 a bolt with a square head is shown. The distances between the parallel faces of this head is equal to 1½ times the diameter of the bolt plus ⅛ inch. The height is equal to ½ the distance between the parallel faces. The arc for the chamfer of the head is usually drawn with a radius equal to 2½ times the diameter of the bolt.

A set screw is shown in Fig. 354. The figure illustrates all required proportions, as they are

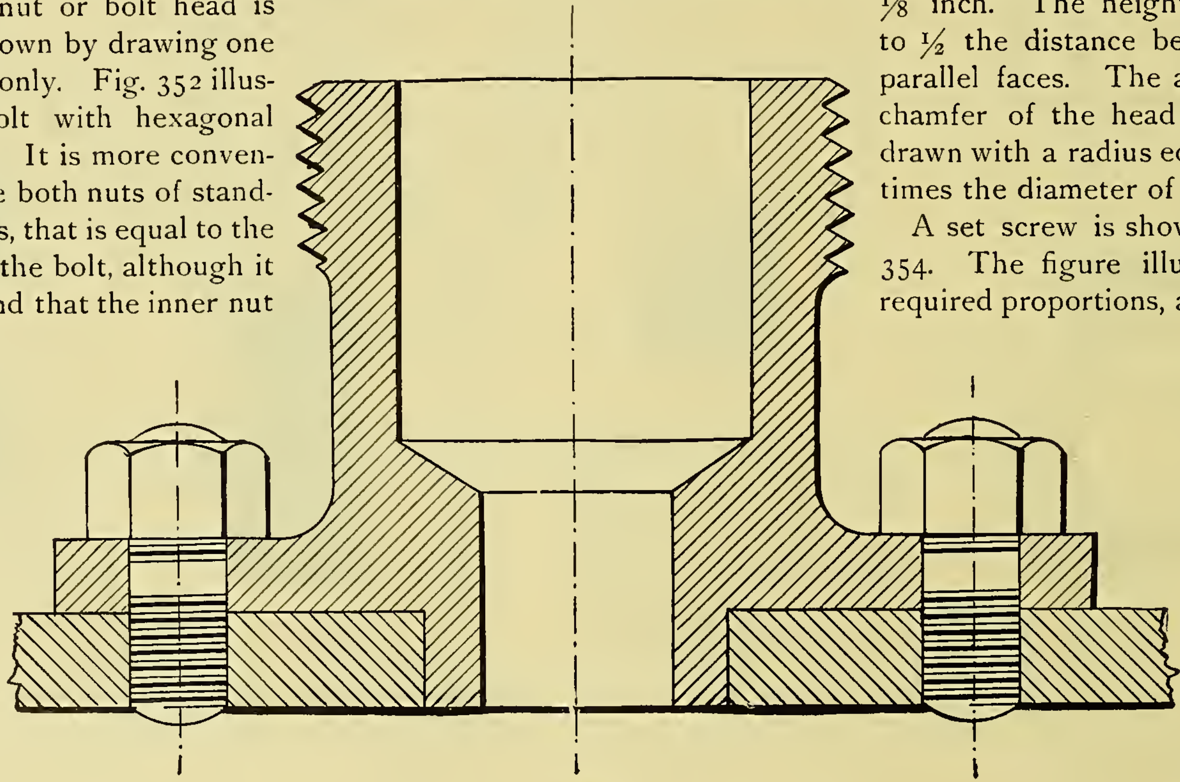


Fig. 356.

commonly used. The point of the set screw is usually made with an arc having a radius equal to four times the diameter of the screw.

A stud-bolt is one which is threaded at both ends, Fig. 355, one end being screwed into one of the

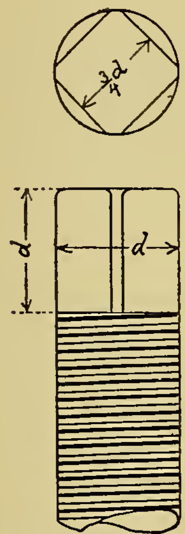


FIG. 357.

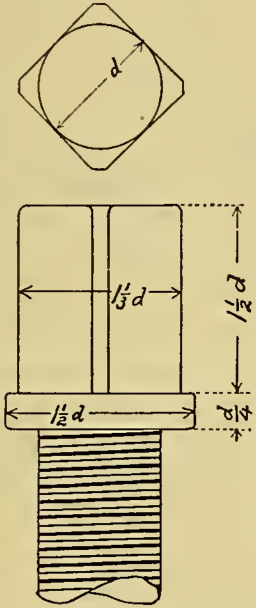


FIG. 358.

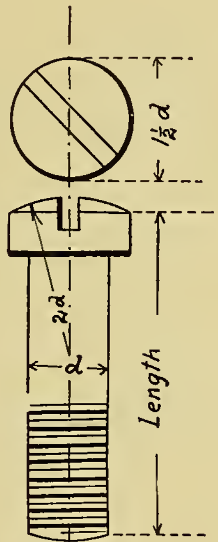


FIG. 359.

pieces of a machine to be connected, while the other end passing through the other piece, which is to be fastened to the first, carries an ordinary nut, as in Fig. 356, which illustrates how a stuffing box is fastened to a cylinder head.

The conventional way of representing screws with square heads is shown in Figs. 357, 358. A round head screw is shown in Fig. 359. The head of the screw is slotted. In the top view the parallel lines showing the slots should be drawn at an angle of 45° with a horizonal line. This head is particularly adopted for countersunk work.

In conclusion a few words are added concerning the strength of bolts. *The weakest part of the bolt is the section at the bottom of the thread.* The following is a table of the tensile strength of U. S. Standard Bolts at 5,000 lbs. per sq. in. :

TENSILE STRENGTH OF U. S. STANDARD BOLTS AT 5,000 LBS. PER SQUARE INCH.

DIAMETER OF SCREW.	TENSILE STRENGTH.	DIAMETER OF SCREW.	TENSILE STRENGTH.
$\frac{1}{4}$	134	$1\frac{3}{8}$	5,300
$\frac{5}{16}$	226	$1\frac{1}{2}$	6,400
$\frac{3}{8}$	339	$1\frac{5}{8}$	7,650
$\frac{7}{16}$	465	$1\frac{3}{4}$	8,800
$\frac{1}{2}$	625	$1\frac{7}{8}$	10,150
$\frac{9}{16}$	809	2	11,500
$\frac{5}{8}$	980	$2\frac{1}{4}$	15,600
$\frac{3}{4}$	1,500	$2\frac{1}{2}$	18,500
$\frac{7}{8}$	2,100	$2\frac{3}{4}$	23,000
1	2,750	3	27,200
$1\frac{1}{8}$	3,450	$3\frac{1}{2}$	37,700
$1\frac{1}{4}$	3,900	4	49,500

The figures in the second and fourth columns show the total load which can be sustained by bolts of the above diameters. In calculating the strength of a bolt the stress to which it is subjected by the use of the wrench must be taken.

The figures in the second and the fourth columns show the total load which can be sustained by bolts of the respective diameters. In calculating the strength of a bolt, the stress to which it is subjected by the use of the wrench must be taken into consideration. Small bolts frequently break because of this strain.

It is also necessary to take into account the manner in which the load is applied. As the nature of metal of the bolt may not be known as to its resisting strength, the value of the safe stress per square inch of section must be taken comparatively low, and it is advisable for the purpose of overcoming all difficulties here mentioned, not to take the safe stress higher than 5,000 lbs. per sq. in. as given in the table.

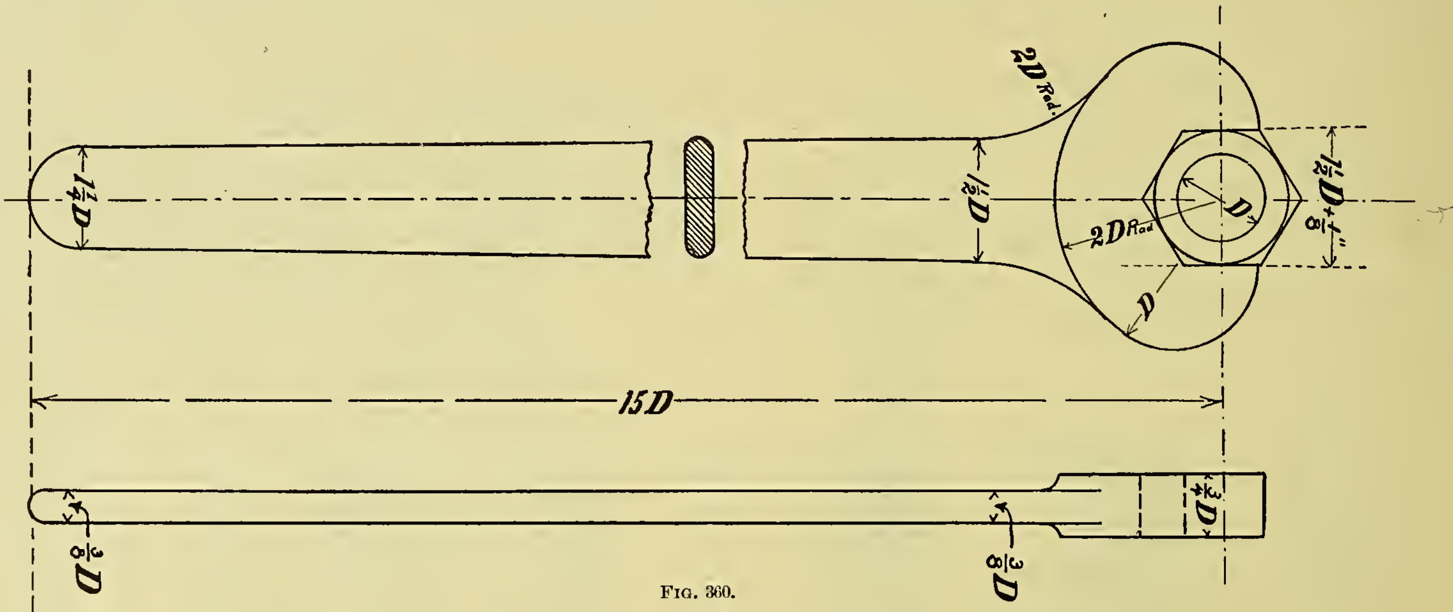


FIG. 360.

Fig. 360 shows the generally adopted proportions of a wrench. The wrench may be drawn for any size of a bolt head or nut, with the proportions of the parts as given in this illustration.

RIVETS AND RIVETED JOINTS.

For fastening together two or more comparatively thin pieces of metal, rivets are generally employed; their greatest application is found in boiler work, where the joining of plates by riveting is found to be the only practical method.

This method of fastening, however, is comparatively expensive and unsatisfactory in many ways; the rivets form a permanent fastening and can only be removed by cutting off one of the heads; this creates trouble and expense.

The process of punching the holes in the plates for riveting also has a serious effect by reducing the tensile strength of the plates by the disturbing influence of the punch on the metal near the riveted joints; for better work the holes are now generally made by drilling; this, again, is more expensive, especially without the use of multiple drilling machines.

The injury due to punching, when the plates have not been cracked by the process, may be remedied by annealing them after punching; the ill effect of punching may also be removed by punching the holes ⅛" smaller in diameter than the required size of the hole, which may then be completed by reaming.

Other injurious effects of punching are, 1, the difficulty of correct spacing by this method, and 2, the fact that a punched hole is always tapered, the wider end of the hole being that next to the die.

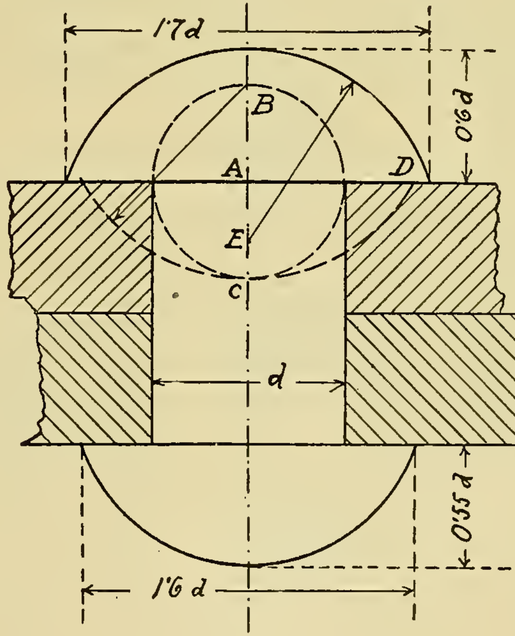


FIG. 361.

Rivets are made in different forms; that most commonly employed being of a spherical or cup head form, as illustrated in Fig. 361; both parts of this rivet show the spherical head.

The rivet shown in Fig. 362 has a conical head, the lower part showing a pan head. The right proportions of the parts of the above rivets are given in the illustrations.

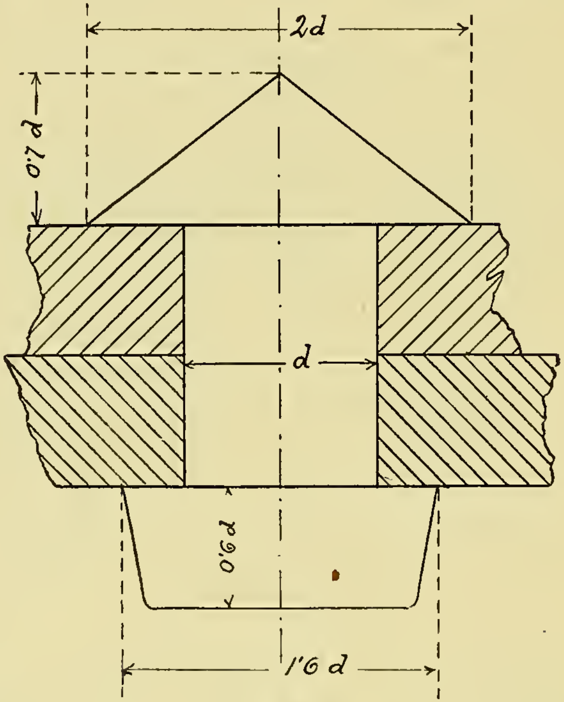


FIG. 362.

Fig. 363 shows a rivet with countersunk heads. The usual proportions of this kind of rivet are marked on the figure.

In all the above illustrations *the diameter of the rivet* is taken as the unit of all proportions.

The construction of the spherical head, Fig. 361, is as follows:

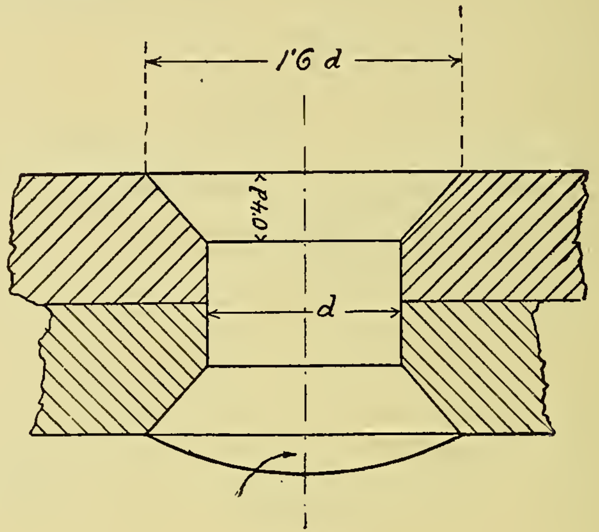


FIG. 363.

With a radius equal to one-half the diameter of rivet, from the center A on the vertical center line, describe a circle cutting the center line at the points B and C. Set the compasses to the distance BC and from the point B as center, describe an arc cutting the outline of the upper plate in the point D. Make BE equal to the distance AD and with E as center and CD as radius, describe the arc which forms the outline of the spherical head.

The construction of the other kinds of rivets may be easily understood from the illustrations without special explanation.

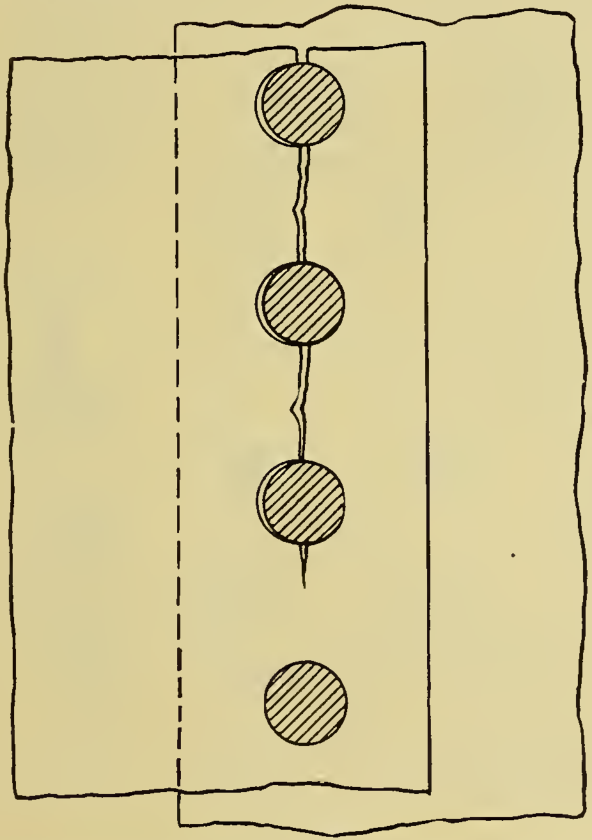


Fig. 364.

The length of the rivet required to form the head is about 1¼ times the diameter of the rivet. For countersunk rivet heads, a trifle more than one-half of this amount is allowed.

Riveted joints may give way because of the tearing of the plates between the rivets, as illustrated in Fig. 364, by breaking of the plates between the

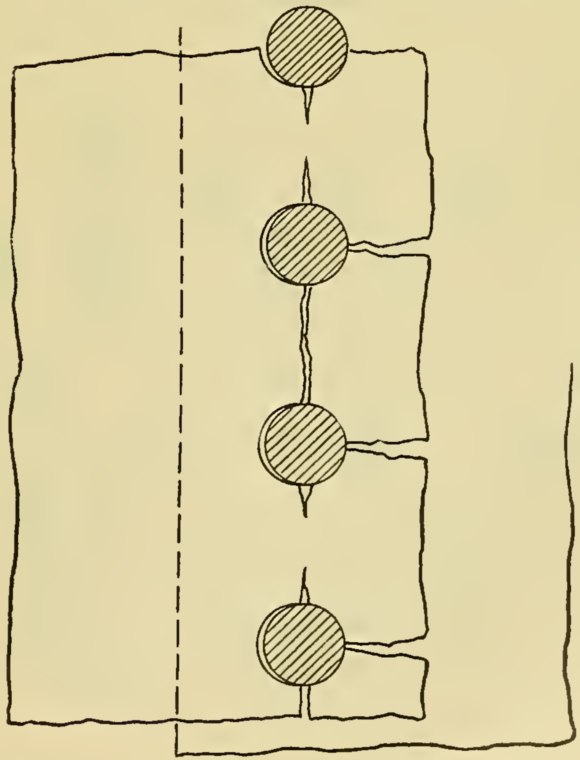


Fig. 365.

rivet holes and the edge of the plate, as shown in Fig. 365; by crushing of the plate or by crushing of the rivet, and by the breaking of the rivet through shearing, as indicated by Fig. 366.

By the pitch of rivets is meant the distance between the centers of two adjoining rivets, in a single riveted joint, that is where the seam is formed by one row of rivets, Fig. 367. When more than one row of rivets make the joint, the pitch is the distance between the center lines of rivets in the same row, Fig. 368.

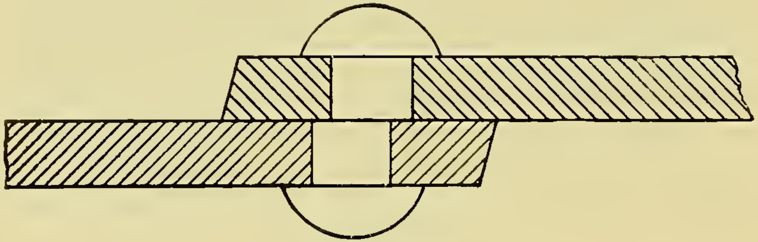


FIG. 366.

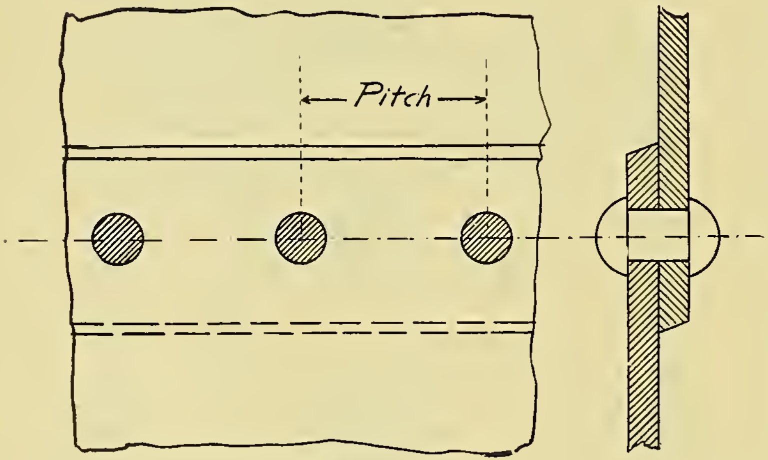


FIG. 367.

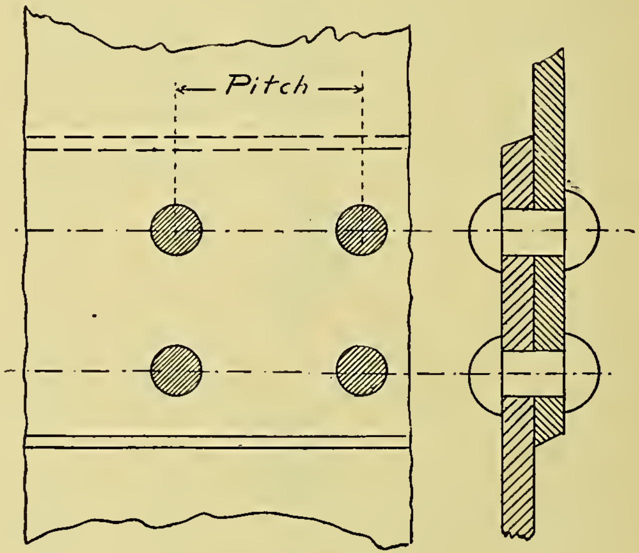


FIG. 368.

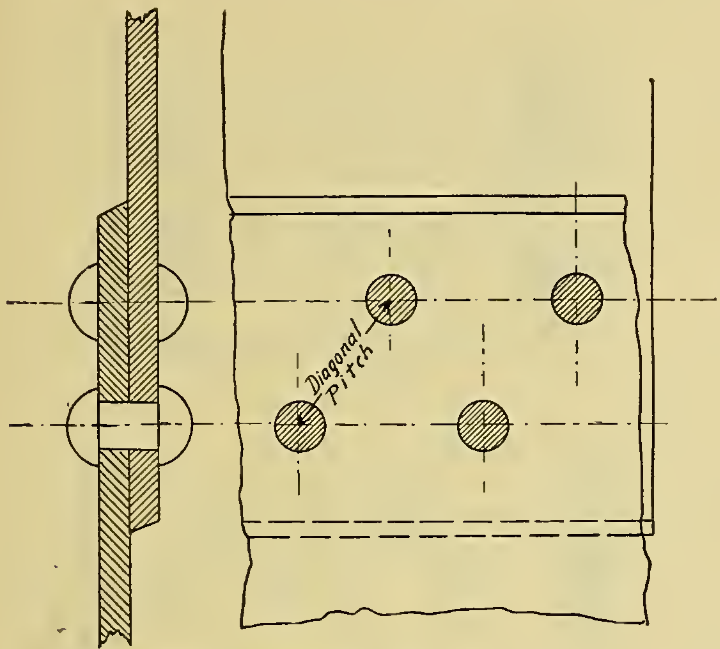


FIG. 369.

The distance between the centers of two adjoining rivets, both in the same diagonal row is called the diagonal pitch, Fig. 369.

The strength of a riveted joint depends upon the arrangement of the rivets and upon their proportions.

Since a rivet may part either by shearing or by crushing, it is necessary for a given thickness of plate to find the proper diameter of a rivet having

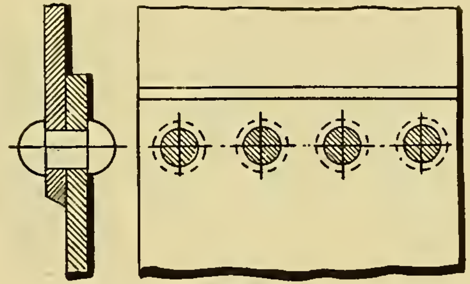


FIG. 370.

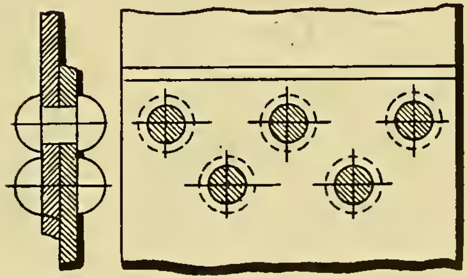
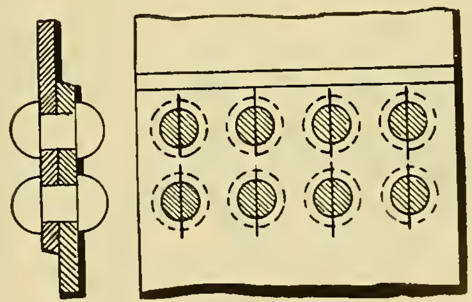


FIG. 371.



equal shearing and crushing strength. The relation between the thickness of the plate and the diameter of the rivet, calculated for single shear, is

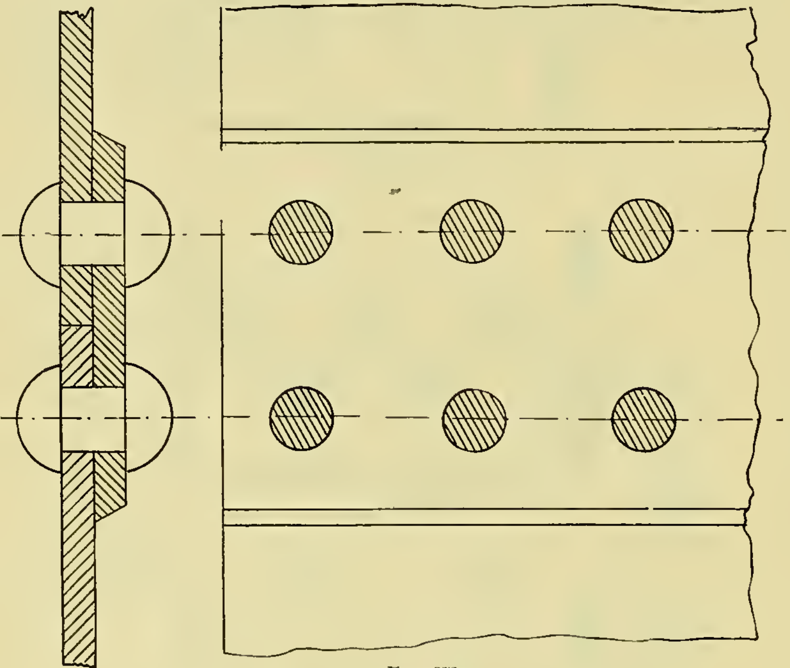


Fig. 373.

expressed by the following formulæ, of which the first is true for iron rivets and the second for steel rivets:

d=2.06 t for iron rivets.

d=2.28 t for steel rivets.

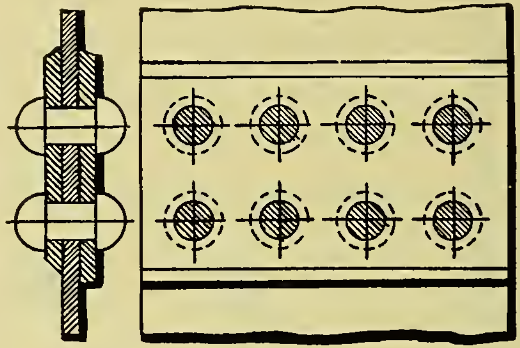


Fig. 374.

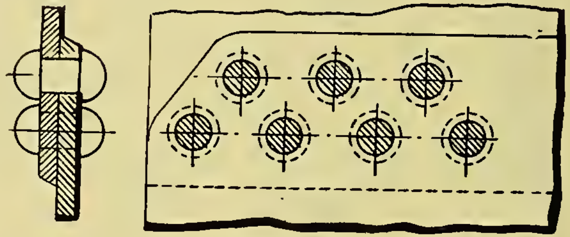


Fig. 375.

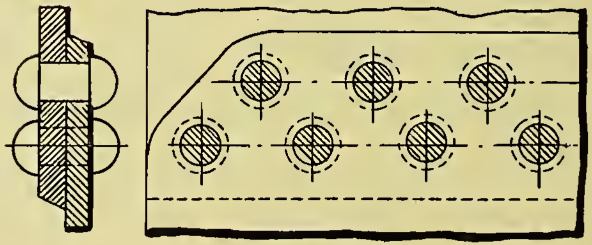


Fig. 376.

d expresses the diameter of the rivet and t stands for the thickness of the plate.

For plates thicker than 3/8-in. the diameter of the rivet may be smaller in proportion to the thickness of the plate than is required by these formulæ.

The proportions commonly observed in practice for lap-joints and single-strap butt-joints is given in the following table:

Thickness of plate in inches.	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$
Diameter of rivet in inches.....	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	1	1	$1\frac{1}{8}$	$1\frac{1}{4}$

Numerous styles of riveted joints are in general use. The two classes into which the different styles may be divided are the lap-joint and the butt-joint.

In the lap-joint, Fig. 370, the plates overlap each other. Figs. 371, 372 show other examples of this form of riveted joint.

Fig. 373 shows a butt-joint. Here the plates are butted against each other and a cover plate or strap is placed over their junction and the rivets passed through the plates and strap. Fig. 374 shows a butt-joint with two cover plates.

The examples of joints thus far illustrated differ as to the number of rows of rivets that are used for the seam. Fig. 370 is a single-riveted joint. The butt-joints shown in Figs. 373, 374, are also single-riveted. In a single-riveted joint the edge of each plate is pierced by only one row of rivets.

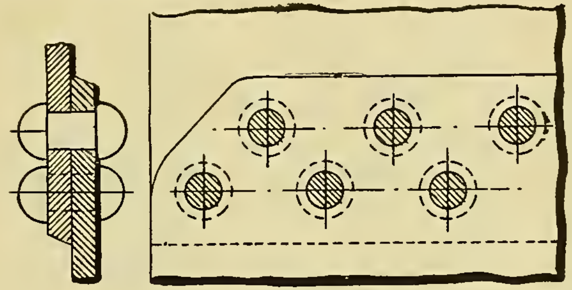


Fig. 377.

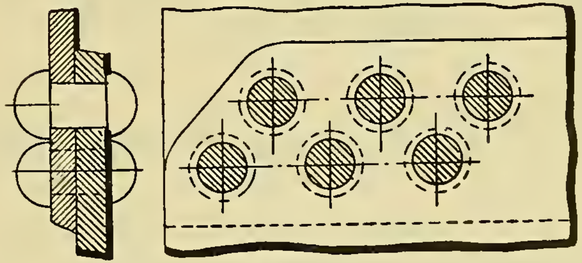


Fig. 378.

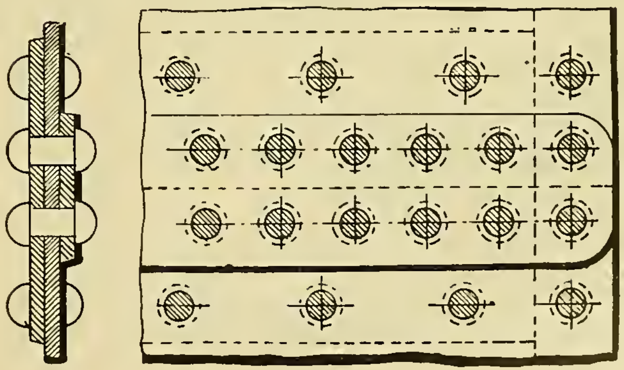


Fig. 3.9.

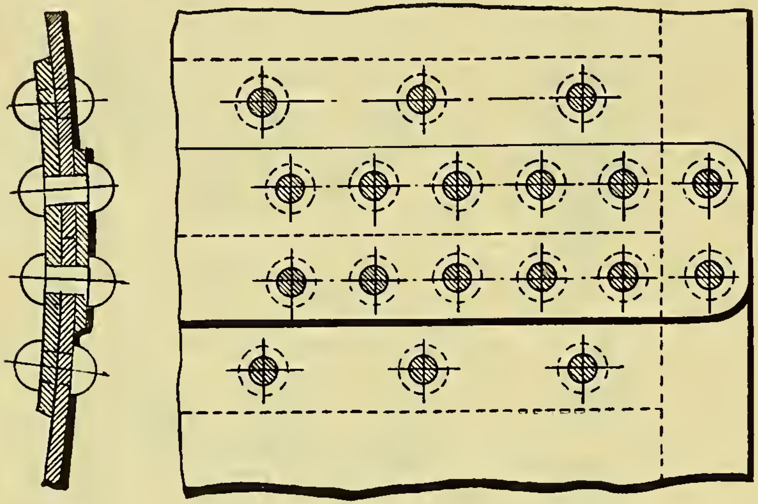


Fig. 380.

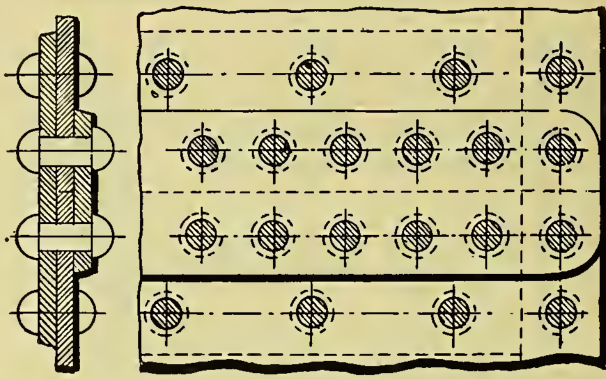


Fig. 381.

A similar joint for 5/8" plates is also shown in Fig. 376. Here the pitch is 2 3/4" and the rivets 15/16", the holes being made 1". Another joint of the same

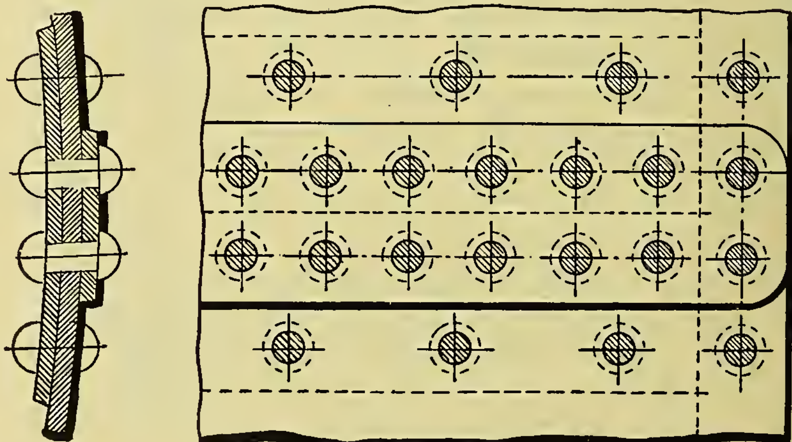


Fig. 382.

Figs. 371 and 372 show double-riveted joints; here the edge of each plate is pierced by a double row of rivets. When the rivets are opposite each other, as in Fig. 372, the seam is known as chain-riveted.

When the positions of the rivets in one row are opposite the spaces between the rivets in the other row, the seam is staggered.

The following illustrations are examples of riveted joints taken from practice in boiler work.

Fig. 375. A double-riveted lap-joint for two 1/2" plates, having 13/16" rivets, 7/8" holes. The pitch of the rivets in this case is equal to 2 1/2".

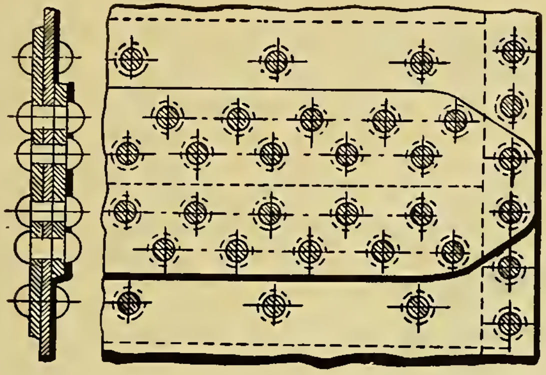


Fig. 383.

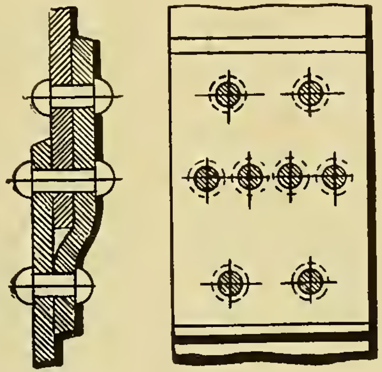


Fig. 385.

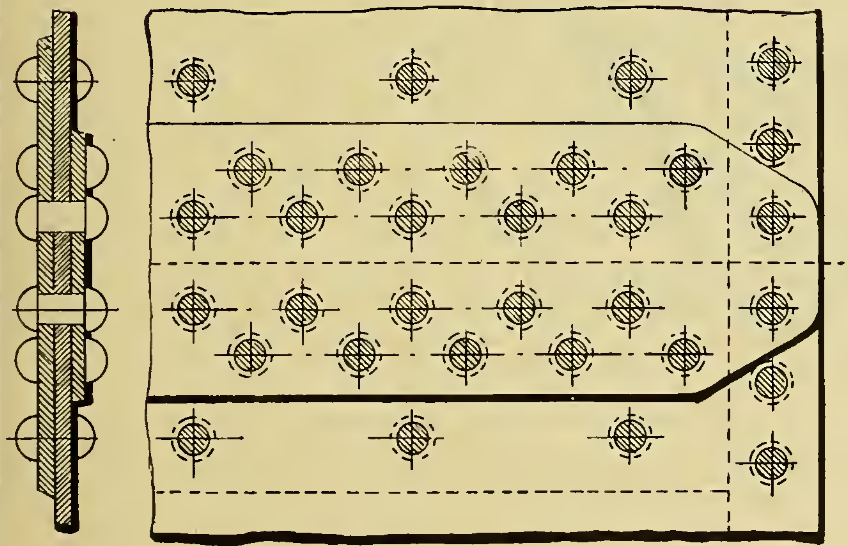


Fig. 384.

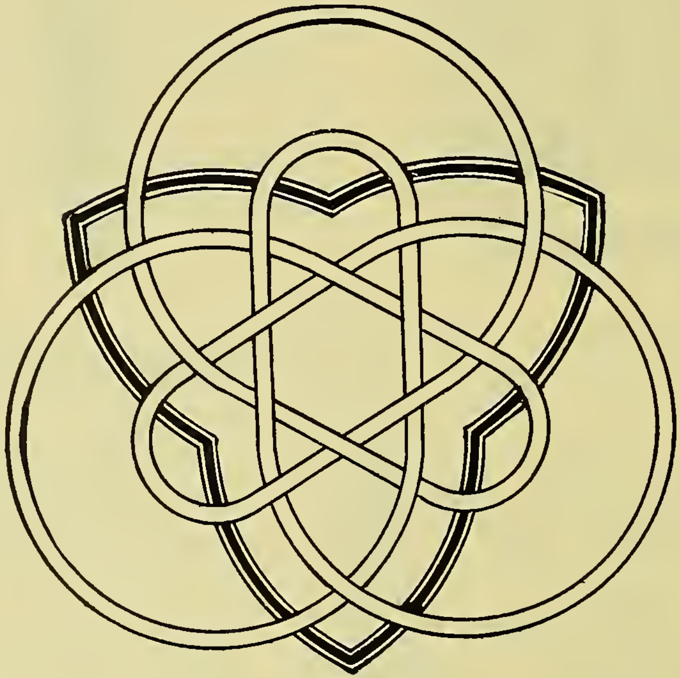
character is illustrated in Fig. 377. Here the plates and rivets are the same as in Fig. 376; the pitch, however, is 3½″.

In the double-riveted lap-joint shown in Fig. 378, the plate is $\frac{11}{16}$″, the rivets $1\frac{1}{16}$″, the holes are made $1\frac{1}{8}$″ and the pitch is 3″.

A butt-joint with double cover plates is illustrated in Fig. 379. Here the plate is $\frac{5}{8}$″ steel and 1″ rivets. The inner covering strap is ⅞″ thick, the outside strap is equal in thickness to that of the plate.

Similar joints are shown in Figs. 380, 381, 382, 383 and 384.

The joint shown in Fig. 385 is not used very frequently.



POWER TRANSMISSION.

The oft-repeated word *transmission* comes from two Latin words, *trans*, across, or over, and *mittere*, to send, hence, to carry from one place to another; the illustration of a few devices for the transmission of power from *its cause* to its place of *useful employment* is the limit of this section of design.

Prime movers or receivers of power, are those pieces or combination of pieces of mechanism which receive motion and force directly from some natural source of energy; the mechanism belonging to *the prime mover may be held to include all pieces which regulate or assist in regulating the transmission of energy, from the source of energy or power.*

Throughout this preliminary sketch, power and energy are used synonymously.

The useful work of the prime mover is the energy exerted by it upon that piece which it directly drives; and the ratio which this bears to the energy exerted by the source of energy is the *efficiency* of the prime mover; in all prime movers the loss of energy may be distinguished into two parts, 1, *necessary loss;* 2, *waste.*

The sources of power in practical use may be classed as follows: (a) Strength of men and animals, (b) Weight of liquids, (c) Motion of fluids, (d) Heat, (e) Electricity and magnetism. *The duty of a prime mover* is its useful work in some given unit of time, as a second, a minute, an hour, a day.

Among the first examples of power transmission may be mentioned the case of a man hauling up weight with a rope or pushing or pulling an oar or capstan; in these instances the man is the prime mover and the duty performed is the raising of the weight and the moving of the vessel.

The various combinations of mechanical powers *produce* no force: they only *apply* it. *They form the communication between the moving power and the body moved;* and while the power itself may be incapable of acting except in one direction, we are able by means of cranks, levers, and gears, to direct and modify that force to suit our convenience. Every one may see examples of this in the construction of the most common pieces of machinery as well as in the most complicated.

SHAFTS.

When a shaft is rotated by a lever attached to it, as in Fig. 386, or by a pulley or a gear-wheel as in Fig. 387, and a force P is applied to the free end of the lever or to a point at the rim of the pulley or

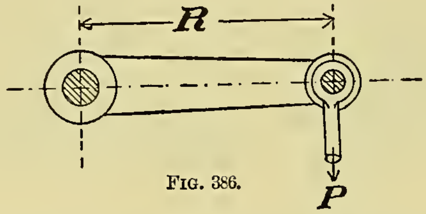


FIG. 386.

at the pitch-circle of the gear-wheel a twisting strain is produced on the shaft, this twisting strain causes a combination of stresses within the fibres of the

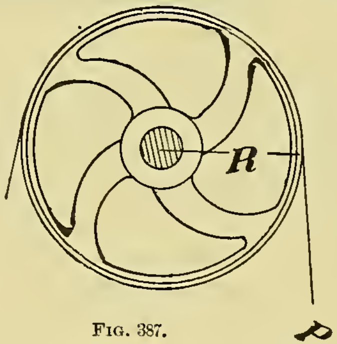


FIG. 387.

shaft, which mainly consist of shearing stress. The shearing stress is equal to nothing at the center of the shaft and it is greatest at its circumference. The twisting strain is obtained by multiplying the length of the lever, or the perpendicular distance from the point at which the force is applied to the center of the shaft, by the force P. If this distance be equal to R, Fig. 386, then $R \times P = T$, which is called the twisting moment and is expressed in inch pounds.

It is evident that the twisting moment must be equal to the resisting moment of the shaft.

For finding the diameter of a crank shaft of a stationary engine with cylinders up to 30″ in diameter some authorities recommend the following practical rule:

The diameter of the crank shaft is equal to the radius of the cylinder minus ⅛ of an inch.

In practice many different diameters are found performing the same work.

Now let T = twisting moment on shaft in inch pounds. N = number of revolutions of the shaft per minute. H = horse power transmitted, then the horse power equals

$$H = \frac{2 \times 3.1416 \times T \times N}{12 \times 33{,}000} = 0.00001587$$

The number 33,000 in this formula expresses 33,000 foot pounds of work performed per minute, and this amount of work is called one horse power.

The above formula gives a method of finding the horse power transmitted by a shaft.

RULE: Multiply the twisting moment in inch pounds by the number of revolutions per minute, and multiply the product by the number 0.00001587 the product will be the horse power transmitted by the shaft.

EXAMPLE:

Find the horse power transmitted by a shaft making 100 revolutions per minute, provided with a gear wheel 36 inches in diameter (pitch circle), the turning force being 4,000 pounds.

SOLUTION:

Multiply the pitch radius of the wheel,=18 inches by the force applied,=4,000 pounds, and multiply the product by the number of revolutions and by the number 0.00001587: Horse power= 18 × 4000 × 100 × 0.00001587=114.264.

From the above formula the following expressions are obtained:

$$T = \frac{12 \times 33{,}000 \times H}{2 \times 3.1416 \times N} = \frac{63025.21 \times H}{N}$$

From the same formula the twisting moment may be determined when the horse power transmitted by the shaft and the number of its revolutions are given.

The number of revolutions may also be obtained from the same formula; thus,

$$N = \frac{12 \times 33{,}000 \times H}{2 \times 3.1416 \times T} = \frac{63025.21 \times H}{T}$$

EXAMPLE:

To find the number of revolutions which a shaft must make per minute in order to transmit 114.264 horse power, when a force of 4,000 pounds acting on the pitch circle of a gear-wheel of 36″ in diameter produces the twisting moment.

SOLUTION:

The twisting moment in this case is equal to 18 × 4,000 = 72,000-inch pounds. To find the number of revolutions required divide the given horse power 114.264 by 72,000 and multiply the product by the number 63025.21 thus obtaining a quotient of 100.2 or the revolutions per minute.

When the twisting moment only is to be considered in calculating the diameter of a round shaft, which is to transmit a given horse power at a given speed, the following formula may be used:

The cube of the diameter of the shaft or,

$$D^3 = \frac{\text{Twisting moment}}{0.196 \times \text{stress in pounds per square inch.}}$$

The stress is taken in pounds per square inch at the outer fibres of the diameter of the shaft. For steel shafts the stress may be taken at 10,000 pounds and for wrought iron at 8,000 pounds per square inch.

Long shafts are subjected to combined twisting and bending actions.

Let B = bending moment;
T = twisting moment;
T_1 = the equivalent twisting moment.
Then $T_1 = B + \sqrt{B^2 + T^2}$.

In practice for long shafts in factories the following simple formula is recommended:

$$D^3 = \frac{125 \times \text{horse power}}{\text{number of revolutions of shaft.}}$$

The speed of the shaft depends upon the speed of the driving belt or by the diameters of the pulleys upon it. Shafts in machine shops are run from about 120 to 150 revolutions per minute; wood working machinery shafts usually run from about 200 to 250 revolutions per minute. Shafts in woolen mills run up to 400 revolutions per minute. Line shafts should, as a rule, not be less than 1¾″ thick in diameter.

The distance between the centers of the bearings should not be great enough to permit a deflection of more than $\frac{1}{100}$″ per foot of length. The more pulleys are on the shaft the closer the bearings must be. The beams may be placed about 8 feet apart, and each beam to be provided with a hanger on its lower side. To prevent end motion on shafts a collar is placed on each side of one of the bearings.

JOURNALS.

That part of a horizontal shaft which rotates in a bearing is called a *journal.* The pressure of a shaft on a journal acts in a direction perpendicular to its axis. When the shaft is placed in an inclined position the pressure acts in a direction inclined to the axis of the shaft. The pressure of a shaft placed in a vertical position acts in the direction of its axis. The journal of a vertical shaft is called a pivot.

The diameter of a journal must be made as small as the required strength will permit and as long as is necessary to keep the pressure per square inch as small as possible. This pressure per square inch is not measured on a circumference of the journal but by the area of its projection.

EXAMPLE: A journal 3″ in diameter and 6″ long will have a projected area of 3 × 6=18 square inches. Now if the pressure of the journal is 300 pounds per square inch then the total pressure is equal to 18 × 300=5,400 pounds.

EXAMPLE: If the total pressure of a 3" diameter journal equals 5,400 pounds and it is desired not to exceed a pressure of 300 pounds per square inch then the length of the journal is found thus:

$$\frac{5{,}400}{300 \times 3} = 6 \text{ inches.}$$

EXAMPLE: If a given journal is 3 inches in diameter and 6 inches long and its total pressure is known to be 5,400 pounds, then the pressure per square inch of projected area is found as follows:

$$\frac{5{,}400}{3 \times 6} = 300 \text{ pounds.}$$

To find the pressure per square inch of projected area for a pivot bearing, multiply the square of the diameter of the shaft by .7854 and divide the total pressure of the shaft by the product thus found.

The magnitude of pressure per square inch varies greatly in different cases in practice. It is generally reduced where a greater speed is required. The maximum intensity of pressure on the main journal bearings of steam engines is 600 pounds per square inch for slow running and 400 pounds for high speed engines. Wherever possible it is advantageous to make long bearings, thus reducing the pressure by about 200 to 300 pounds per square inch.

Some manufacturers allow a pressure of 150 pounds per square inch for cast iron journals for factory shafts.

For pivot bearings the following pressures per square inch are given by a high authority, as being the most desirable.

1. Wrought iron pivot on gun metal bearing, 700 pounds.

2. Cast iron pivot on gun metal bearing, 470 pounds.

3. Wrought iron bearing on lignumvitæ bearing, 1,400 pounds.

According to the latest practice it seems, however, that, for pivots which have to run continuously, the above-mentioned pressures should be reduced to one-half.

BEARINGS.

The simplest form of a journal bearing for a shaft or spindle of a machine is simply a hole in the frame supporting the rotating piece. If it is necessary to increase the length of the bearing the frame must be made thicker in this particular place by casting bosses on it as shown in Figs. 388 and 389. Fig. 389 is an end view and 388 is a section of such a bearing. The above described form of bearing is not durable as it has no means of adjustment for taking up the wear, and it cannot be renewed without renewing part of the frame of the machine. It is therefore better to use the form of solid bearing shown in Figs. 390 and 391. In this case the hole is bored much larger than the journal, and lined with a solid bushing of soft metal, which can easily be replaced when worn. This arrangement requires a screw or key to hold the bushing in place; in most cases the bushing is driven into the hole with considerable force to prevent it from turning, see Figs. 390 and 391.

Bearings for horizontal shafts have different names, which indicate the manner in which they are used.

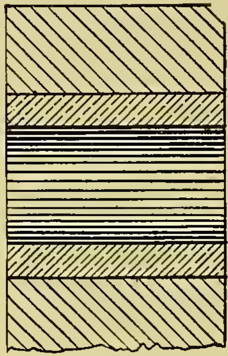


Fig. 390.

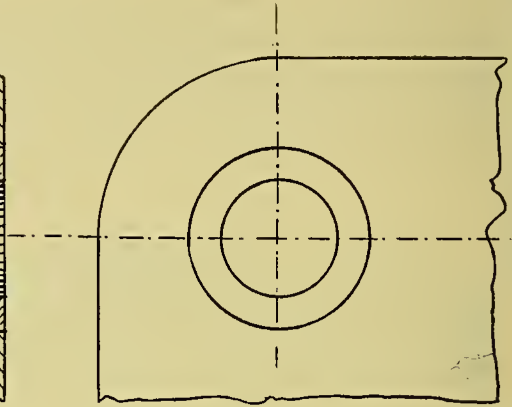


Fig. 391.

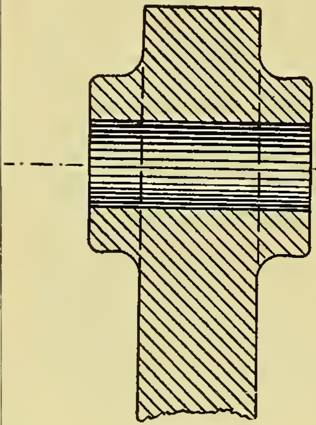


Fig. 388.

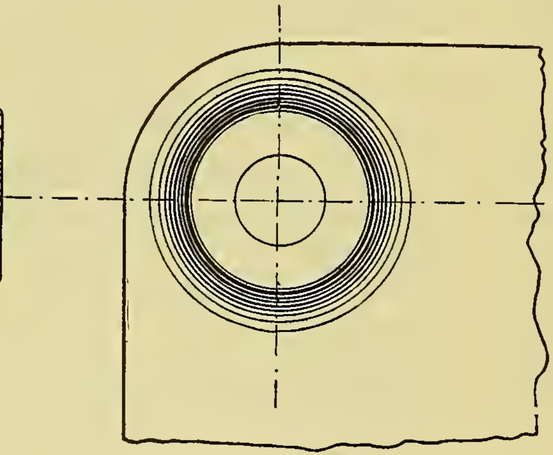


Fig. 389.

HANGERS.

When a bearing is suspended from the ceiling it is called a hanger. Figs. 392 to 395 show the various details of a hanger made by a leading manufacturer. Fig. 392 is a side view; Fig. 394 the longitudinal section. This design was first introduced by Sellers, and has been reproduced and modified by different manufacturers. It has a bearing box, Fig. 393, with a spherical center which is held between the ends of two hollow stems, all these parts are made of cast iron.

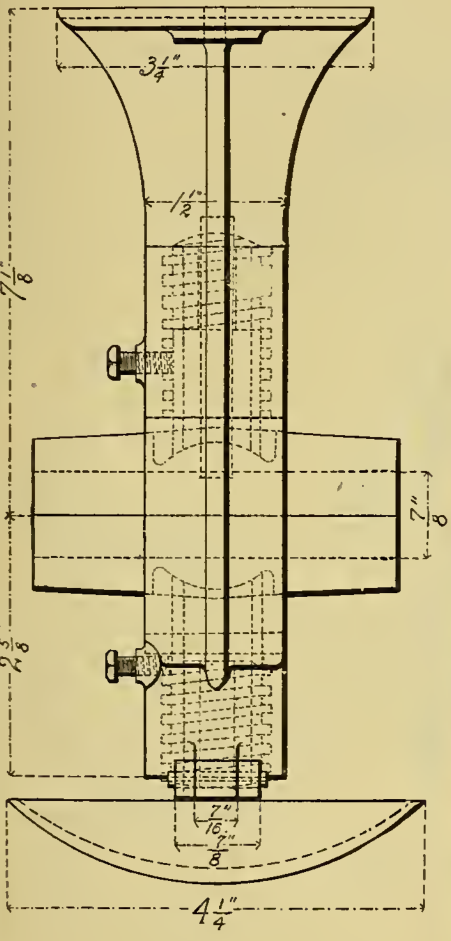


FIG. 392.

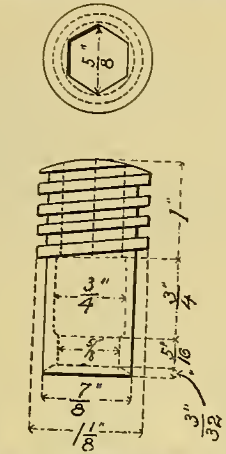


FIG. 395.

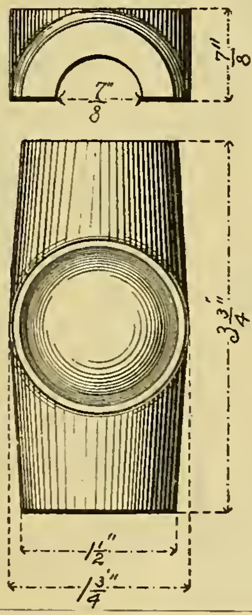


FIG. 393.

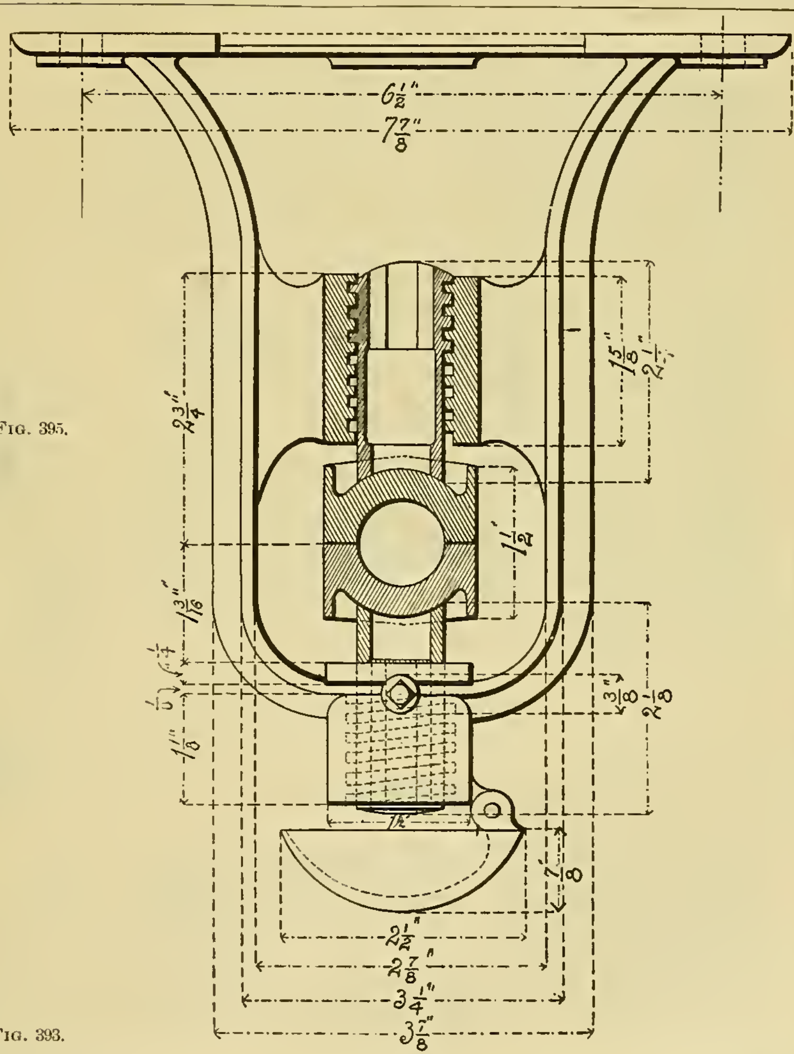


FIG. 394.

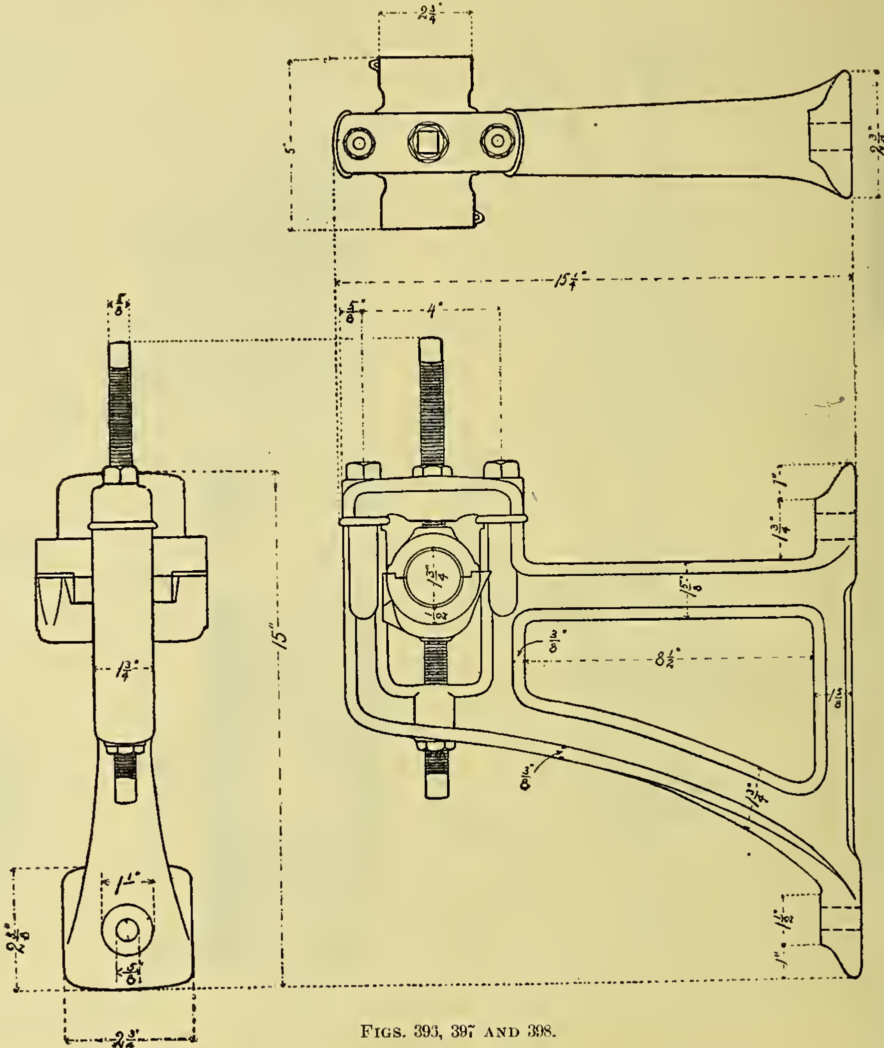
These stems, Fig, 395, are provided with screw threads at their outer ends, ordinarily shallow square thread. The bosses on the frame are also provided with a similar screw thread, into which fits the screw of the stem.

By means of the thread on the stems the height of the bearing can be adjusted, and the spherical centers allow a considerable adjustment in other directions.

This construction makes the setting up or lining up of shafting much easier and the hangers made as described above enjoy therefore the greatest popularity at the present time.

WALL BRACKETS.

When a shaft is to be supported by a bearing fixed to a wall or pillar, a wall bracket is generally used for this purpose. In Figures 396 to 398 is shown a form of a wall bracket of an elegant and most solid design.



FIGS. 393, 397 AND 398.

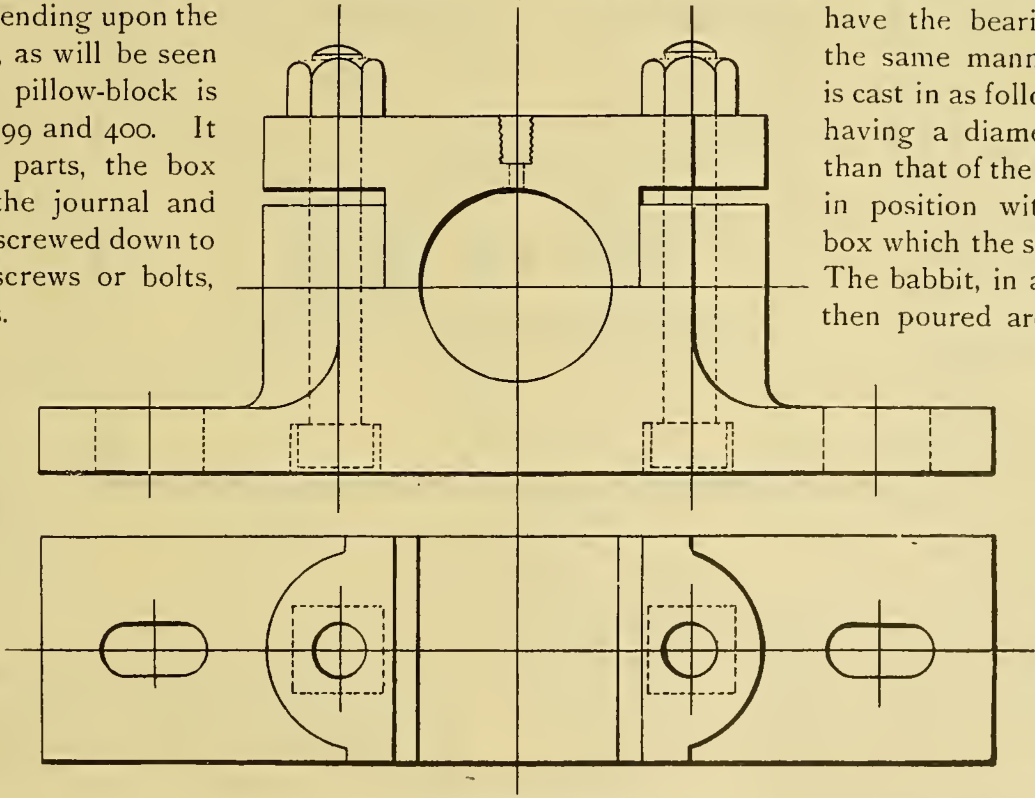
PEDESTALS AND PILLOW-BLOCKS.

The words pedestal, pillow-block, bearing and journal box are used indiscriminately.

A bearing designed to support a shaft above a floor or any fixed surface is called a pedestal or pillow-block, depending upon the type of bearing, as will be seen later. A simple pillow-block is shown in Figs. 399 and 400. It consists of two parts, the box which supports the journal and the cap which is screwed down to the box by two screws or bolts, called cap-screws.

Fig. 399 shows the front view of a complete pillow-block with cap and bolts. Fig. 400 is a top view of base with the cap removed. The seats in the journal-box are usually babbited, that is, lined with babbit, a soft metal whose composition is as follows: One pound of copper, ten pounds of tin and one pound of antimony. To hold the babbit in place recesses are cast in the cap and base, extending almost across the entire width of the bearing. The hangers as well as the wall brackets shown above have the bearings babbited in the same manner. The babbit is cast in as follows: A mandrel, having a diameter a trifle less than that of the journal, is placed in position within the bearing box which the shaft is to occupy. The babbit, in a molten state, is then poured around it and the bearing is then bored to the proper diameter.

Instead of using babbit for the friction surfaces in bearings other metals, such as brass, gun metal or other alloys may be used.



FIGS. 399 AND 400.

The melting point of these metals, however, is so high, that they cannot be poured into the box and cap directly, as in the case of a babbited bearing.

They consequently are made as separate pieces, called steps or brasses, and are fitted into the box and cap in different ways.

In some cases, where very little, and slow motion is required, the method described in Figs. 390 and 391 may be employed.

The bearing in this case is made by boring a hole through the casting, and the brasses consist of a simple sleeve, which is called a bushing.

This bushing is simply turned off and bored, and is then forced into the hole. Bearings that are made in halves, for the taking up of wear, and for removing the shafts, are fitted with two brasses however, the bearing and the cap brass. In this case the outside of the brasses is often made square or octagonal, fitting into recesses of similar shape in the box and cap of the pillow-block. This is done to prevent them from turning with the shaft.

To prevent the brasses from sliding out endwise, they are provided with a shoulder on each end, which fits over the ends of the bearing. Brasses of the octagonal type as well as their application are fully illustrated in Figs. 402 to 404. When a shaft is to be supported a considerable distance above the floor, the pillow-block is placed on a standard.

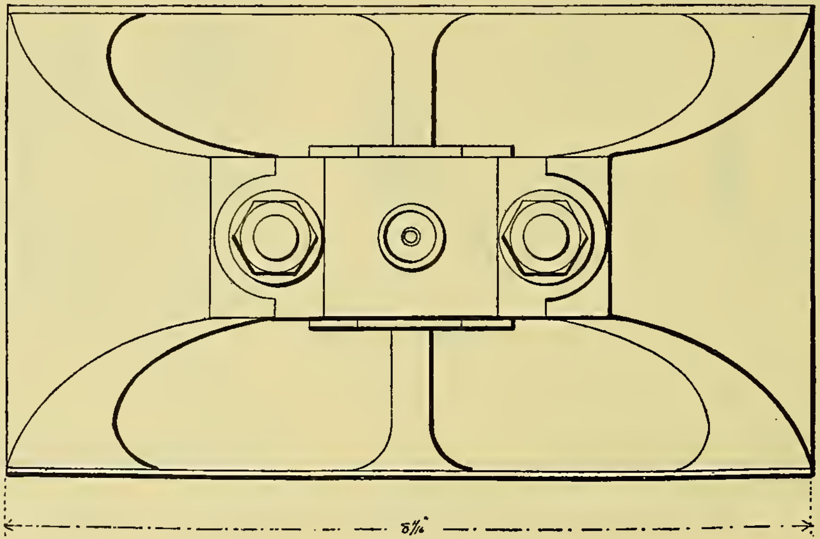


FIG. 401.

This standard may be cast separate from the pillow-block, and in this case both are fastened together by bolts.

NOTE.—Brasses are made from different alloys which vary according to the judgment of the designer. Some engineers recommend the following composition: Six pounds of copper, one pound of tin and to every hundred pounds of this mixture one-half pound of zinc and one-half pound of lead are added.

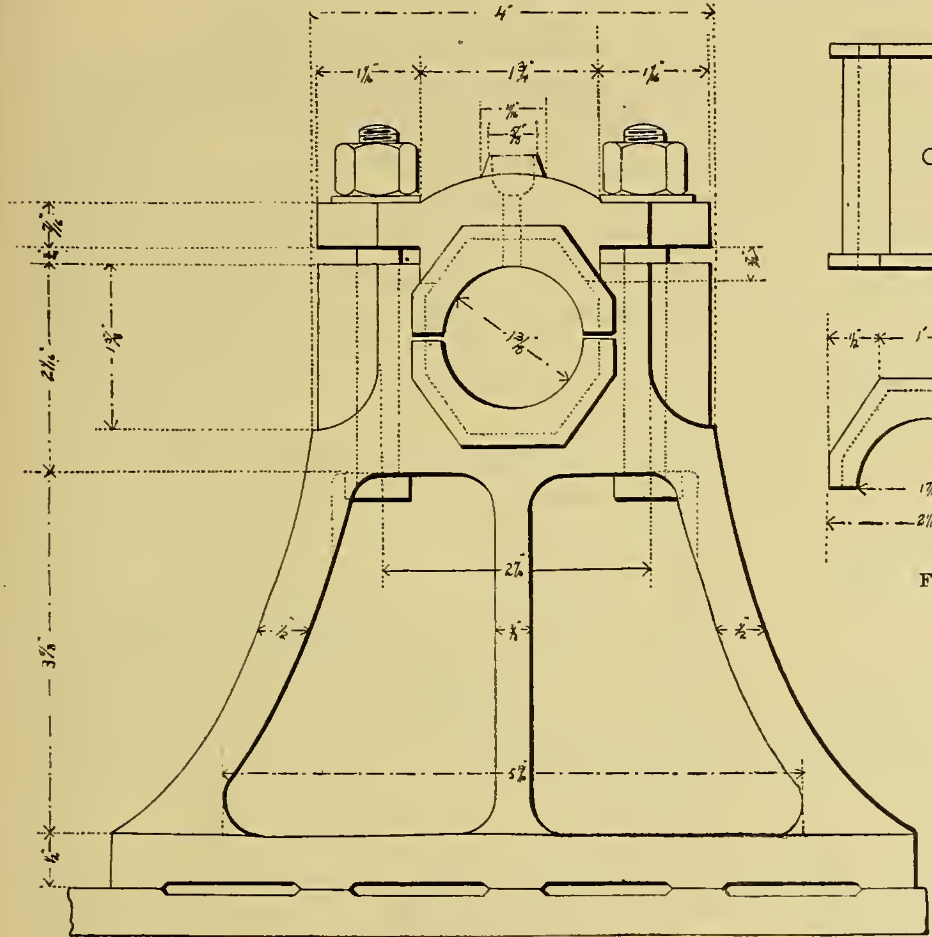


FIG. 402.

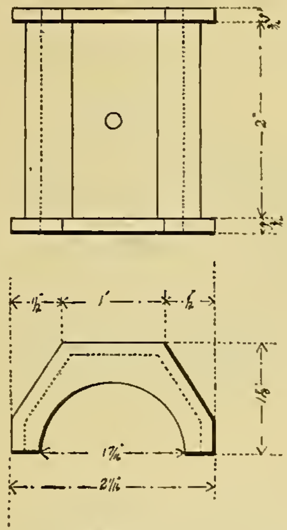


FIG. 404.

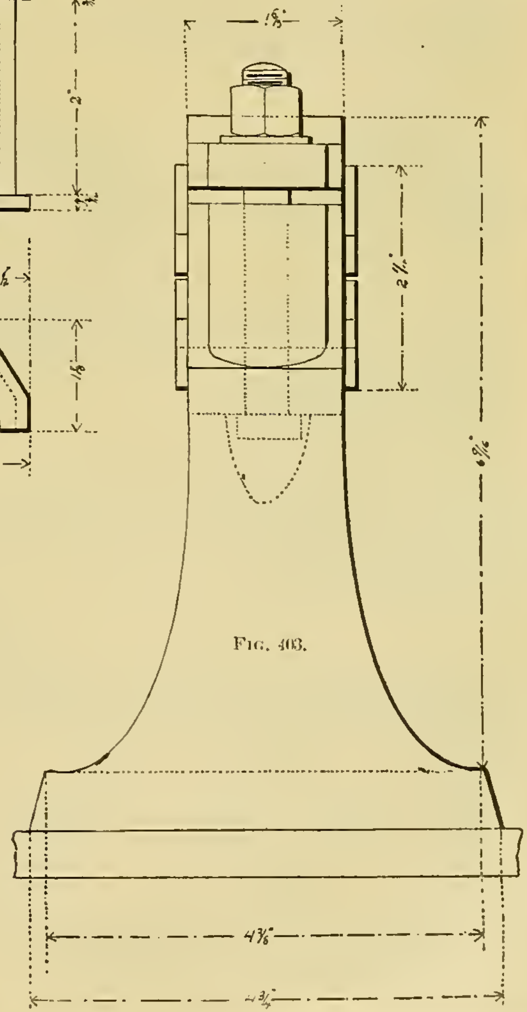


FIG. 403.

Very often, however, the pillow-block and standard are cast in one piece and it is then called *a pedestal.*

A pedestal is shown in Figs. 402 to 404. Fig. 403 is a front elevation and 402 shows its top view. Fig. 404 represents a side view of the pedestal.

The various parts of this pedestal are exactly the same as in the above-described pillow-block with the exception that the seats or steps in this case are of an octagonal shape.

There is no established standard of proportions for the parts of a bearing; the proportions of pillow-blocks made by different manufacturers vary considerably.

A pedestal for supporting a very small shaft is often obtained by turning a hanger upside down, reversing, of course, the bearing.

Such small pedestals are usually called *floor stands.*

The main bearings of large engines with girder beds are also often called pedestals.

BELTS AND PULLEYS.

Belts most commonly used are made of leather; they may be single or double; in damp places, canvas belts, covered with rubber are sometimes used; leather belts are usually run with the hair side on the outside or away from the pulley. Long belts when running in any other than a vertical direction, will work better than short belts, as their own weight holds them firmly to their work.

Fig. 405 shows an open belt, and Fig. 406 a cross-belt.

Pulleys connected by open belts run in the same direction, while those connected by cross-belts run in opposite directions. When two pulleys are connected by a belt, the motion of one, *the driving pulley*, is transmitted to the other pulley, *the follower.* If we assume that there is no stretching or slipping of the belt, every part of the circumference of the follower will have the same velocity as the driving pulley being equal to the velocity of the belt passing over them.

If the pulleys are of different diameters, for instance, if the driver has a diameter two times greater than the diameter of the follower, the latter will make two complete revolutions for each revolution of the driver. This ratio between the speeds of two pulleys is expressed in the following

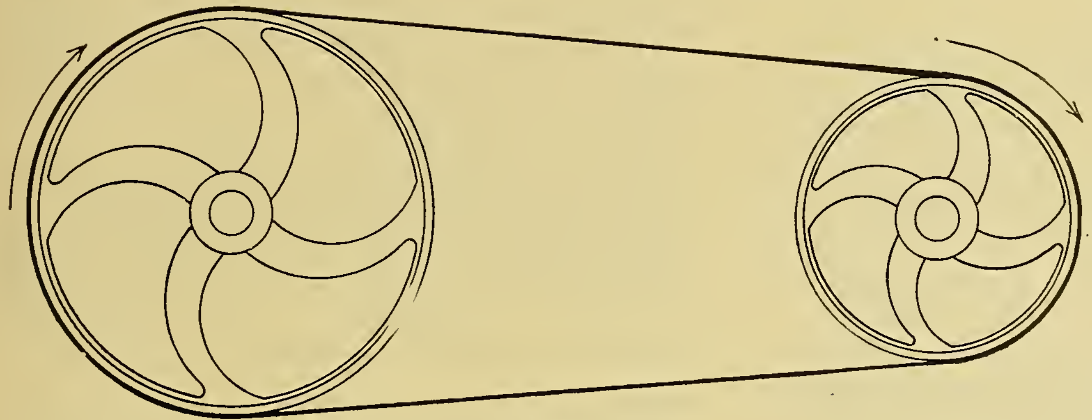


Fig. 405.

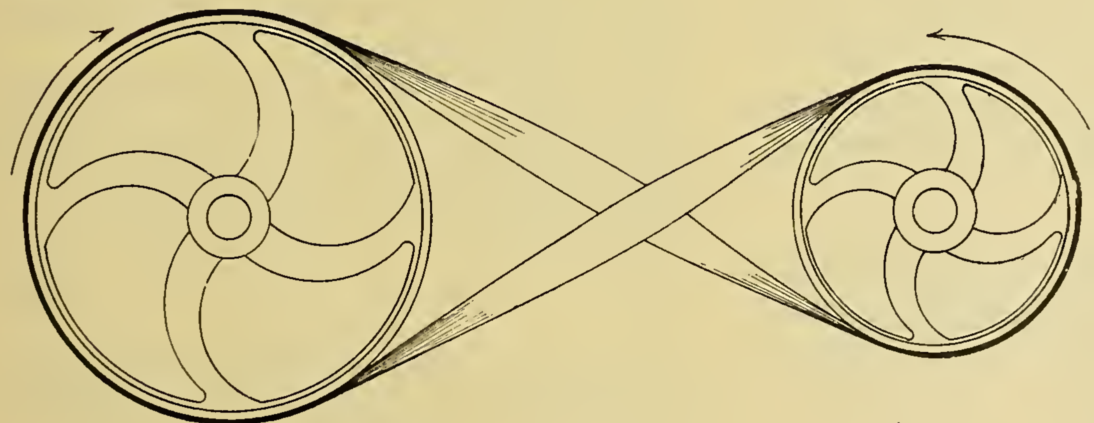


Fig. 406.

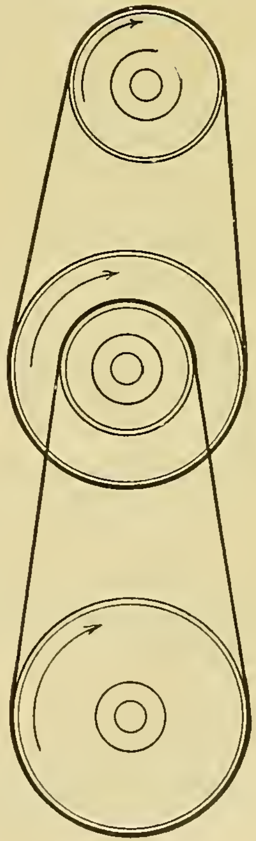


Fig. 407

RULE:

The number of revolutions of two connected pulleys are inversely proportional to their diameters.

This may be expressed in the following formula:

$$\frac{\text{Number of revol. of first pulley}}{\text{Number of revol. of second pulley}} = \frac{\text{Diameter of second pulley}}{\text{Diameter of first pulley}}$$

EXAMPLE:

A pulley 40″ in diameter, making 300 revolutions per minute, drives a second pulley 20″ in diameter. How many revolutions per minute does the second pulley make?

$$\text{No. of revol. of second pulley} = \frac{40 \times 300}{20} = 600 \text{ revol.}$$

To find the revolutions of the follower:

Multiply the diameter of driver by its number of revolutions, and divide the product by the diameter of the follower.

EXAMPLE:

The follower is 20″ in diameter and makes 150 revolutions. What is the size of the driver used on a driving shaft that makes 200 revolutions per minute?

$$\text{Diameter of driver} = \frac{150 \times 20}{200} = 15 \text{ inches, that is,}$$

the diameter of the driver is found by multiplying the diameter of the follower by its number of revolutions, and dividing the product by the number of revolutions of the driver.

For four pulleys connected by belts, as shown in Fig. 407, the following rule is to be applied:

The number of revolutions of the first pulley, multiplied by the diameter of each of the drivers, equals the number of revolutions of the last pulley, multiplied by the diameter of each follower.

EXAMPLE:

Let the diameter of the drivers be 40″ and 30″, the diameter of the first follower 10″ and of the second follower 15″. What is the number of revolutions of the last shaft, when the first shaft makes 100 revolutions per minute?

Here the speed of the last shaft, multiplied by the diameter of the followers, 10″ and 15″, must equal the speed of the first shaft, 100 multiplied by the diameter of the drivers, 40″ and 30″; that is,

$$\text{speed of last shaft} \times 10 \times 15 = 100 \times 40 \times 30, \text{ or}$$

$$\text{speed of last shaft} = \frac{100 \times 40 \times 30}{10 \times 15} = 800 \text{ revol.}$$

When the number of revolutions of the first and last shafts are known, and it is required to find the diameters of the pulleys, apply the following

RULE:

Divide the higher number of revolutions by the lower.

In a case where four pulleys are to be used, we find the numbers whose product is equal to the quotient resulting from the above division of the speeds. One of these numbers is taken as the ratio of the diameters of one pair of the pulleys, and the other number, of the other pair.

EXAMPLE:

It is required to run the last shaft with a speed of 1,500 revolutions, the driving shaft making 300 revolutions per minute. What size of pulleys are required when four pulleys are to be used?

The quotient resulting from division of the two speeds, equals $\frac{1500}{300} = 5$. Two numbers whose product equals 5 are 2½ and 2. Consequently one pair of the pulleys must be taken in the ratio of 2½ to 1 and the other pair as 2 to 1. Therefore, the first pair may be 30″ and 12″ and the other pair 24″ and 12″

To find the speed of the belt:

Multiply the circumference of the pulley by the number of revolutions per minute.

EXAMPLE:

Let the diameter of the pulley be equal to 2 ft. and the number of revolutions per minute 100. Then, $2 \times 3.14 \times 100 = 628$ ft. per minute, the speed of the belt.

The relation between the speed of the belt in feet per minute, the width of the belt in inches, and the horse power to be transmitted, is expressed in the following practical formulæ:

The horse power to be transmitted is found by multiplying the speed by the width of belt and dividing the above product by 900; or

To find the required width of the belt, multiply the horse power to be transmitted, by 900, and divide the product by the speed; or

To find the speed in feet per minute, multiply the horse power by 900, and divide the product by the width of the belt.

EXAMPLE:

Two pulleys, each 2 ft. in diameter, connected by a belt, make 200 revolutions per minute. It is desired to transmit 20 H. P. What is the proper width of the belt to be used?

The speed of the belt is equal to $2 \times 3.14 \times 200 = 1{,}256$ ft. per minute; consequently the width of the belt equals

$$\frac{900 \times 20}{1{,}256} = 14.6 \text{ inches, or a belt } 14\tfrac{1}{2} \text{ inches.}$$

The above formulæ are true of a single belt. When double belts are used, made of two single belts cemented and riveted together through their entire length, they should be able to transmit twice as much power as a single belt, and even more.

The above formulæ may be applied to the calculation of double belts, provided the number 630 is put in the formula instead of the constant number 900. This will give the required proportions for belts, when used upon small pulleys, in which case more power is required for the transmission.

SPEED OF MACHINE TOOLS.

In selecting the speed of pulleys, the designer must be guided by the speed of the machine which is to be driven.

The speed of different machines varies according to the work which they perform, as, for example, the cutting speed of machine tools, or the velocity of emery wheels.

Grindstones in machine shops, suitable for grinding machinists' tools may be run with a peripheral speed of about 900 ft. per minute; grindstones for pattern makers' use, run about 600 ft. per minute.

Emery wheels may be run with a peripheral velocity of 5,500 ft. per minute.

Polishing wheels, such as leather-covered wooden wheels, or rag wheels, may run with a peripheral velocity of 7,000 ft. per minute.

The speed of cut for cast iron is 20 to 30 ft. per minute, for tool steel about 10 ft. per minute. Cutters in the milling machine may be run with a peripheral velocity of 80 ft. per minute for gun metal; 35 to 40 ft. for cast iron; and for machine steel about 30 ft. per minute.

EXAMPLE:

What is the proper number of revolutions of the spindle of a machine shop grindstone 24″ in diameter? The usual peripheral speed is 900 ft. per minute. The circumference of the given stone is equal to 2 ft. × 3.14 = 6.28 ft.

$$\frac{900}{6.28} = \text{about 143 revolutions per minute}$$

EXAMPLE:

Let the emery wheel in a grinder be 12″ in diameter, and let it be required to run the wheel with a peripheral velocity of 3,600 ft. per minute. What should be the speed of the spindle of this bench grinder?

The circumference of the wheel is 3.14 ft. Divide 3,600 by 3.14 and the speed of the spindle is found.

$$\frac{3{,}600}{3.14} = \text{about 1,150 revol.}$$

The following are rules recommended by practical experience for the use of belts.

Pulleys of small diameter, say of less than 18″, should not be used for double belts. Narrow, thick belts work better than thin ones. If wide belts are used, it is proper to increase their thickness.

This, however, is only true within certain limits; the tendency among engineers is to go to the extreme in this direction; it depends largely upon the class of work the belt is to be used for, and the only way anyone can claim to be expert in this line is through practical experience and good judgment.

The weakest part of the belt is at the joint; for this reason joints should be made very carefully according to the most approved methods; the same fastening does not answer for all belt-joinings.

It is not advantageous to place two pulleys connected by a belt too near one to the other. A distance of 15 ft. between the shafts for narrow belts running over small pulleys is a good average. Wider belts running over larger pulleys for good work require a greater distance between the shafts. 30 ft. is a good average for such cases. The distance between the shafts should not be made too great, as this may cause too much of a sag of the belt, which may produce such a pressure on the journals of the shaft as to injure them.

Running belts in a vertical direction should be avoided whenever possible. Machine tools driven by vertical belts require particularly good well-stretched leather belts, which must be kept very tight.

In tightening belts it must be remembered, that while tightening the belt, the pressure on the bearing is also increased, causing greater friction and wear on the bearing, especially with overhung pulleys.

The angle of the belt with a horizontal line should not exceed 45° whenever possible. Belts are not run advantageously when their speed exceeds 2,500 ft. per minute.

PULLEYS.

The rim of a belt pulley may be made either straight, Fig. 408, or convex, as in Fig. 409. It would seem that the belt would remain on the straight pulley more readily than on the convex one. Experience shows, however, that the belt always tends to run on the highest part of the pulley, provided it does not slip, in which case the belt will fall off more readily from a convex surface than from a straight rim of the pulley.

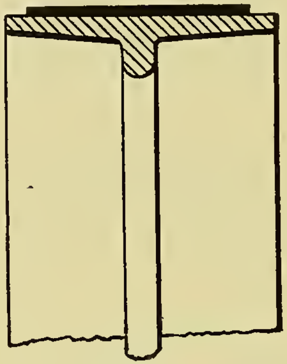


FIG. 408.

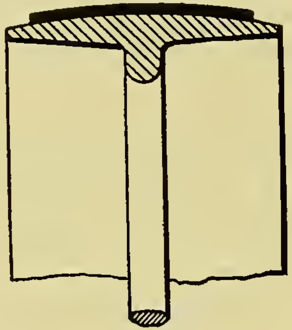


FIG. 409.

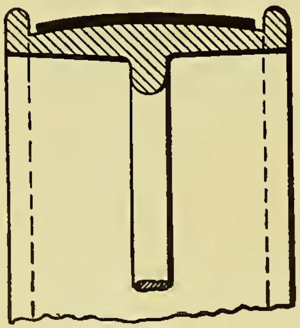


FIG. 410.

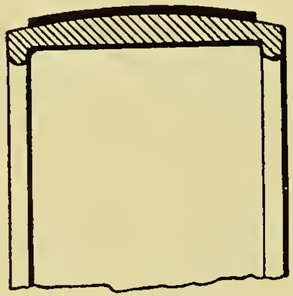


FIG. 411.

The flat or straight rim pulley is used where it is necessary to move the belt from one side of the rim to the other, as in the case where one pulley drives a pair of fast and loose pulleys.

Whenever there is frequent slipping off the rim of a belt, through a temporary increase in resistance, the pulley is provided with flanges, as shown in Fig. 410.

The amount of curvature in a section of the rim, is made greater, the faster the speed at which it runs. The curve may be an arc described with a radius equal to about 5 times the breadth of the pulley. The breadth of the pulley is generally made a little wider than the width of the belt, Fig. 411. The thickness of the rim at the edge may be found by dividing the diameter of the pulley by 200 and adding 1/8 of an inch. For a pulley 25″ in diameter, the thickness of the rim should be

$$\frac{25 \text{ inches}}{200} + \tfrac{1}{8} \text{ inch} = \tfrac{1}{4} \text{ inch.}$$

The thickness of the walls in the central part of the pulley, called the hub. is found by a formula given by Mr. Thomas Box, as follows:

Thickness of hub $= \frac{D}{96} + \frac{d}{8} + \frac{5}{8}$, where D is the diameter of the pulley and d the diameter of the shaft.

Prof. Unwin gives the following formulæ:

For a single belt, the thickness of hub $= 0.14 \sqrt[3]{BD} + \frac{1}{4}$ in.

For a double belt, the thickness of hub $= 0.18 \sqrt[3]{BD} + \frac{1}{4}$ in. where B indicates the breadth of the pulley. The length of the hub is made from $\frac{2}{3}$ B up to B. This is true for fast pulleys only.

The hubs in loose pulleys are usually longer than in fast pulleys. The hubs in loose pulleys need not be so thick, and they project about ¾ inch beyond each side of the face of the pulley. Fig. 412 shows loose and fast pulleys

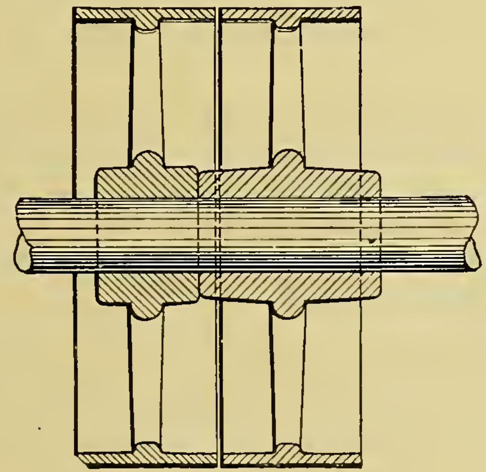


FIG. 412.

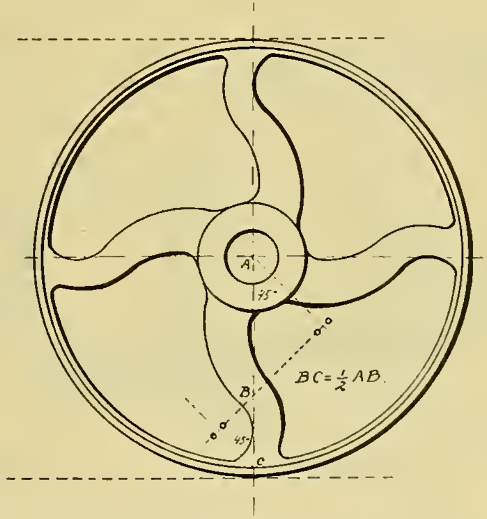


FIG. 413.

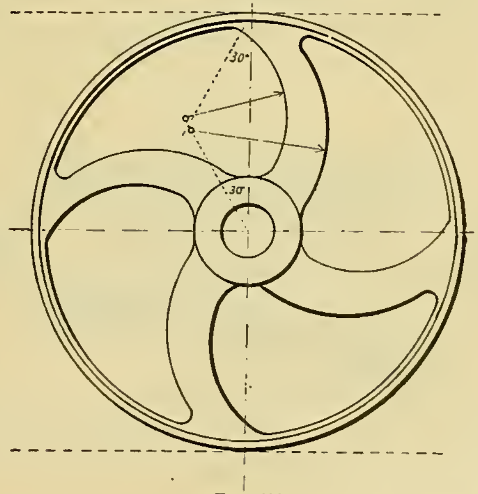


FIG. 414.

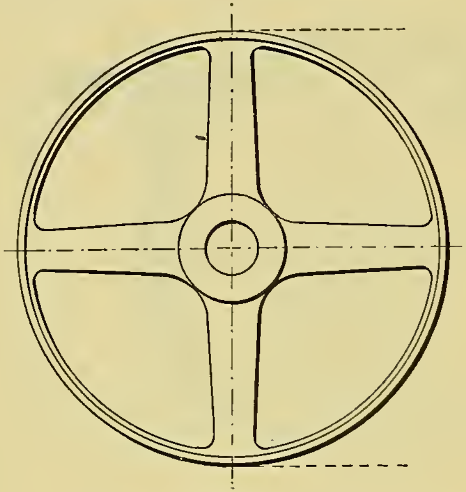


FIG. 415.

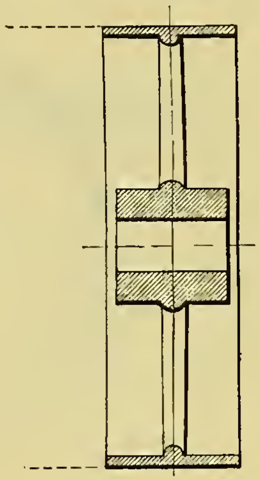


FIG. 416.

The arms of pulleys are usually straight, but sometimes they are curved, as shown in Figs. 413

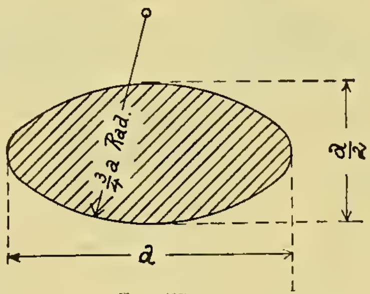


FIG. 417.

and 414. It is the general practice in machine shops to draw the section of a pulley, as shown in Fig. 416, no matter what shape the arms may have.

The straight-armed pulley is simplest in appearance and construction. There is no fixed rule for the number of arms in a pulley. Usually those up to 18″ in diameter have four arms, and those of larger diameters, six arms.

The cross-section of the arms of cast-iron pulleys is generally oval-shaped and of the proportions shown in Fig. 417.

The longest axis of the oval a, may be found from the following practical formulæ: the breadth a being taken at the center of the pulley, supposing the arm to be continued through the hub to that point.

$$a^3 = \frac{B\ D}{4\ N} \text{ for single belts, and}$$

$$a^3 = \frac{B\ D}{2\ N} \text{ for double belts.}$$

In these formulæ B is the width of the pulley, D is its diameter and N the number of revolutions per minute.

The proportions of the section of the arm near the rim may be two-thirds of the proportions given in the above formulæ.

It will be noticed that the breadth of the oval is given in the cubic power. To find the actual breadth a, multiply B by D, divide the product by 4 N and then find the cube root of the resulting number.

For varying the velocity of a shaft, speed cones are used, Fig. 418. As the belt will have a tendency to climb a conical pulley, special provision must be made for keeping the belt in place. It is also desirable to have both cones alike, so that they can be cast from one pattern.

Cone pulleys or speed pulleys, are frequently made in a series of steps, as shown in Fig. 419, in which case they are termed step-pulleys.

It is an established fact, that when two cones are placed with their centers at a given distance, and are so related that the sum of their radii remains constant, an endless cross-belt, containing both cones will not change in length in the smallest degree during the change in the actual diameter of each cone.

It is necessary to keep in mind the fact that the sum of the radii of both cones and the distance between their centers remain constant. As a result of this the sum of the radii of two opposite pulleys in a series of steps must be the same for all steps, as only with this condition will a crossed belt fit any pair of pulleys in the series.

Fig. 420 shows three sets of pulleys which may be arranged into a step pulley with three sets or steps. The distances between each set of pulleys is the same, and the sum of the diameters of the pulleys in each one of the three sets is also the same. As a result of these conditions the length of the crossed belt for all sets is the same.

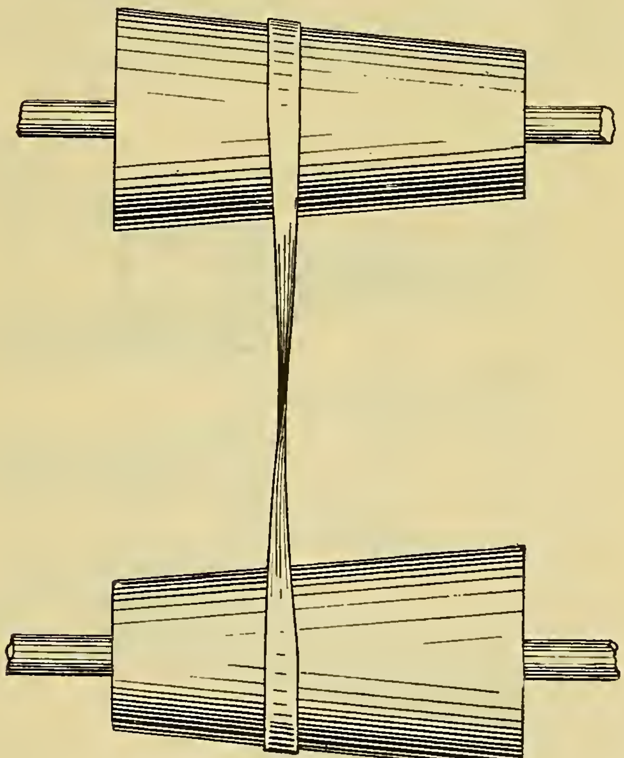


FIG. 418.

The above statement does not hold true for open belts. The middle sections of cone pulleys for open belts must be larger proportionately than for crossed belts.

In the pair of cone pulleys shown in Figs. 421 and 422, both are made alike, and the first one makes N revolutions per minute; let it be required that the second pulley should have a range of speed from m to n revolutions, m being the greater number. Then N must equal the square root of the product of m and n, thus, $N = \sqrt{m \times n}$.

The large diameter in the cone pulleys must equal the small diameter multiplied by the square root of the quotient of m divided by n.

As was remarked before, for open belts, the middle diameter of the cone pulleys must be made larger. If D and d are the large and small diameters of a cone pulley, then the proper middle diameter is equal to $\frac{D + d}{2} + \frac{0{\cdot}08\ (D-d)^2}{C}$, where C is the distance between the two shafts.

When the middle diameter is thus found, the

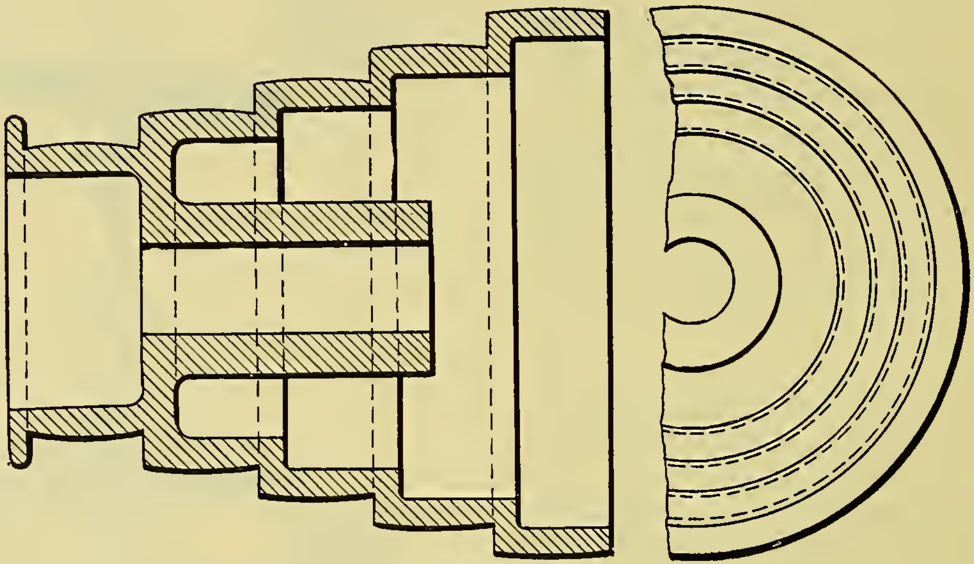


FIG. 419.

outline of the cone is laid out by an arc of a circle passing through the ends of the diameters D and d

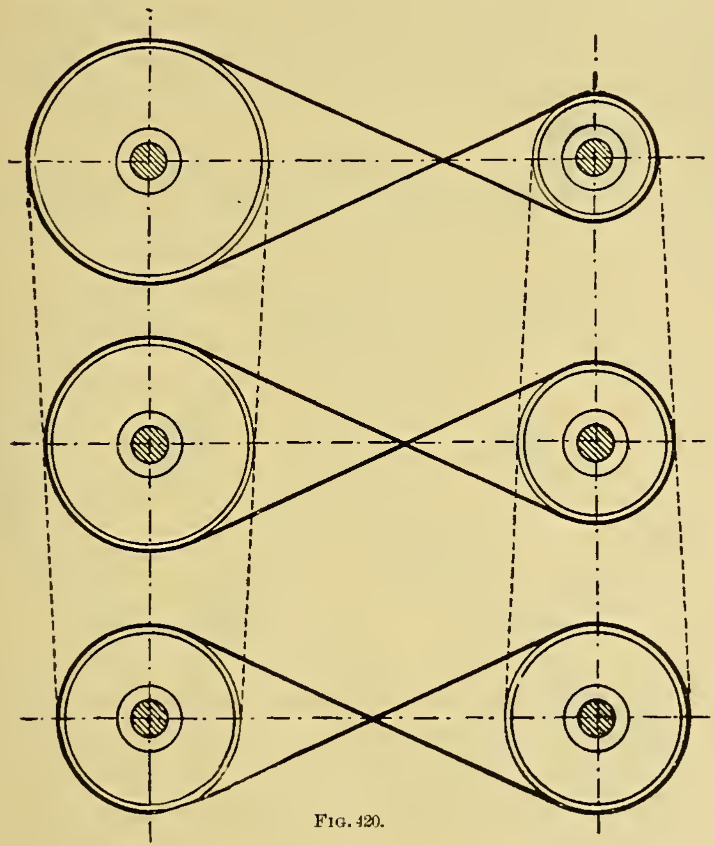
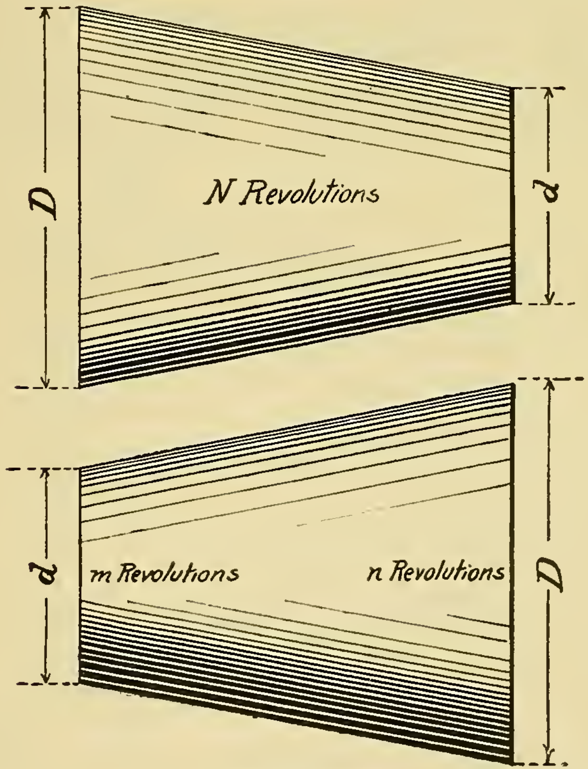


FIG. 420.

as well as the ends of the middle diameter. When it is desirable to substitute a step pulley for a continuous cone, A B D C, Fig. 423, the cone is divided into the required number of equal parts by parallel



FIGS. 421 AND 422.

lines, like E F, etc., drawn at equal distances. These diameters are then taken as center lines for the different steps.

GEAR WHEELS.

When two wheels with parallel axes, as shown in Fig. 424, are placed firmly together so as to form a rolling contact, the motion of one wheel, if there is no slipping, will produce a motion in the other

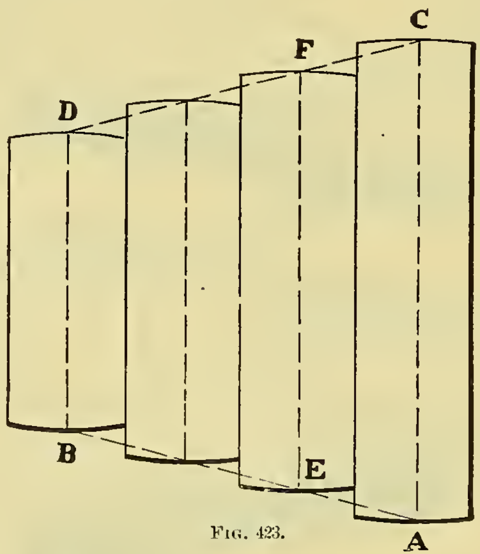


FIG. 423.

wheel; in this case a point on the rim of one wheel will travel exactly at the same rate of speed as any point on the rim of the other wheel; a rotation of this kind is called *a positive rotation.* Both wheels when in positive rotation by rolling contact, will have the same ratio of velocity, or as it is generally termed *a constant velocity ratio.*

The number of revolutions of the shafts will be inversely proportional to the diameters of the wheels, and this ratio will remain constant, provided there is no slipping.

With wheels having smooth surfaces it is impossible to maintain a constant velocity ratio, hence, to

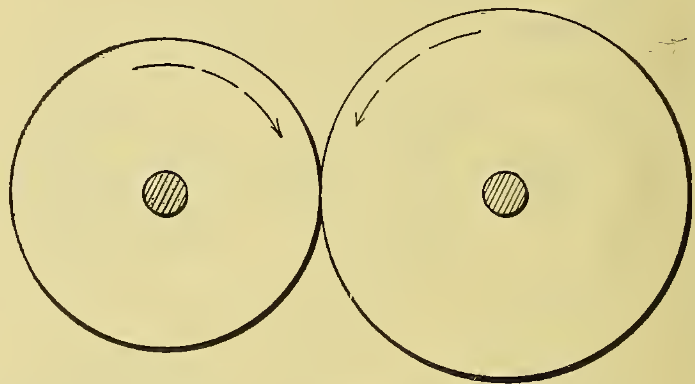


FIG. 424.

secure this condition, the wheels are provided with teeth which will enable them to rotate without the possibility of slipping.

To avoid a separate velocity for each tooth and to obtain an equal speed velocity in all parts of the wheel, the teeth are designed with proper proportions, which will be explained and illustrated hereafter.

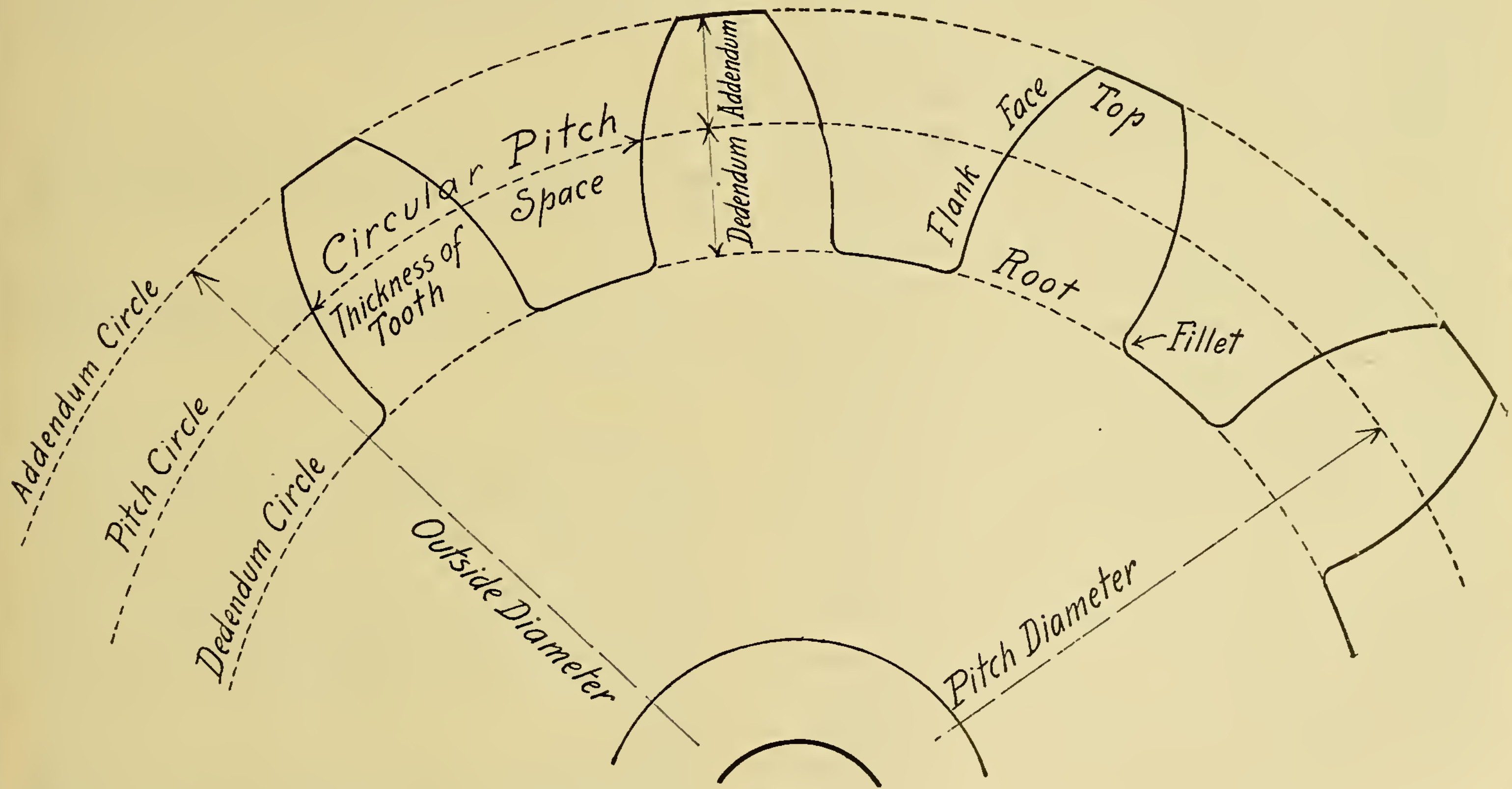

Circular Pitch
Addendum
Dedendum
Face
Top
Space
Flank
Thickness of Tooth
Root
Fillet
Addendum Circle
Pitch Circle
Dedendum Circle
Outside Diameter
Pitch Diameter

FIG. 425.

The rims of two imaginary wheels which have the same axes and which would have the same velocity ratio as two given gear wheels and the same width, form what are called *pitch surfaces;* the circles representing the section of both pitch surfaces, at right angles to the axes, are called *the pitch circles.*

The part of a tooth in a gear wheel outside of the pitch circle is called *the addendum*, and the part of the outline or curve of the tooth on the addendum is called *the face of the tooth*, as shown in Fig. 425.

That part of the tooth inside of the pitch circle is called *the dedendum*, and the part of the surface of the tooth inside of the pitch circle forming the front or back of the dedendum is called *the flank of the tooth.* The point where the flank and the face meet is called *the pitch point* and is situated on the pitch circle. The circle passing through the tops of the teeth is called *the addendum circle* and *is equal in diameter to the blank or disc, from which the gear is to be cut.*

The circle passing through the bottom of the teeth is called the *dedendum circle.* The distance measured on the pitch circle between the pitch points of two consecutive teeth is called *the circular pitch of the gear wheel.* The circular pitch includes one thickness of tooth and one space between teeth; *the circular pitch is equal to the circumference of the pitch circle divided by the number of teeth in the gear wheel.*

EXAMPLE:

If the diameter of the pitch circle is equal to D. The circumference of the pitch circle is equal to $3.1416 \times D$. Let the number of teeth in the wheel be N. Then $\frac{3.1416 \times D}{N}$ is the circular pitch.

By *diametral pitch* is meant the number of teeth in the gear per one inch of its pitch circle diameter.

EXAMPLE:

If the diameter of the pitch circle is equal to D inches, and the number of teeth equals N; then $\frac{N}{D}$ = diametral pitch.

The diametral pitch expresses in a direct and simple manner the ratio between the diameter of the pitch circle and the number of teeth. Usually it may be expressed by a whole number and therefore its form is convenient for expressing the proportions of the teeth, which are usually dependent upon the pitch, for this reason nearly all gear calculations are made in terms of the diametral pitch.

RULE:

To change the diametral pitch to circular pitch, divide 3.1416 by the diametral pitch. To change the circular to diametral pitch, divide 3.1416 by circular pitch.

The proportions commonly adopted for gears made with precision, are as follows:

The addendum equals 1 divided by the diametral pitch.

EXAMPLE:

If the diametral pitch equals 2 then the addendum equals ½. *The pitch circle diameter, plus twice the addendum equals the blank diameter of the gear.*

The dedendun is equal to the addendum, plus the bottom clearance. The clearance is generally equal to $\frac{1}{10}$ the thickness of the tooth, measured on the pitch line.

The thickness of the tooth and width of space, measured on the pitch circle, are each equal to one-half the pitch, on carefully cut gears; in practice, however, it is customary to make the width of the space slightly larger than the thickness of the tooth, in order to allow for inaccuracies of workmanship and operating, unavoidable because of the difficulty of producing theoretically correct gears. This is particularly necessary in cast gears. The difference between the thickness of the tooth and the width of space is called *the back lash;* the amount of back lash necessary for a gear must be left to, the best judgment of the designer; in cast iron gears it is sometimes equal to $\frac{1}{12}$ of the circular pitch; this is good practice only for very rough castings.

The flank and the dedendum circle are joined by small arcs, to avoid sharp corners at the root of the tooth. These are called *fillets* and are usually made with a *radius equal to one-seventh of the distance between two consecutive teeth, measured on the addendum circle.*

When two gear wheels with parallel shafts are turning one the other, the distance between the centers of the shafts is equal to the sum of the pitch diameters of both gears divided by 2.

EXAMPLE.—Let D equal the pitch diameter of one wheel and d the pitch diameter of the other wheel; then the distance between the centers in this pair of gear wheels is $\frac{D + d}{2}$

The number of teeth is found by dividing the circumference of the pitch circle by the circular pitch. If the diametral pitch be given, the number of teeth is found by multiplying the pitch diameter by the diametral pitch.

The pitch diameter is found by multiplying the number of teeth by the circular pitch and dividing the product by 3.1416.

If the diametral pitch is given, the pitch diameter can be found by dividing the number of teeth by the diametral pitch.

The diameter of the blank equals the pitch diameter plus 2 divided by the diametral pitch.

If the number of teeth and the diametral pitch are known, add 2 to the number of teeth and divide by the diametral pitch.

Gears may be classified as follows:

Spur Gears for shafts which are parallel; in this case the pitch surfaces would be cylinders.

A gear wheel with a comparatively small number of teeth is termed a pinion. Bevel gears for connecting shafts which intersect when lengthened. The pitch surfaces in this case are cones. Bevel gears of the same size connecting shafts at right angles are called miter gears.

If the shafts are neither intersecting nor parallel, the pitch surfaces will be hyperboloids of revolution and the gears are called hyperbolic or skew gears. In all gears enumerated up to the present, the teeth are made with rectilinear elements and the pitch surfaces touch each other along straight lines.

Worm Gears are used for connecting shafts which are at right angles to each other and which do not meet when lengthened indefinitely in either direction. The pitch surfaces meet in spiral lines. When the pitch circle is made with a diameter indefinitely increased, it will become a straight line and the gear is termed a rack.

There are two kinds of teeth generally used and classified according to the methods of producing them; these are involute teeth and cycloidal teeth.

The cycloidal system of gearing was, for a long time, used almost exclusively; of late, however, the involute system is rapidly gaining in popularity and many engineers advocate its general application in all cases.

Involute teeth are of greater strength and will run well with their centers at varying distances and still transmit uniform velocity. The chief objection that has been raised against involute teeth is the obliquity of action, causing increased pressure upon the bearings.

If a flexible line be wound around a circle, and the part which is off the circle is kept stretched and straight, any point in it will describe a curve which is the involute of the circle.

To draw the involute to a given circle, PABCO, Fig. 426. Divide the given circle into any number of equal parts by the points P, A, B, C, D, etc., through which points draw tangents to the circle. Make the length Aa equal to the length of one division AP, the length Bb equal to two such divisions Cc to three divisions, Dd to four and so on. Through the points P, a, b, c, d, etc., draw the required curve, which is a portion of the circle's involute.

The outline of an involute gear tooth is made with a single curve, the involute of an especially selected circle which is called the base circle. The center of the base circle lies in the center of the pitch circle, and the base circle is always smaller than the pitch circle.

Different manufacturers make the base circle of an involute gear of different diameters. Brown and Sharp make the diameter of the base circle equal to 0.968 of the pitch circle. The ordinary method of finding the base circle is as follows:

If H is the center of the wheel and P the pitch circle, draw the addendum and dedendum circles, Fig. 427.

Take any point O, as the pitch point on the pitch circle and draw a radial line HH through this point. Draw a line EE making an angle of 75° with the radial line HH. The base circle is found by drawing inside of the given wheel, a circle tangent to the inclined line, EE (which line is called the line of action). Let the base circle intersect the line HH at the point W. From this base circle the involute is drawn, passing through the point W and extending to the point V on the addendum circle. The part of the flank between the base circle and the dedendum circle is straight and is part of the radius of the circle.

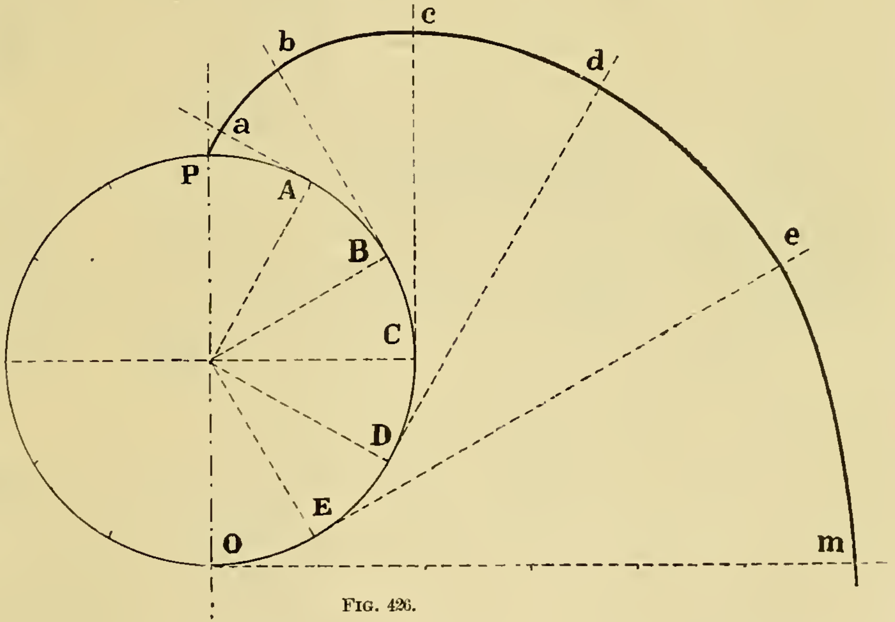


FIG. 426.

No wheel having less than 12 teeth will gear correctly together when the base circle is laid out in

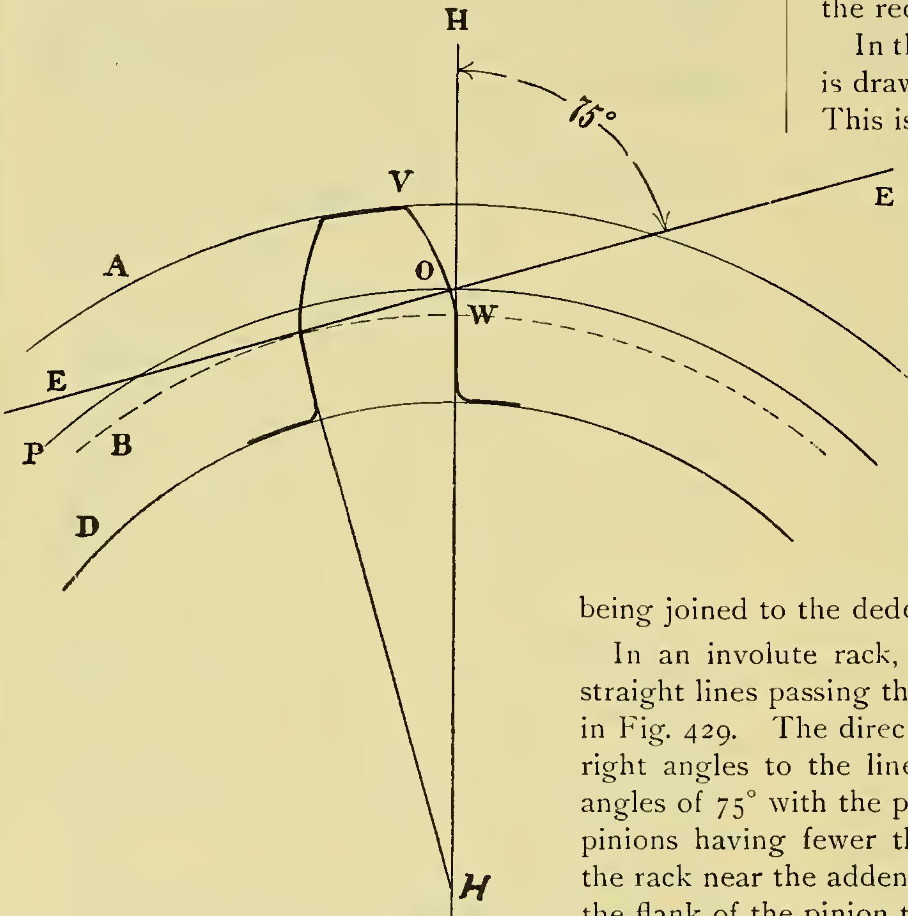


FIG. 427.

this manner; in practice a curve which approximates the required involute curve is generally employed.

In the Brown & Sharp system the line of action is drawn so as to make an angle of 75½°, Fig. 428. This is true for gears having more than thirty teeth; for gears having a smaller number of teeth, special rules are followed.

The Brown & Sharp method explained above cannot be used for involute gears having less than thirty teeth, as the space left at the root is too narrow for the free motion of the mating gear. In such cases the curve is drawn from the base circle to the addendum; from the base circle to the dedendum circle, the flank is drawn parallel to a radius of the wheel through the middle of the space between two adjoining teeth, being joined to the dedendum circle by an arc or fillet.

In an involute rack, in many shops, the teeth are made with straight lines passing through the pitch points of the teeth, as shown in Fig. 429. The direction of the straight edges of the teeth is at right angles to the line of action, that is generally lines making angles of 75° with the pitch line. For racks which are to run with pinions having fewer than thirty teeth, the outline of the teeth on the rack near the addendum are rounded to prevent interference with the flank of the pinion tooth. In the cycloidal system of gearing the outline of a tooth is made by a double curve; here the face is a por-

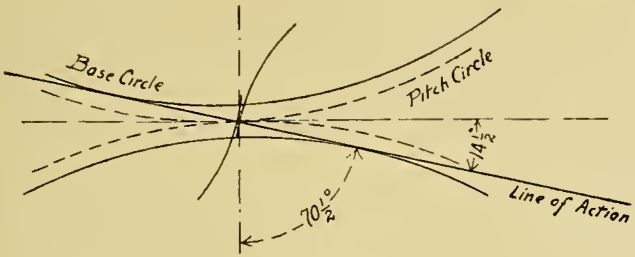


FIG. 428.

tion of an epicycloid and the flank a hypocycloid, both joined in the pitch point.

If a circle is made to roll along a straight line, always remaining in the same plane, a point in the circumference of the rolling circle will describe a cycloidal curve. The rolling circle is called the generating circle or describing circle.

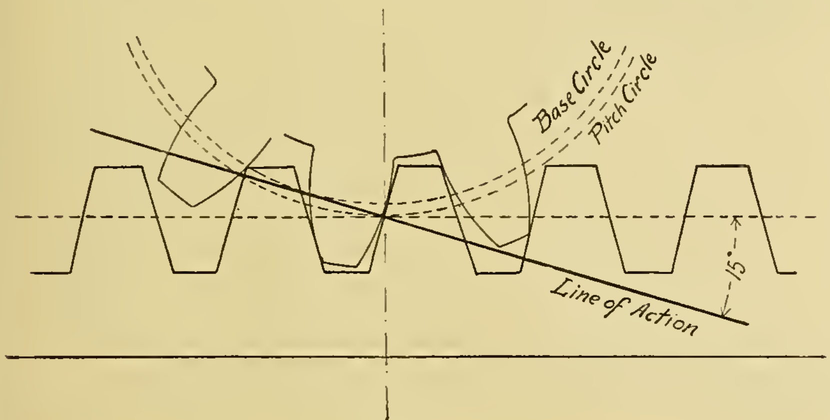


FIG. 429.

If the generating circle rolls along a straight line it will describe a cycloid. If the generating circle rolls along the outside of a circle it will describe an epicycloid, and when rolling along the inside of a circle, it will describe a hypocycloid.

The construction of these curves is shown in Figs. 430, 431 and 432,

To draw the cycloid in Fig. 430, draw a straight line AC. Describe the generating circle and divide it into any number of equal parts by the points 1, 2, 3, 4, etc. From B, the point of contact of the generating circle with the straight line, set off distances equal to the portions of the circle, so that BC will be equal in length to one-half of the circumference of the rolling circle and will be divided into the same number of equal parts by the points 1′, 2′,3′, etc.

Through these points draw lines perpendicular to the line ABC. Through the center of the generating circle draw a line parallel to the line AC; this line will cut the perpendicular in the points a, b, c, d, e, etc. With these points as centers, describe arcs of circles with a diameter equal to the diameter of the generating circle. These arcs will touch the line AC in the points 1′, 2′, 3′, 4′, etc. Through the point 2 on the generating circle, draw a line parallel to AC, cutting the arc which passes through 1′.

Through point 3 in the generating circle, draw a line parallel to AC and cutting the arc which passes through the point 2′. Through the points 4, 5, 6, etc., in the generating circle, draw parallels to meet the arcs cutting the points 3′, 4′, 5′, etc., respectively. The intersections of these lines with the arcs determine the required curve.

Fig. 431. To draw the epicycloid, describe the generating circle tangent to the circumference of the given circle at the point B. Divide the generating circle into any number of equal parts by the points 1, 2, 3, 4, etc. Set off the equal portions of the generating circle on the circumference of the given circle by the points 1′, 2′, 3′, etc., through which draw radial lines extended outside of the base circle AC and cutting them in the points a, b, c. d, etc., by a circle having one common center with the base circle and passing through the center of the generating circle O.

With the points a, b, c, d, etc., as centers, draw arcs with a radius equal to the radius of the generating circle, these arcs touching the base circle in the points 1′, 2′, 3′, etc. Through the points 1, 2, 3, etc., in the generating circle draw arcs concentric with the base circle AC, to meet the arcs touching the points 1′, 2′, 3′, etc., respectively, and through these points of intersection draw the required epicycloid.

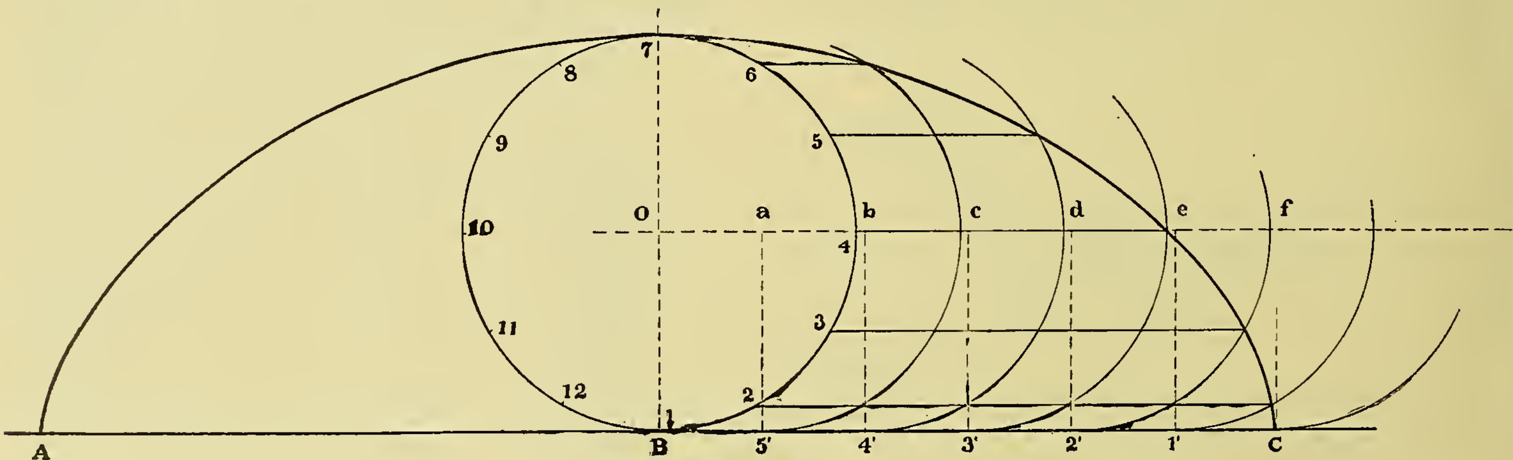


FIG. 430.

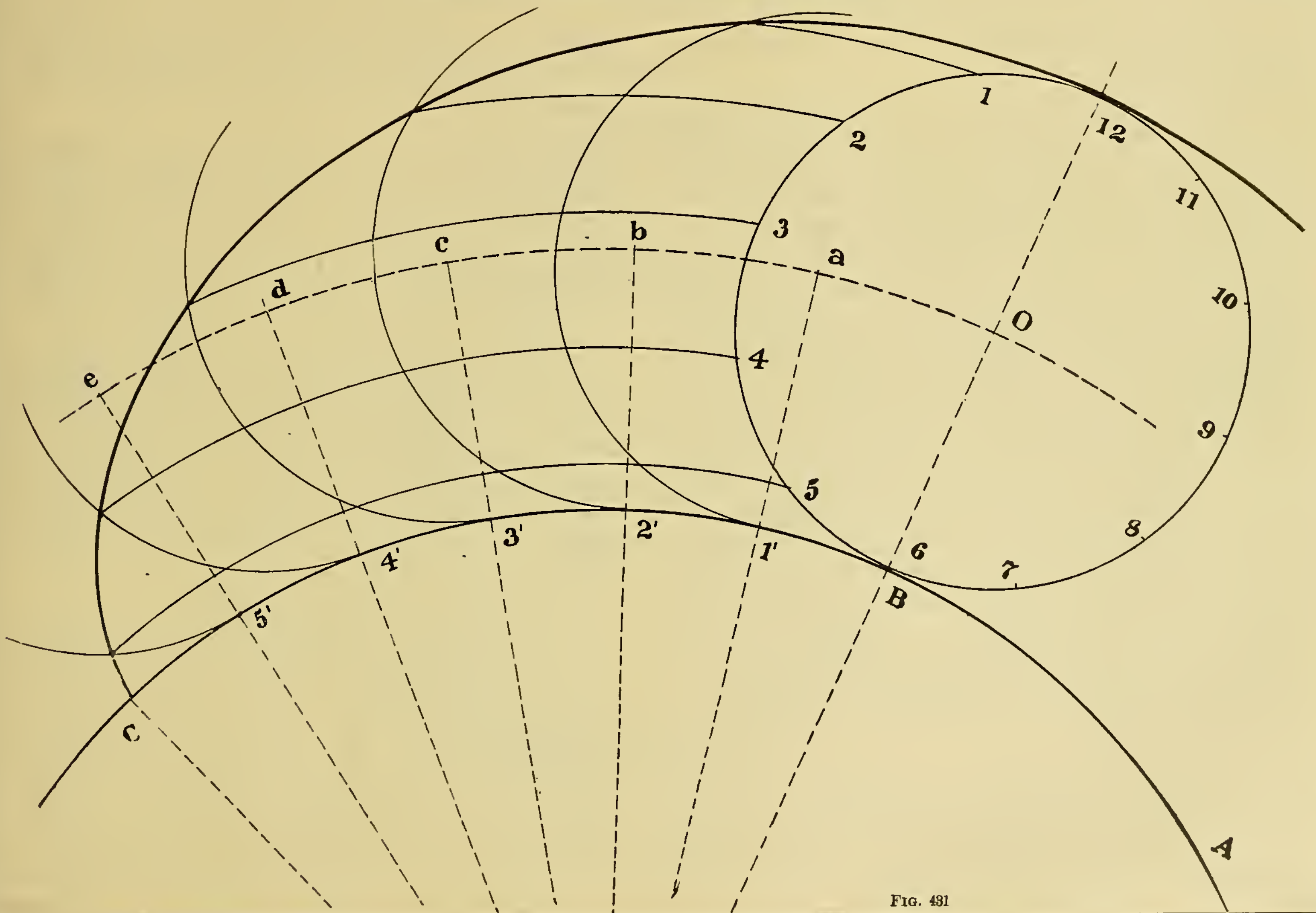


FIG. 431

The *hypocycloid* is drawn in the same manner, as shown in Fig. 432.

To lay out the outlines of a cycloidal gear, draw the pitch circle, Fig. 433, and divide it into a number of equal parts, corresponding to the number of teeth required. Each one of these parts is equal to the circular pitch of the wheel. Bisect each one of these pitch distances to obtain the thickness of the tooth and the width of the space between the teeth. Wherever necessary make the space larger than the thickness, thus providing for back lash. Next, draw the addendum and dedendum circles, and select the proper describing circle. The profile of the tooth between the dedendum and the pitch circle, the face of the tooth, is made by an epicycloid generated by the generating circle as it rolls along the circumference of the pitch circle. The flank, that is the outline of the tooth between the pitch circle and the dedendum circle, is a hypocycloid of a generating circle equal to the above generating circle, or, if convenient, with a generating circle having a different diameter.

For two gears which are to run together, as in Fig. 434, the faces of the teeth in both wheels must be described by one generating circle. Wherever one generating circle is used for the face as well as the flank of one wheel, the same generating circle should be used for both face and flank of the teeth in the mating gear.

When the outline of one tooth is found, a template of thick paper may be cut to one of its sides and by attaching this template to an arm of suitable length, which may be held to the center of the wheel by a pin, we can swing it around and bring it in position to draw the profiles of the rest of the teeth.

Since it would be too much to describe all teeth by tracing for each one of them the proper cycloidal curves, it is usual to approximate these curves by means of circular arcs. We find an arc which very closely coincides with the proper curve for the face, and the same is done for the flank. The centers of these arcs are found by trying with the compass until the proper arc is found.

In Fig. 435, the point A is found to be the center of an arc which very closely coincides with the flank of the tooth ab. Draw a circle through A, concentric with the pitch circle. The centers of all arcs for the flanks of the rest of the teeth in this gear will lie in the circumference of this circle, and the radii of these arcs will equal in length Aa. To draw the flank d on the tooth cd, set the compasses to a radius equal to Aa, put the needle point in d and

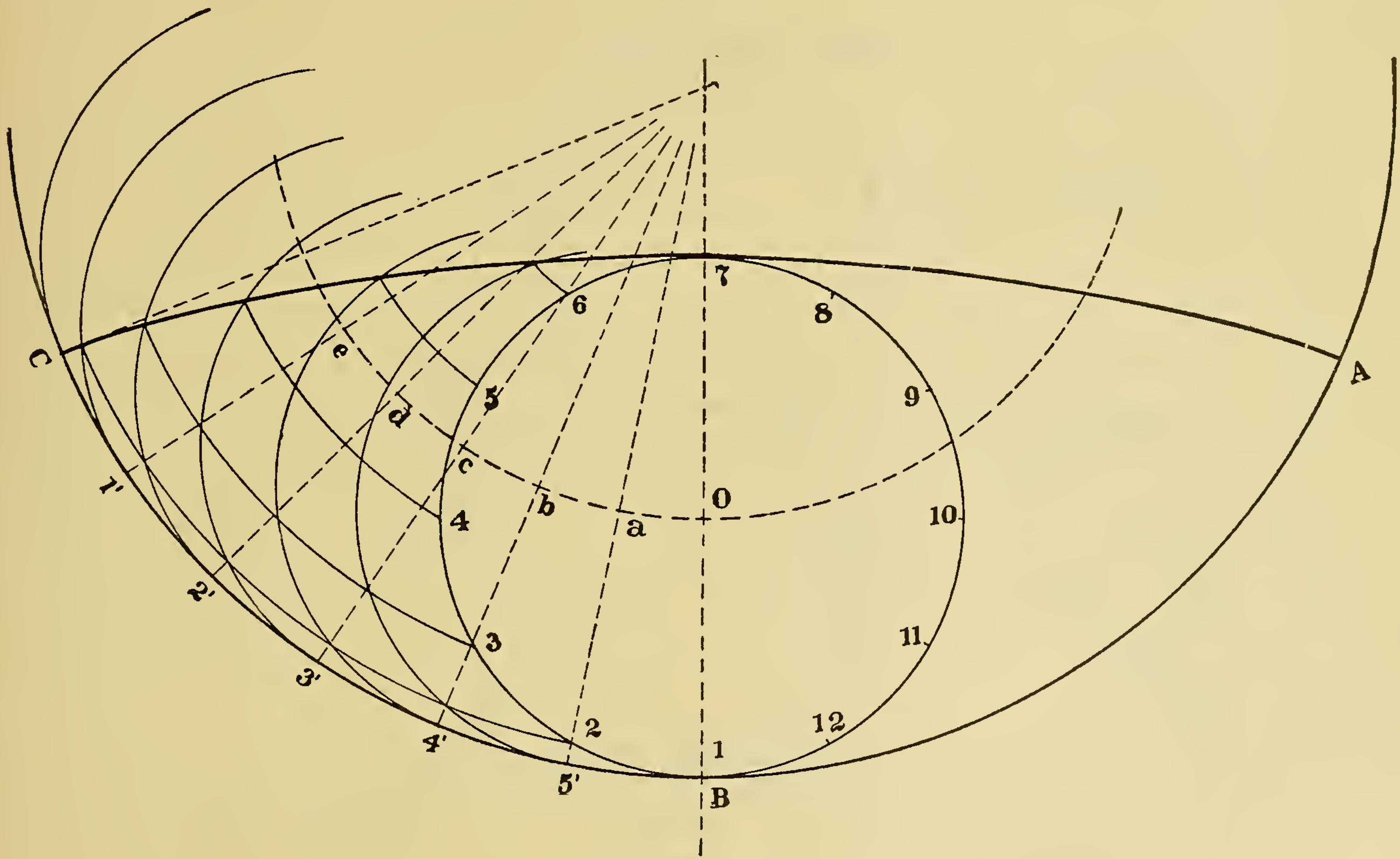


FIG. 432.

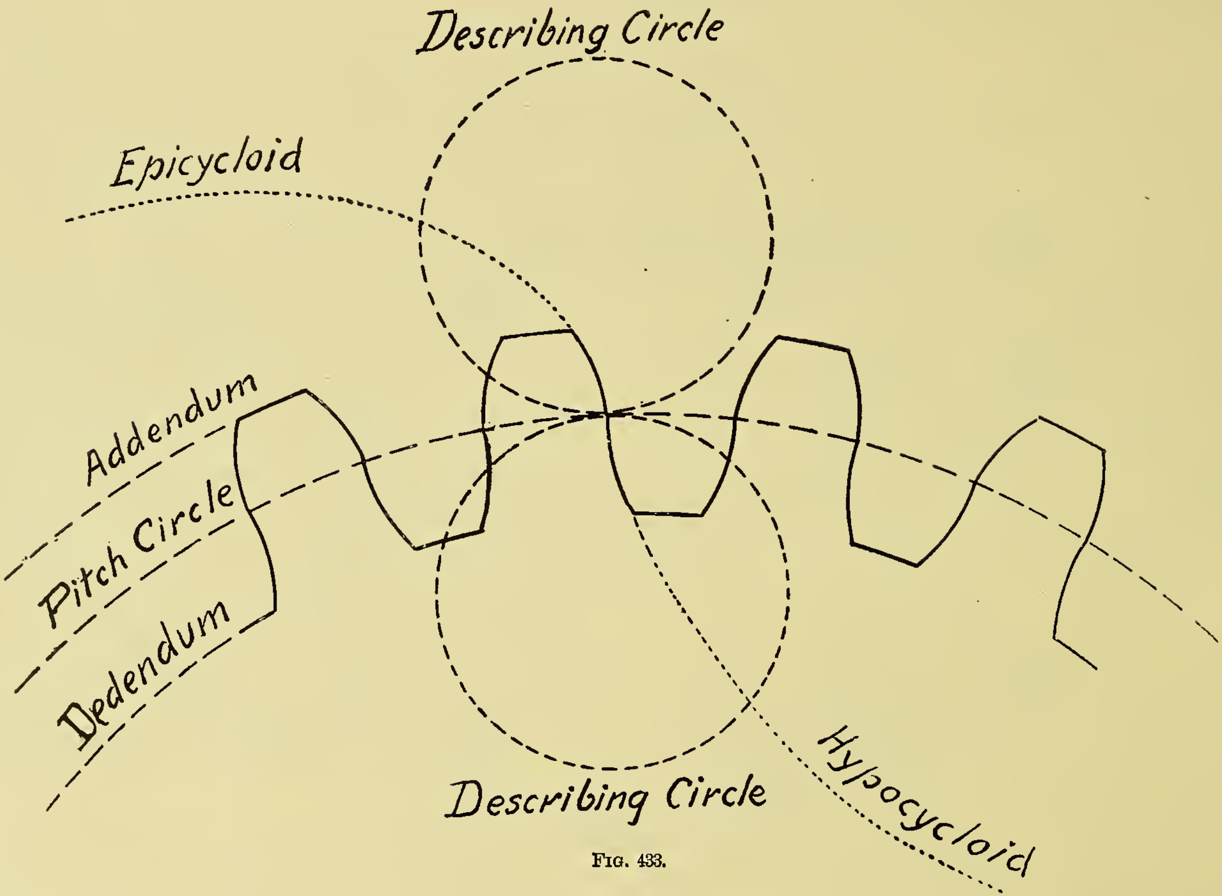

Describing Circle
Epicycloid
Addendum
Pitch Circle
Dedendum
Describing Circle
Hypocycloid

FIG. 433.

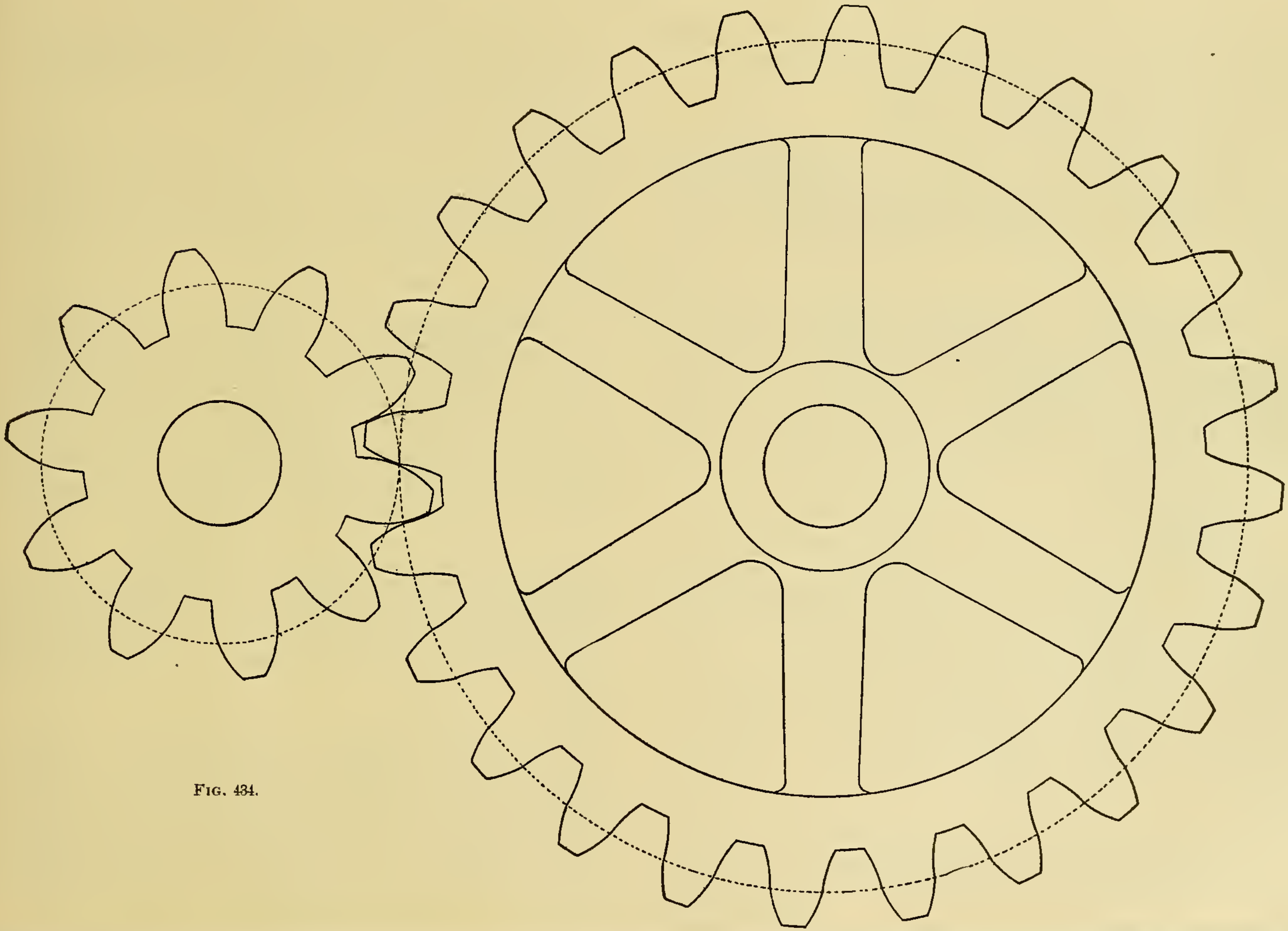


Fig. 434.

cut the circle A2 by the arc at the point 2; this point will be the center for the arc of the flank d. In this way all flanks may be drawn.

When the center of an arc, which as closely as possible coincides with the face of the tooth ab is found, the circle of centers for the faces is drawn, and all arcs for the faces of the teeth will lie in this circle

The generating circle may be, within certain limits, of any diameter, so long as it is not greater than the radius of the wheel on which it is used. When the diameter of the generating circle is equal to the radius of the pitch circle, the path of any point in the circumference of the generating circle is a straight line.

According to the Brown & Sharp system, in cycloidal gearing, the diameter of the generating circle is equal to the radius of a 15-tooth gear of the pitch required, this being the base of the system. The teeth of the rack of this system have double curves, which may be traced by the base circle, rolling alternately on each side of the pitch line. The same generating circle is used for all gears of the same pitch.

According to the prevailing practice, the flank of the 15-tooth pinion in cycloidal gearing is made radial; accordingly the diameter of the generating circle equals one-half of the pitch diameter of a 15-tooth pinion. According to other practice a 12-tooth pinion is taken as the base.

In Fig. 436, is shown a cycloidal rack and pinion. The curves of the teeth-profiles for the rack are generated by rolling the generating circle along each side of the pitch line, on which all pitch points are set off.

A spur gear in which the teeth are on the inside of the rim is termed *an annular or internal gear.* In such a gear the teeth correspond with the spaces of an external gear of the same pitch circle, as do also the other proportions of the teeth. They are consequently designed in the manner described above as involute or as cycloidal gears.

One particular rule must be observed in regard to epicycloidal internal gears; *the difference between the diameters of the pitch circles must be at least as great as the sum of the diameters of the describing circles.*

Bevel gears are used to connect two shafts which intersect when lengthened indefinitely. In most cases the shafts are at right angles with each other. The pitch surfaces of bevel gears are cones which have a common vertex, the point of intersection of the axes of the shafts, Fig. 437.

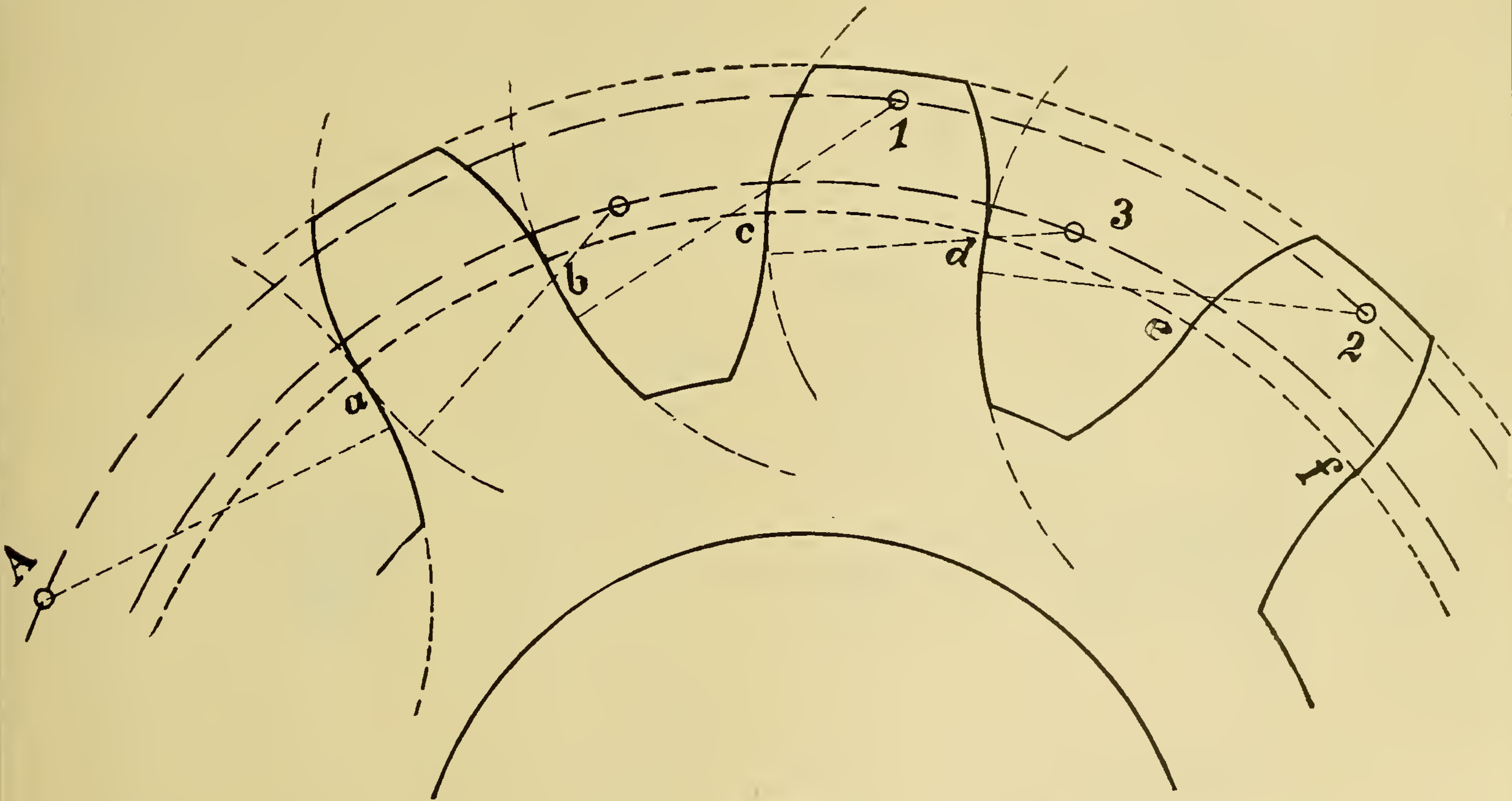


FIG. 435.

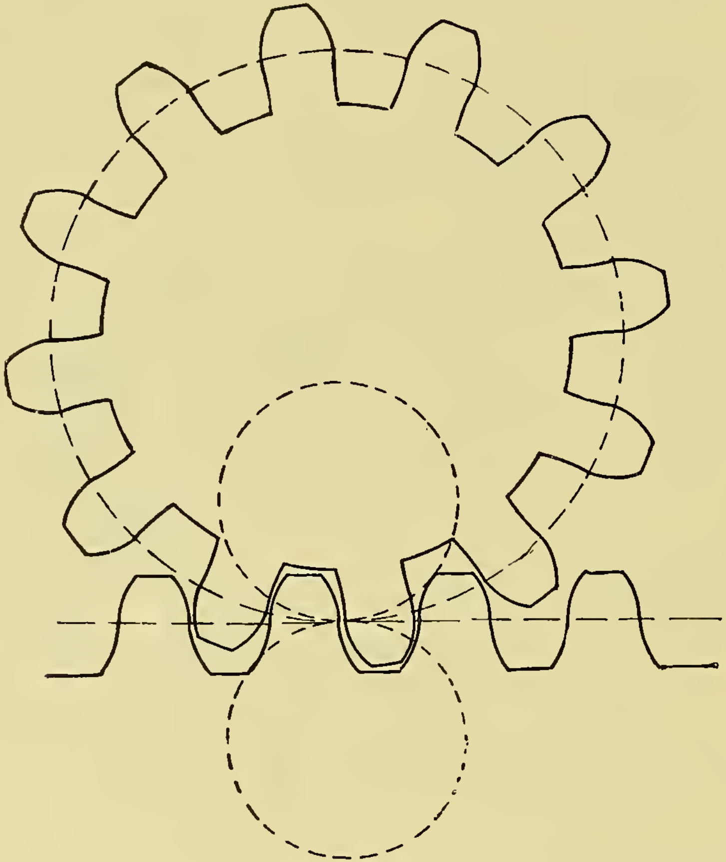


Fig. 436.

Before proceeding to draw a pair of bevel gears draw a section through the shafts of both gears, thus showing a section of one-half of each gear. Draw the two axes of the shafts, OA and OB meeting at O, Fig. 438 shows the two axes at right angles with each other.

Determine the diameter of the largest pitch circles in the bevel gears proportionate to the required velocity ratio corresponding to the circles which form the bases of the two pitch cones.

Let ef be the maximum pitch diameter of the larger, and gh the maximum pitch diameter of the smaller bevel gear. An indefinite distance away from and parallel to OB draw the line ef; then draw the line gh parallel to OA, each one of these lines being bisected by the axes. Through the points e and f draw lines parallel to OA and through g and h lines parallel to OB. The lines intersect in the points E, F and H. Connect the point O by straight lines with the points E, F and H. The resulting triangles EOF and FOH are sections of the pitch cones of the bevel gear. Make FG equal to the width of the face of the teeth. From the point G draw the lines IG and GJ parallel to EF and FH respectively. Each one of the gears is then completed separately with the required proportions for the teeth. The manner in which this is done is

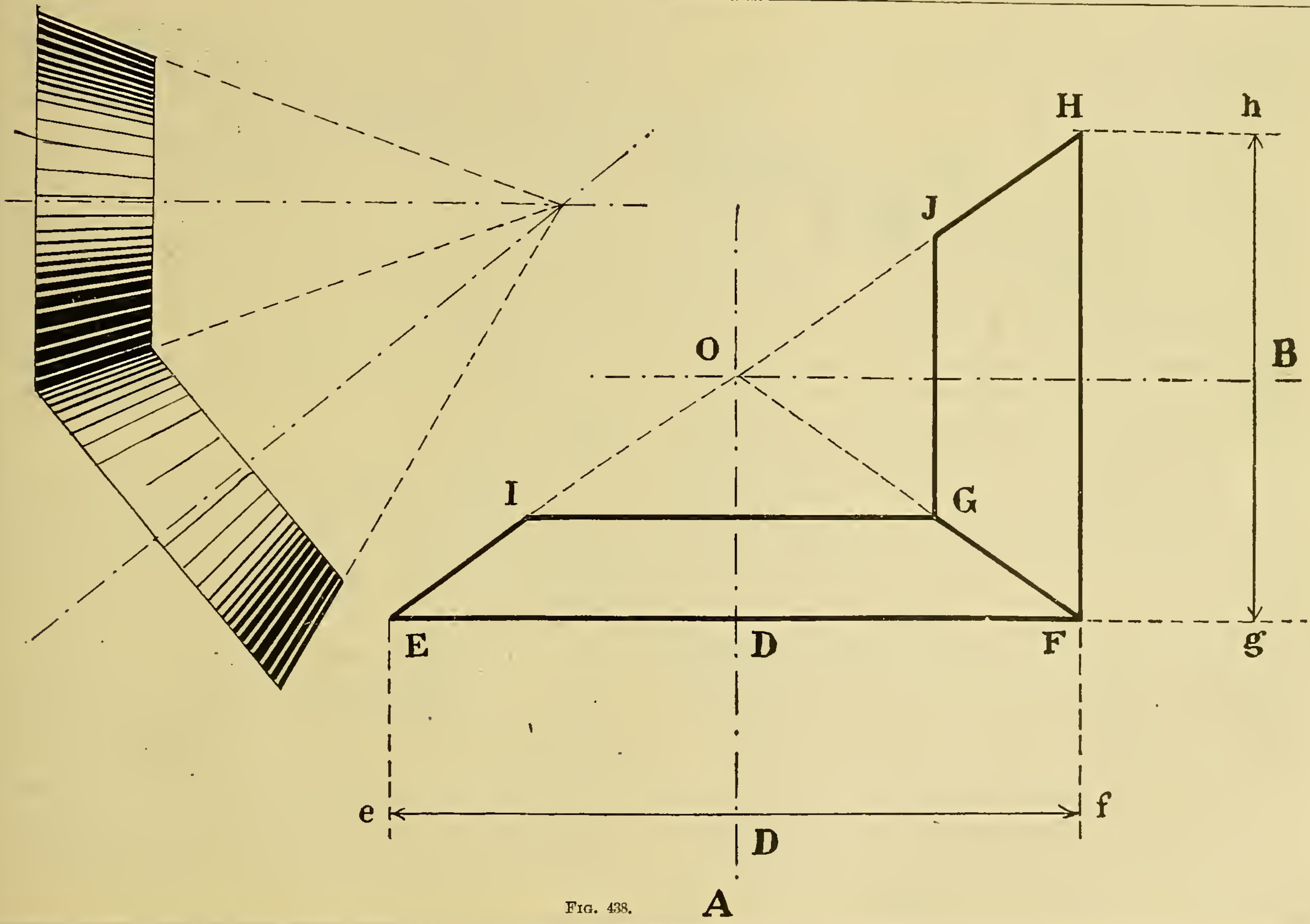


FIG. 438.

illustrated in Fig. 439. In this figure, ABC is a part of the pitch cone laid out according to the principles explained with Fig. 438.

This view must be drawn first. K are the outlines of the teeth of a spur gear laid out for a pitch diameter equal to the maximum pitch of the bevel gear. The proportions of the teeth on the bevel gear are laid off from these outlines. EB and BD are the addendum and dedendum; the line ED being drawn at right angles to the line AB of the pitch cone. BF is made equal to the length of the teeth on the bevel gear; at F a line perpendicular to AB is drawn, and the addendum and dedendum of the smallest outline of the tooth is determined by the intersection of the line GH with the lines EA and DA. Next the other view is drawn.

OJ is a line drawn parallel to BC. A perpendicular to this line dropped from the point B determines the maximum pitch circle and a perpendicular from the point F the minimum pitch circle.

In the same manner the addendum and dedendum circles for the largest as well as for the smallest profiles of the teeth may be found by dropping perpendiculars from the points E and G, D and H. The maximum pitch circle is then divided into a number of equal parts corresponding to the number of teeth required. Through each one of the divisions a line is drawn to the center O; these lines are the center lines of the teeth. The proportions of the teeth shown at K are then set off from each center line for the purpose of forming the projection of the teeth. The distance a is set off on the largest dedendum circle, the distance b on the maximum pitch circle; the distance c on the addendum circle. All these lengths are set off so as to be bisected by the center line of the tooth for which they are intended.

The projection of the smallest profile of the tooth is obtained by drawing radial lines from the points at the addendum of the large profile to the addendum circle to the smallest addendum circle.

The pitch points of the tooth for the projection of the smallest profile at L, is obtained by drawing radial lines from the pitch points of the large profile to the smallest pitch circle, and the root of the smallest profile is obtained in the same manner by drawing radial lines from the dedendum points of the large profile to the smallest dedendum circle.

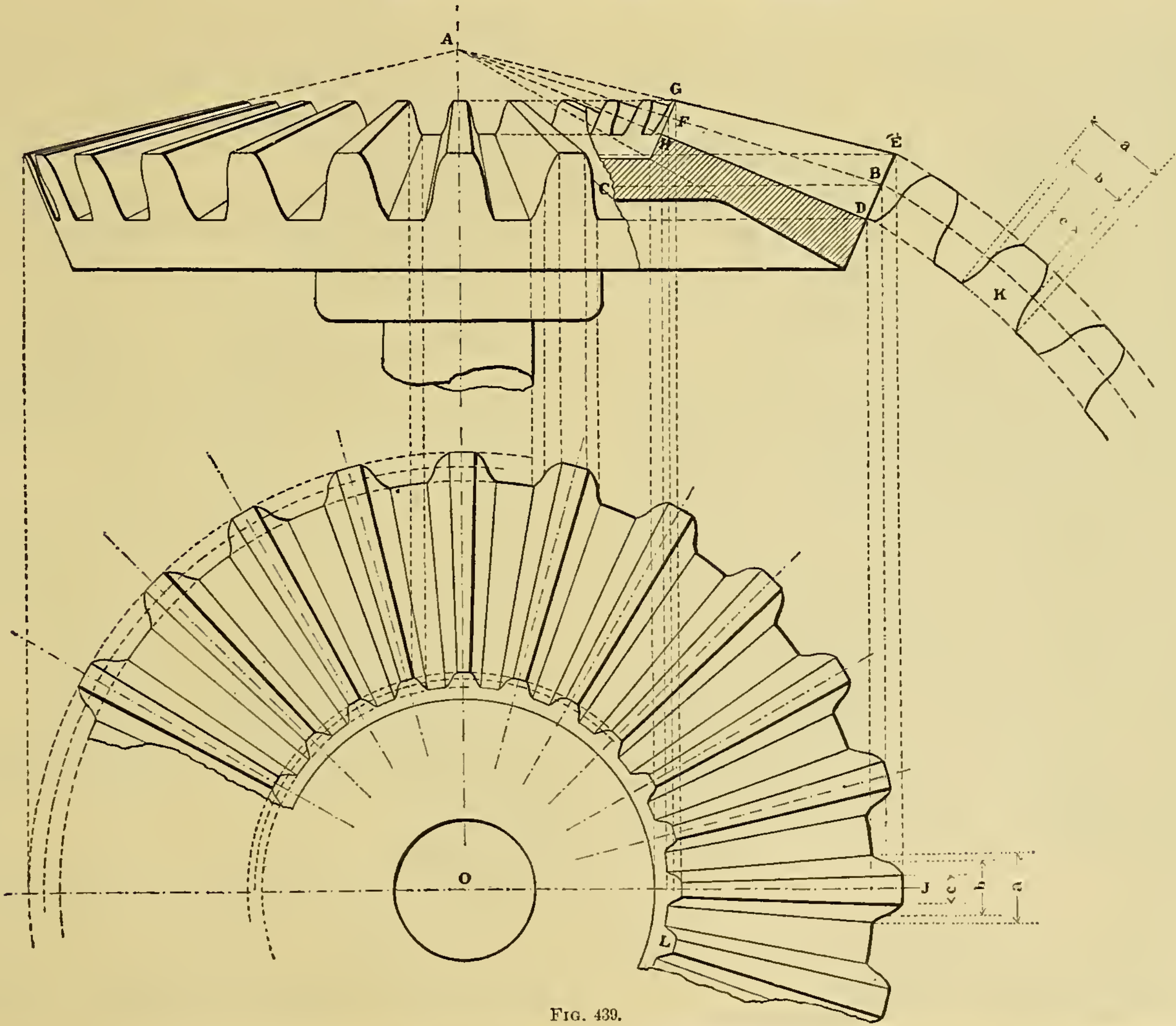


FIG. 439.

In speaking of the diameter of a bevel gear, the largest diameter of the pitch cone is meant.

The relations between the pitch diameter of a bevel gear pitch, number of teeth and velocities are the same as for spur gears, and all calculations are made in the same manner.

In Figs. 440, 441 and 442 are shown 3 views of a completed bevel gear.

For transmitting motion from one shaft to another at right angles to it, when the axes of the shaft do not intersect, the worm gear and worm shown in Figs. 443 and 444 are used. The section of the worm shown in Fig. 445 is of the same outlines as a rack of corresponding pitch, and may be of either the involute or cycloidal form. The involute form is generally adopted, as its teeth are easier to produce. The worm is cut in a lathe like a screw. The diameter of the worm is ordinarily taken about 5 times the pitch, although it could be made of any convenient diameter. The worm must always be the driver. It is not well adapted to the transmission of heavy power, as the tooth action is purely a sliding one.

Fig. 446 shows a partial section of a worm gear made by a plane perpendicular to the axis of the worm through the axis of the gear.

When made by the involute system the worm teeth will be straight. The worm may be drawn by the aid of helices like a screw. The worm may also be single, double, etc., like a screw.

Figs. 443 and 444 show the outside views of a worm gear. Fig. 446 also shows the outside view of a complete tooth.

The drawing of the outside views of a worm gear involves considerable labor. Fortunately, however, it is wholly unnecessary for the purposes of machine shop construction, to make complete outside views of worm gears. The same is also true in the case of bevel gears. A sectional view is most generally adopted to show the wheel. The wheel is usually made to embrace about one-sixth the circumference of the worm.

When the diameter of the worm is increased and approaches the diameter of the wheel and when the worm is given a multiple thread and the number of teeth in the worm wheel is comparatively low, then both worm and worm wheel take the shape of spiral gears.

To add strength to spur gears, the rim is made wider than the teeth and is carried outward, as shown in Figs. 447 and 448. This is called shrouding of the teeth. If two wheels gearing together do not differ greatly in diameter, each may be

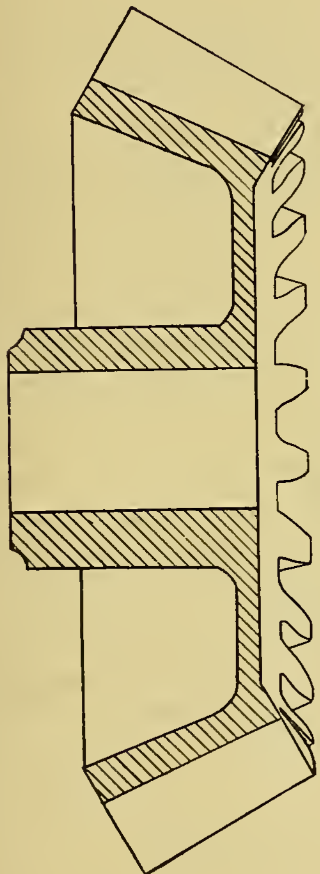


FIG. 440.

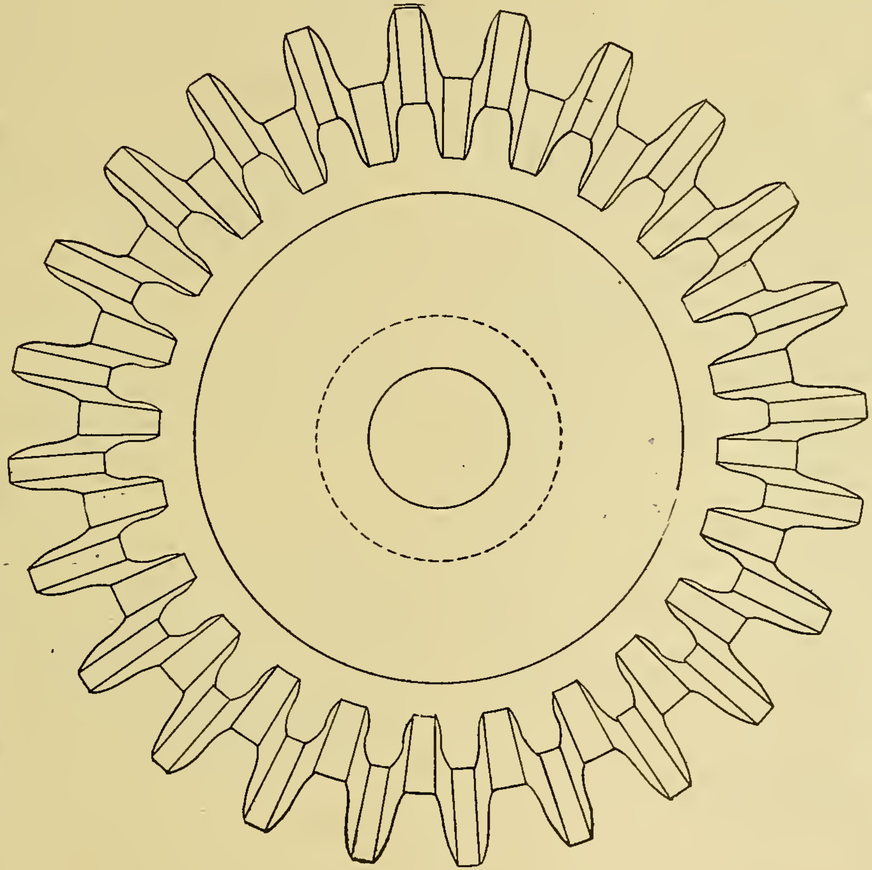


FIG. 441.

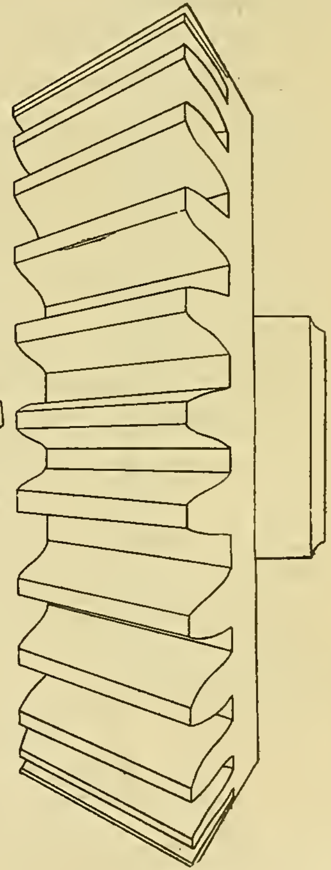


FIG. 442.

shrouded to the pitch on both sides; but when one is very much larger than the other, it is usual to shroud the smaller only.

For light spur gears the rim is generally made as shown in Fig. 449. The section shown in Fig. 450 shows the rim of a heavy spur gear. The proportions marked on the sections in these figures are in terms of the circular pitch of the gears.

Sections of arms for gear wheels are shown in Figs. 451, 452 and 453. For light spur gears the section shown in Fig. 451 is used. For heavy spur wheels the sections shown in Fig. 452 is adopted. The section in Fig. 453 is for bevel gears. The number of arms is approximately $\frac{D}{33} + 4$ when D is the diameter of the pitch circle in inches. The nearest even number may be taken.

The width of the arms may be calculated in the following manner. In the arm shown in Fig. 451 the greatest breadth of the arm is equal to B; then,

$$B^3 = \frac{1.6 \times \text{width of tooth} \times \text{circular pitch} \times \text{pitch diam.}}{2 \times \text{number of teeth}}$$

and for the other sections,

$$B^2 = \frac{\text{width of tooth} \times \text{pitch diameter}}{2 \times \text{number of teeth.}}$$

A practical rule for finding the thickness of the hub is

$$\text{The thicknes of hub} = \frac{\frac{1.6 \times \text{circular pitch} \times 0.2}{\text{pitch diameter}}}{2}$$

The length of the hub is, in most cases, equal to the width of the tooth; it may vary up to 1½ times the width of the tooth.

The pressure on one tooth may be taken, for most purposes, to equal ⅔ of the whole pressure; that is of the driving force at the pitch line, calculated from the horse power and the speed.

$$P = \frac{H \times 33{,}000}{V}$$

where H is the given horse power and V the velocity of the spur gear. The velocity of the given wheel is found by multiplying the circumference in feet by the number of revolutions per minute. The thickness of the tooth on the pitch line may be found from the following formula, *i. e.*,

$$\text{Square of thickness} = \frac{3 \text{ times pressure on one tooth}}{\text{safe stress}}$$

For cast iron gears the safe stress may be taken to equal 4,000 pounds per sq. in.

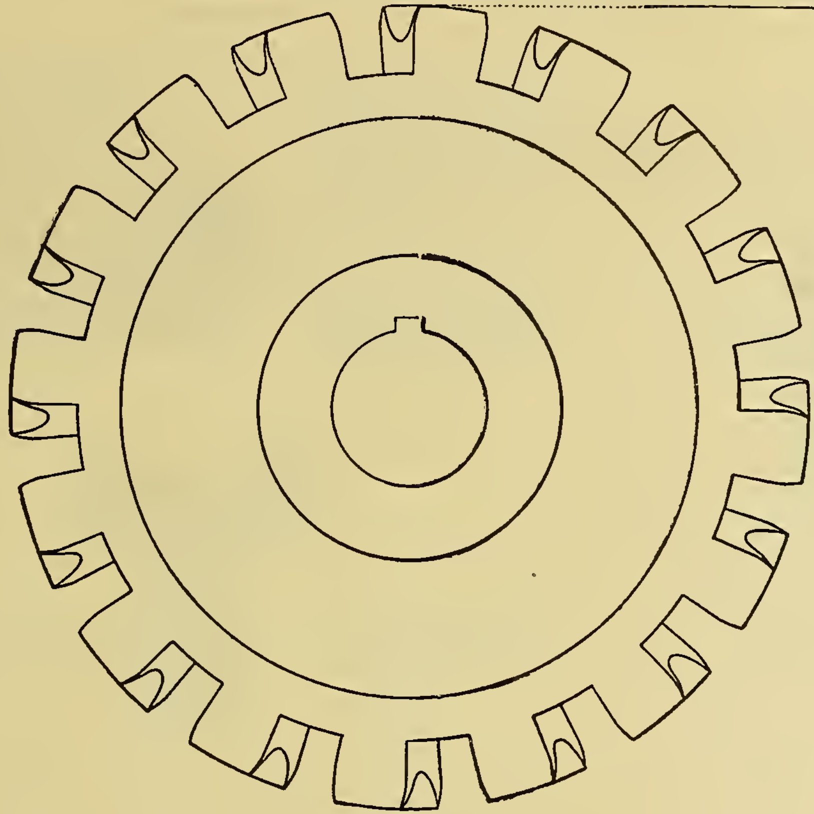


Fig. 443.

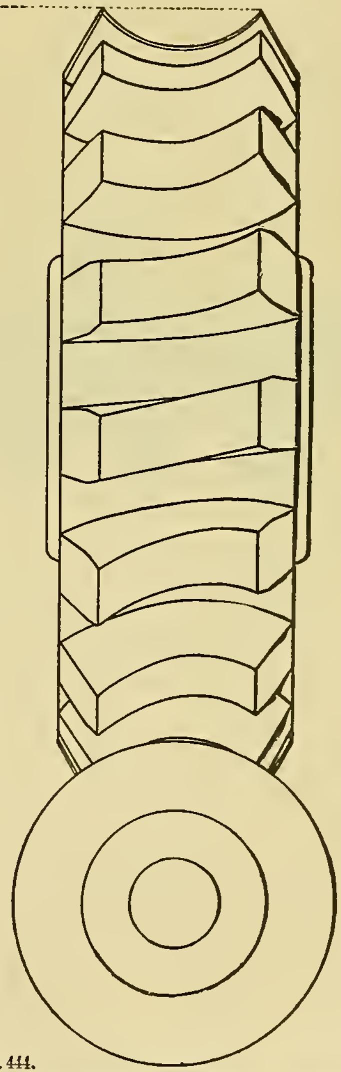


Fig. 444.

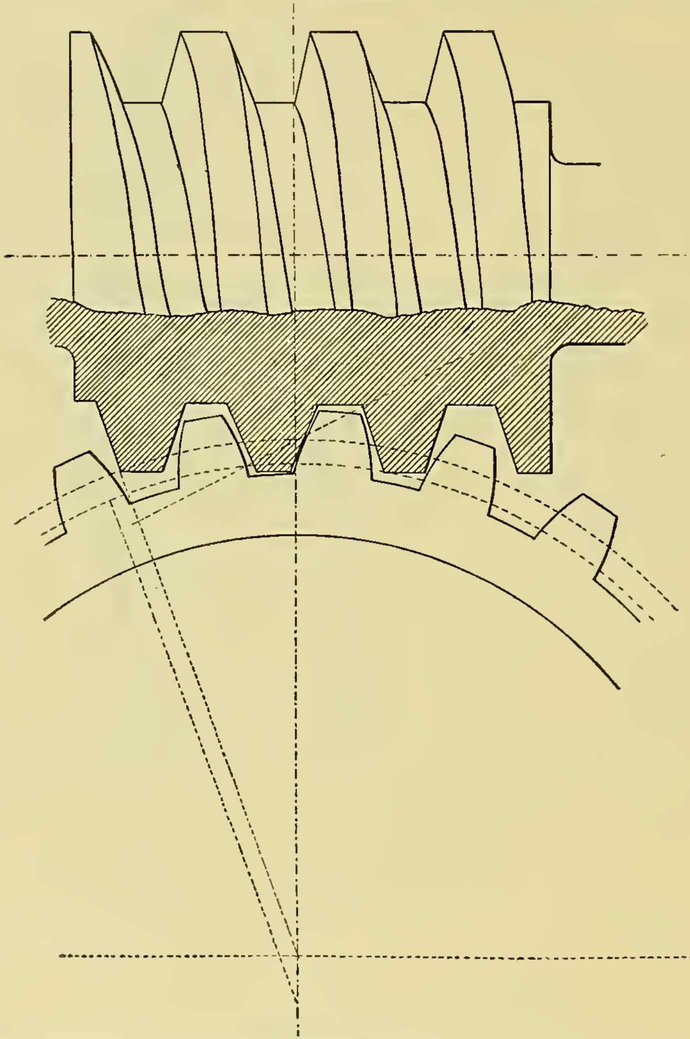


FIG. 445.

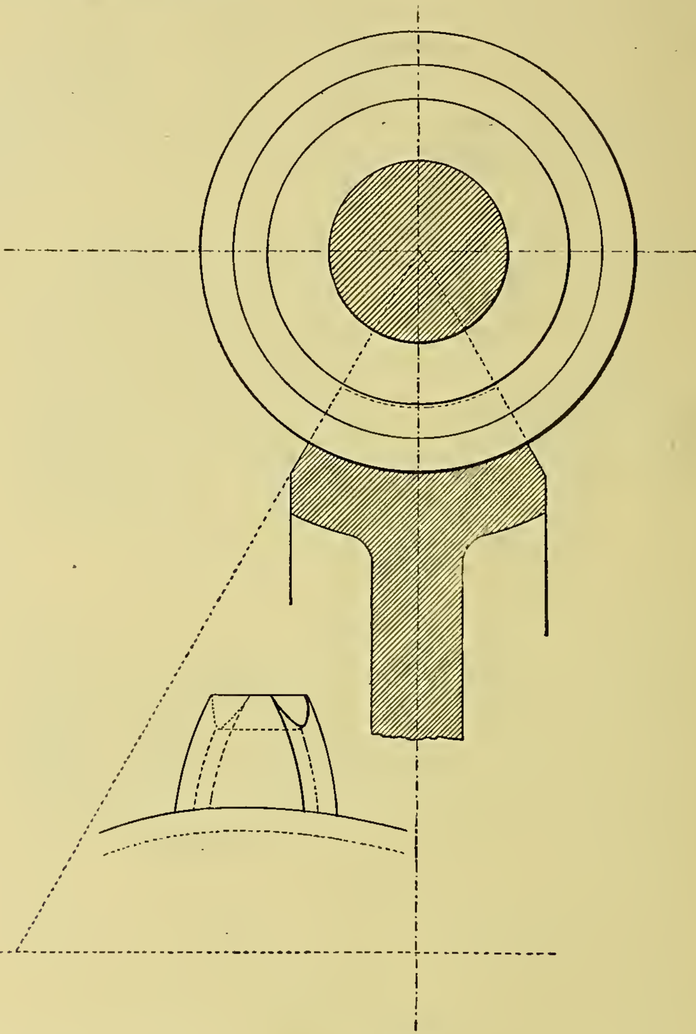


FIG. 446.

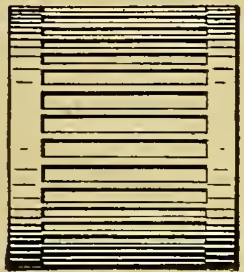


Fig. 447.

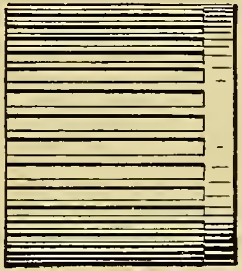


Fig. 448.

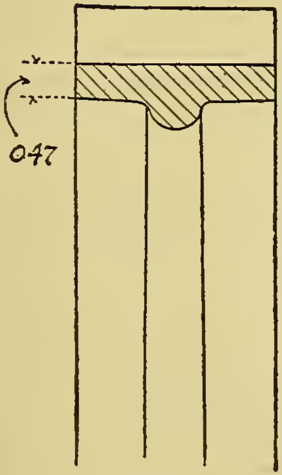


Fig. 449.

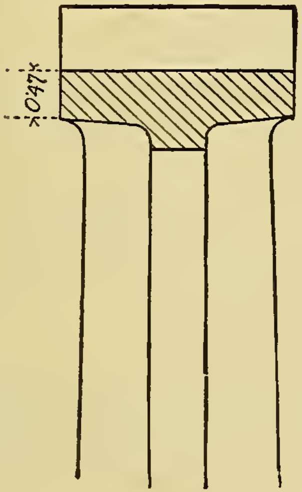


Fig. 450.

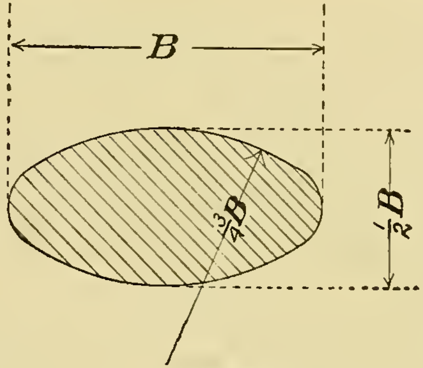


Fig. 451.

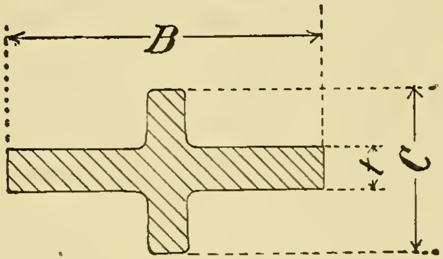


Fig. 452.

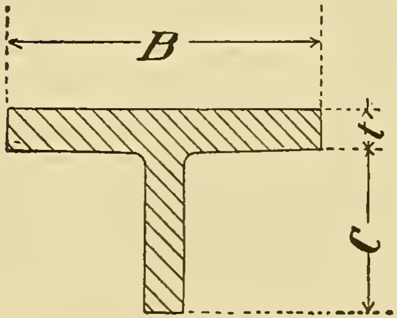


Fig. 453.

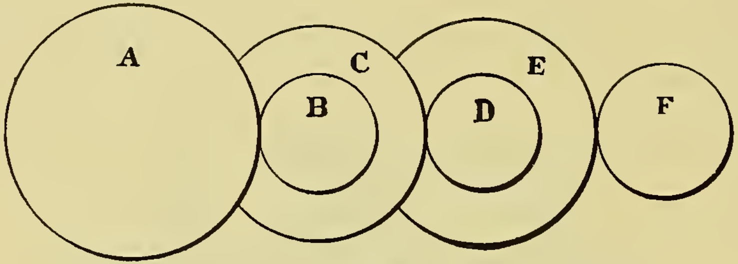


FIG. 454.

EXAMPLE:

If the whole driving force at the pitch circle is equal to 12,000 pounds, then the pressure on one tooth will be 8,000 pounds, and the square of the thickness of the tooth will equal $\frac{8,000 \times 3}{4,000} = 6$. The thickness of the tooth must then be equal to the square root of 6, *i. e.*, 2.449 in, say 2½ inch

TRAINS OF GEAR WHEELS.

When a train of gear wheels is employed in a machine, the usual arrangement is to fasten two gear wheels of unequal size upon every axis, except the first and the last, and to make the larger wheel of any pair engage the smaller one of the next pair.

If the wheel A in Fig. 454 is the driving wheel, and the wheel F the last follower, and if it be determined that for each single revolution of A, the wheel F shall make 50 revolutions, then it is said that the value of the train is equal to 50.

That is, the value of a train of gear wheels is equal to the number of revolutions in the last follower in a given time, divided by the number of revolutions of the main driver in the same time.

Suppose that the first wheel had A teeth, the second B, the third C teeth, the fourth wheel D teeth, the next E and the last F teeth; then,

$\frac{A}{B} =$ the velocity ratio between the first and the second axes upon which are fastened the wheels B and C;

$\frac{C}{D} =$ the velocity ratio between the second and third axes;

$\frac{E}{F} =$ velocity ratio between third and fourth axes, and

$\frac{A}{B} \times \frac{C}{D} \times \frac{E}{F} =$ the velocity ratio between the two extreme axes, that is, it will equal the value of the train.

EXAMPLE:

Let A have 120 teeth, B 15 teeth, C 100 teeth, D 50 teeth, E 150 teeth and F 30 teeth.

Then, the value of the train is equal to

$$\frac{120}{15} \times \frac{100}{50} \times \frac{150}{30} = 80$$

METAL WORKING MACHINERY.

The discovery of metals and the means of working them are among the first stages in the development of primeval man ; the earliest evidence of a knowledge and use of metals is found in the primitive implements of the so-called Bronze and Iron Age. Attention is called to the interesting note below.

The Old Testament mentions six metals—*gold, silver, copper, iron, tin* and *lead ;* the old Greeks in addition to these, and to *bronze*, came also to know *mercury ;* the same set of metals without additions seem to be the only ones known until the Fifteenth Century when *antimony* was discovered ; about 1730 A. D., *arsenic* and *cobalt* were discovered, *nickel* and *manganese* were discovered in 1774 ; in the meantime something had become known in a general way of *zinc, bismuth* and *platinum.*

Since the date last mentioned the discovery of many rare metals has become frequent, *aluminum* being among the last most useful and interesting discoveries of metals unknown at the beginning of the Nineteenth Century.

The following pages deal, in text and illustrations, with iron working machinery, as against those machines devised to work *in wood*, etc., and few as are the cases named they show vividly the progress made in the methods of working the metals named.

In designing machines it is well to keep in mind, 1, that each machine ought to be made of as few parts as possible, 2, as simple as possible, 3, the strength of every part should be made proportional to the stress it has to bear, 4, all superfluous weight which clogs the machine's motion should be avoided, 5, all parts should be contrived to last equally well, 6, in wheels with teeth, the number of teeth that play together ought to be so constructed that the same teeth may not meet at every revolution, but as seldom as possible.

NOTE.—" Some recent analyses of the iron of prehistoric weapons have brought to light the interesting fact that many of the prehistoric specimens of iron manufacture *contain a considerable percentage of nickel.* This special alloy does not occur in any known iron ores but is invariably found in meteoric iron. It thus appears that iron was manufactured from meteorolites which had fallen to the earth in an almost pure metallic state, possibly long before prehistoric man had learned how to dig for and smelt iron in any of the forms of ore which are found on this planet."—*Enc. Britannica.*

DIES AND PRESSES.

The use of dies and presses has increased in recent years to an almost marvelous extent, and a numberless variety of articles are now being pressed out easily and rapidly by the aid of dies, which in former times involved great labor as well as a long special training. The number and variety of dies are so very large that it is beyond the limits of this book to give even a partial list or classification of these useful tools.

In this section we shall limit ourselves to a few examples of the most frequently employed forms of dies, so as to give the reader an opportunity to acquaint himself with this importamt part of modern mechanism sufficiently to understand further special literature upon this subject, if it should be the desire of the reader to make a thorough study of this branch of machine shop practice.

The simplest form of a die is *a blanking die.* Blanking dies are made for the purpose of cutting out various pieces of metal from a comparatively thin sheet of metal, cardboard, etc., leaving the cut out piece perfectly flat; this piece is called *a blank.*

A set of blanking dies consists of a male die, or punch, and the lower or female die. The lower die has an opening exactly equal to the form of the punch.

Fig. 455 shows a punch and die for a circular blank. The narrow part of the punch, *the shank*, is preferably made in one piece with the punch.

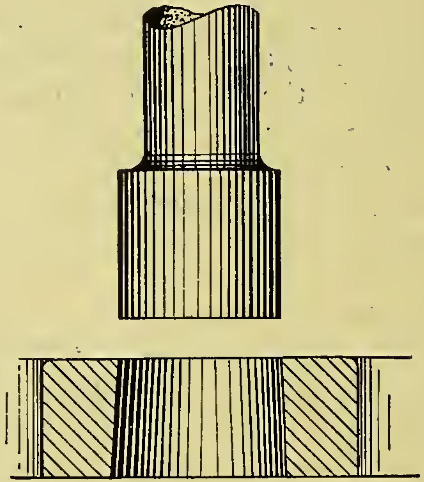


FIG. 455.

The shank is fastened to the *ram of the press*, while the die is secured to the *bed of the press.* The taper of the lower die gives *the clearance*, required for the purpose of facilitating the dropping of the blank from the die as soon as it is cut; the clearance is made from $\frac{1}{4}°$ to $3°$ for average work.

For the purpose of greater rapidity of work and uniformity in the matter of spacing the holes, dies and punches are grouped; that is, several punches

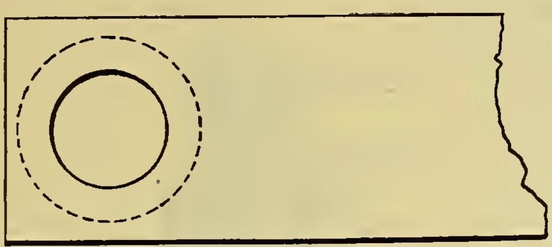


FIG. 456.

are fastened to one shank, while several separate openings are worked out in the lower die to correspond with the number of required separate dies, if the work were done by single dies.

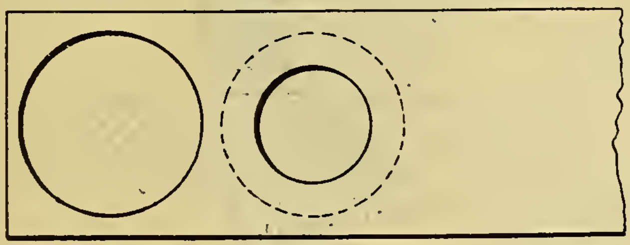


FIG. 457.

Fig. 458 shows such a gang die, as it is called, made for cutting out washers of the shape shown in Fig. 459. One stroke of the die produces two holes, as shown in Fig. 457. The metal is fed into the

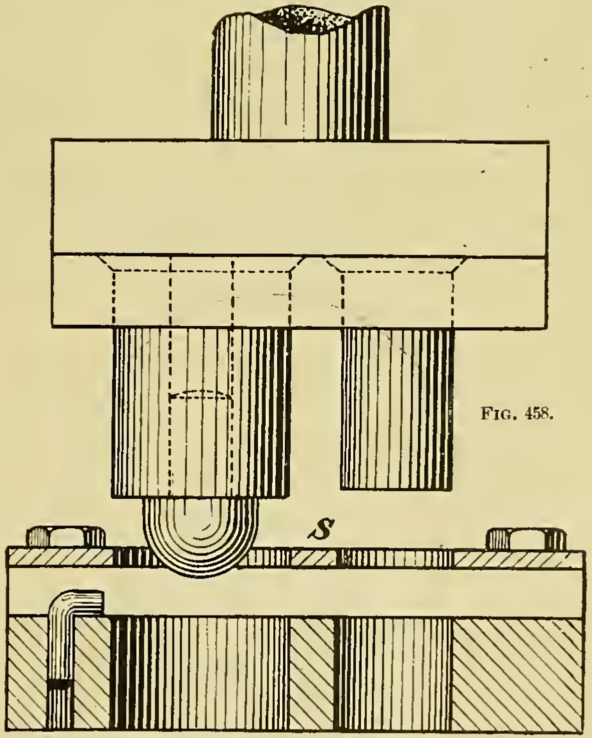


FIG. 458.

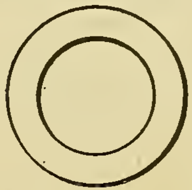


FIG. 459.

die from the side of the smaller hole. The small punch will cut a hole in it equal to the inside diameter of the washer, as shown in Fig. 456; the metal is then advanced and at the second stroke the large punch will cut out the complete washer, while the small punch pierces the metal for the next washer at the same stroke. The plate S, Fig. 458, is *the stripper* which takes the metal off the punches on their upward stroke. It is evident that the metal must be fed below the stripper.

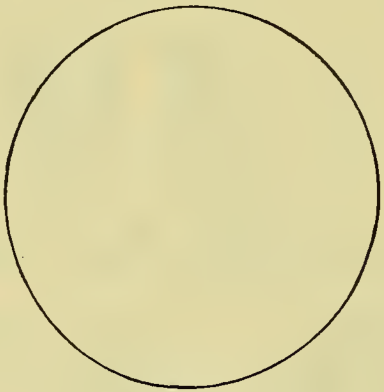


FIG. 460.

Fig. 461 shows the simplest form of *a drawing punch and die.* The flat circular blank, Fig. 460, is placed upon the die so as to fit the set edge S, and is pushed through the die by the punch. While the punch returns upward, the finished shell is pulled off by the edge P, which is made very sharp for that purpose. The diameter of the punch is equal to the diameter of the die, minus two times the thickness of the blank.

FIG. 462.

FIG. 461.

Fig. 462 shows the shell. This simple form of a drawing die should be used only on shallow work, to avoid crimping around the edge of the shell. When the blank is held firmly while being drawn, the crimping even on deeper work may be avoided.

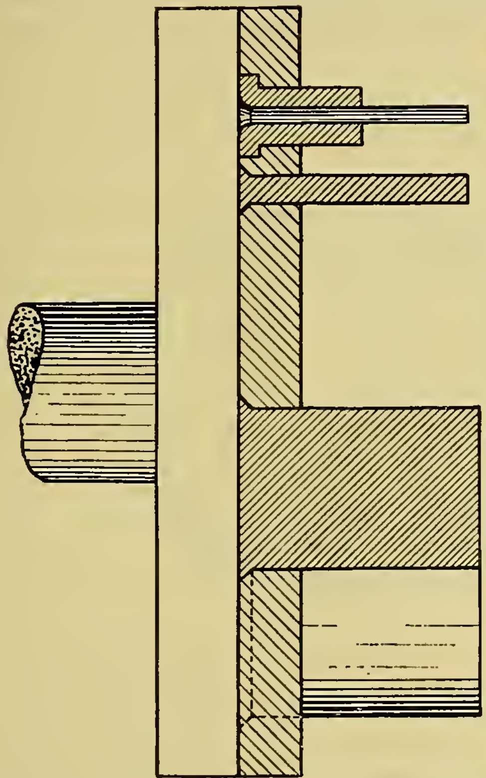


Fig. 463.

Fig. 464.

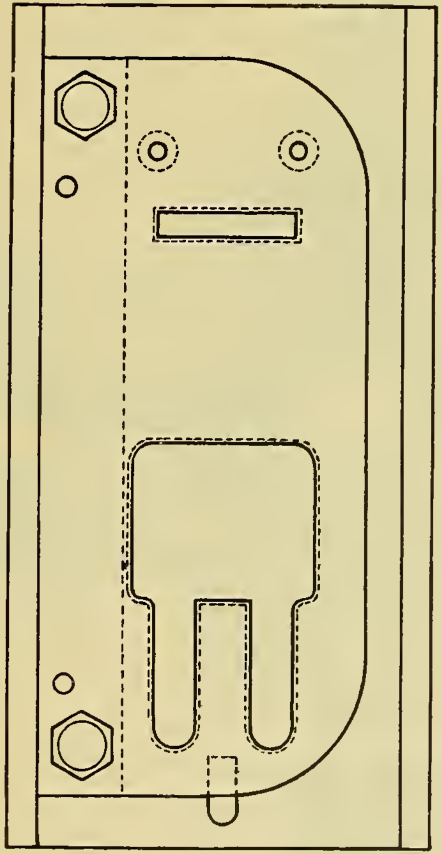


Fig. 465.

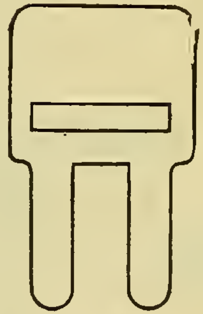


Fig. 466.

FIG. 467.

Another gang die is shown in Figs. 463 and 465.

Fig. 466 is the blank, Fig. 465 the top view of the lower die and stripper; Fig. 464, a sectional view of the same; and Fig. 463 shows the punch in section.

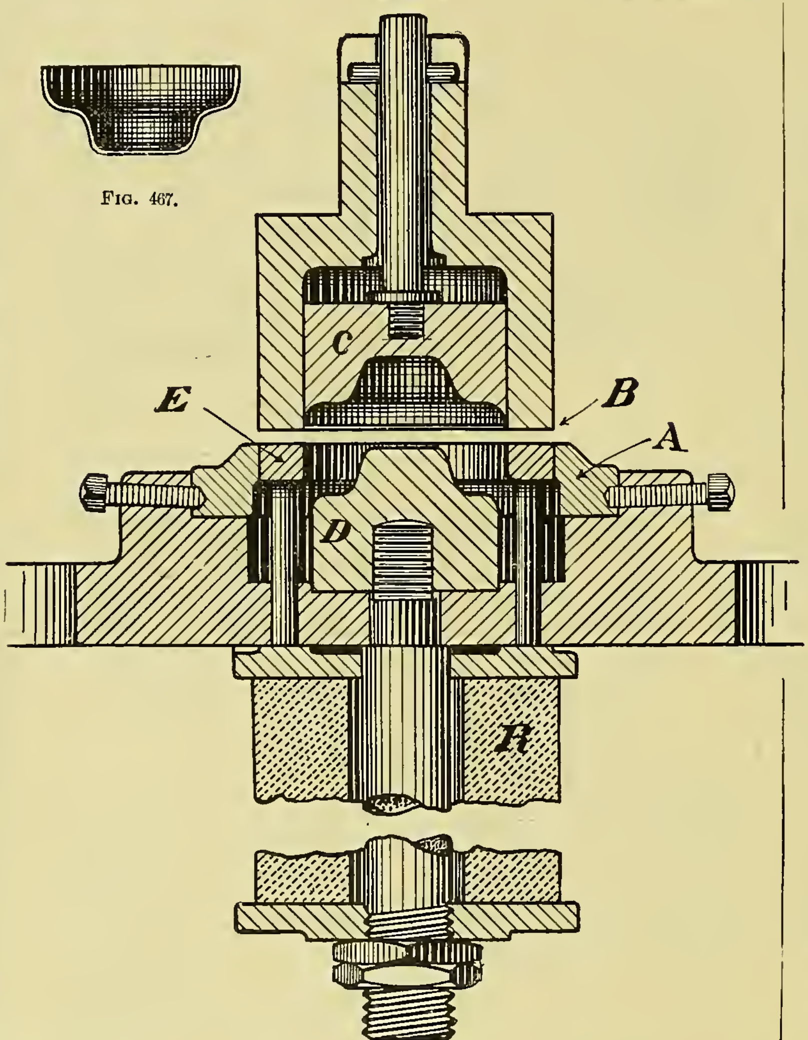


FIG. 468.

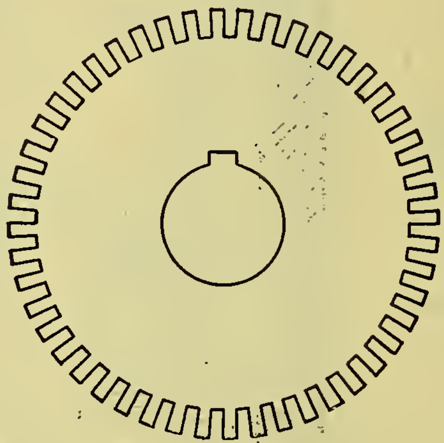


FIG. 469.

In Fig. 468 is shown a type of a die, which by its relative simplicity when compared with the work produced, will always stand as a beautiful example of mechanical ingenuity.

It is a single-action cutting and drawing die, generally called *a single-action combination die;* it is a combination of a blanking and a drawing die in one; it cuts the blank and draws it up into the shell shown in Fig. 467 at the same stroke. In descending the blank is cut by the edge of the blanking punch B, meeting the edge of the blanking die A. The blank continues until the drawing punch C is drawn down on the drawing die D, when the blank is drawn into the required shape.

Fig. 469 shows a sheet iron dynamo armature disc. Fig. 470 is a section on a larger scale of a set of dies of latest construction, designed for cutting such discs. These dies are made to cut discs up to 100″

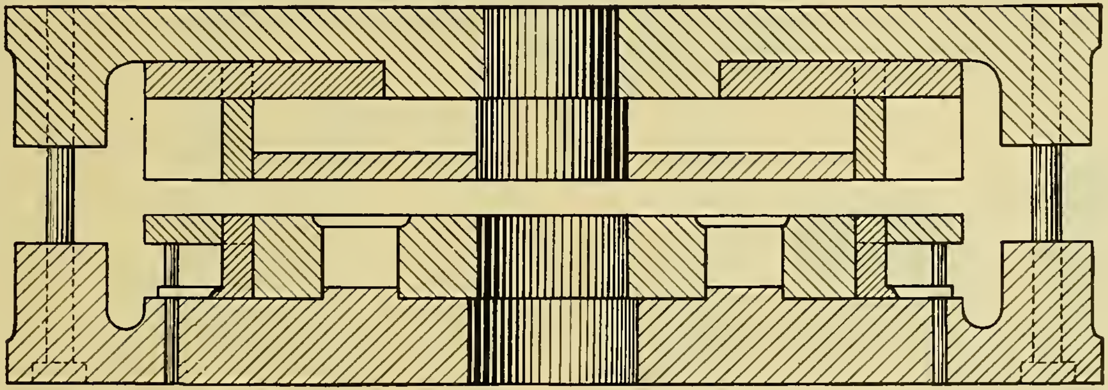


Fig. 470.

is then held firmly by the blank holder ring E and is forced down together with it, by continued downward motion of the blanking punch B. The blank holder ring is forced up by the elastic force of the rubber spring barrel R upon which the ring sets, through the medium of six pins passing through *the bolster* or die holder. The descent of the blanking punch B in diameter, and it is claimed that when the press is run at a speed of 55 revolutions per minute, nearly 6,000 sheets 20″ in diameter may be produced in ten hours.

Fig. 471 shows a well-known type of punching and shearing machine. It will be noticed that the machine is powerfully geared. The machine is really a form of a press and contains all essential parts of such a mechanism.

It will also be noticed that the machine is equipped with *a stop clutch*, operated by a foot-lever. The function of a stop-clutch is, at the will of the operator, to suddenly make a driving connection between the constantly revolving gear wheel and the temporary stationary main shaft. Its further purpose is to disconnect these members again automatically, after the shaft has made exactly one revolution and when the punch has reached its highest open position.

DRILLING MACHINES.

A mechanism of the greatest importance in a machine shop is the drilling machine. The ordinary *drill press*, as the larger drilling machines are generally called, is a complicated machine tool, presenting a great number of interesting mechanical principles to the student. It is, however, not within the scope of this book to take up extensively the construction of this machine; the figure on page 317 is an example of this class of machinery; the drawing shows *a bench drill*, which embodying, as it does, all the parts essential to any drilling machine, will enable the student to understand the favorite types of the drilling machine.

The following is a table of the speeds of drills for different sizes of drills and for different metals, as recommended by the Cleveland Twist Drill Company:

TABLE OF DRILL SPEEDS.

Diameter of Drill.	Speed for Soft Steel.	Speed for Cast Iron.	Speed for Brass.	Diameter of Drill.	Speed for Soft Steel.	Speed for Cast Iron.	Speed for Brass.
$\frac{1}{16}$	1,824	2,128	3,648	$1\frac{1}{16}$	108	125	215
$\frac{1}{8}$	912	1,064	1,824	$1\frac{1}{8}$	102	118	203
$\frac{3}{16}$	608	710	1,216	$1\frac{3}{16}$	96	112	192
$\frac{1}{4}$	456	532	912	$1\frac{1}{4}$	91	106	182
$\frac{5}{16}$	365	425	730	$1\frac{5}{16}$	87	101	174
$\frac{3}{8}$	304	355	608	$1\frac{3}{8}$	83	97	165
$\frac{7}{16}$	260	304	520	$1\frac{7}{16}$	80	93	159
$\frac{1}{2}$	228	266	456	$1\frac{1}{2}$	76	89	152
$\frac{9}{16}$	203	236	405	$1\frac{9}{16}$	73	85	145
$\frac{5}{8}$	182	213	365	$1\frac{5}{8}$	70	82	140
$\frac{11}{16}$	166	194	332	$1\frac{11}{16}$	68	79	135
$\frac{3}{4}$	152	177	304	$1\frac{3}{4}$	65	76	130
$\frac{13}{16}$	140	164	280	$1\frac{13}{16}$	63	73	125
$\frac{7}{8}$	130	152	260	$1\frac{7}{8}$	60	71	122
$\frac{15}{16}$	122	142	243	$1\frac{15}{16}$	59	69	118
1	114	133	228	2	57	67	114

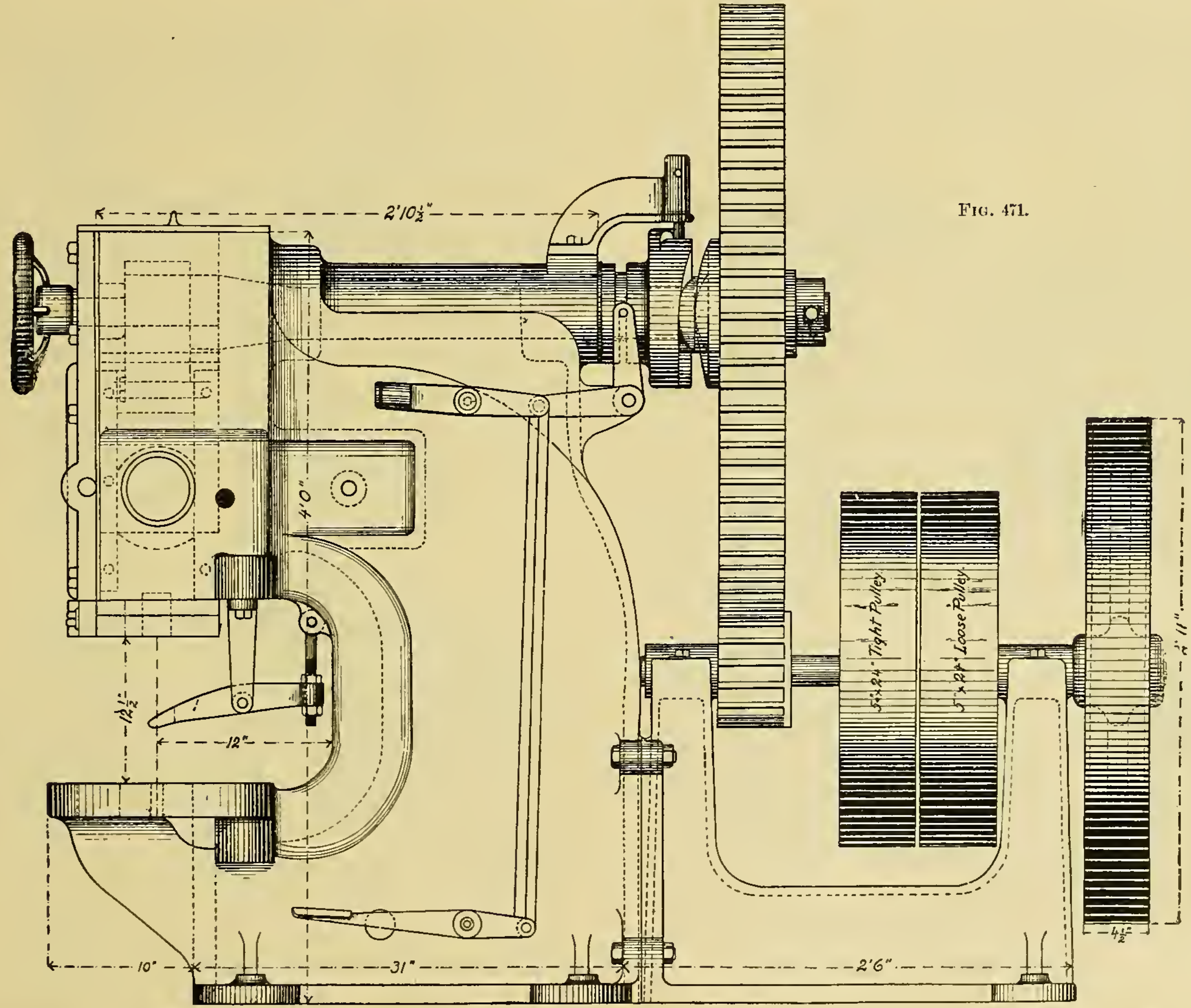

2'10½"
4'0"
12½"
12"
10"
31"
2'6"
5½×2¼ Tight Pulley
5×2¼ Loose Pulley
2'11"
4½"

FIG. 471.

Fig. 472 shows a side elevation of a bench drill of a neat and practical design, suitable for drilling small holes. A front view of this machine is illustrated in Fig. 473, while Fig. 474 exhibits a top view of the same.

The principal parts of the machine are the vertical spindle, holding the drilling tool, a table upon which the work to be drilled is held, and a rigid frame to which all parts of the machine are fastened.

The driving cone pulley, as well as the fast and loose pulley are mounted upon one horizontal shaft, at the back of the frame near its lower end.

The driving belt is led upward from the cone pulley over two horizontal guide pulleys, and then in a horizontal direction to the cone pulley, which is mounted upon the vertical spindle near its highest point.

The lower end of the spindle is provided with a thread for the purpose of holding a chuck which is to receive the drilling tool. The weight of drill, chuck, spindle and other parts which move downward or upward together with these parts are counterbalanced by a weight which is hidden in the hollow frame. For the upward and downward motion of the spindle a pinion and rack motion is provided. The table may also be lowered or raised according to the requirement of the work.

The number of varieties of drilling machines is growing rapidly. Large drilling machines are used also for tapping holes and are generally provided with automatic feed.

A class of drill presses which is particularly adapted for larger work is known as the radial drill; in this type the work is not shifted, after drilling a hole, if there are more holes to be drilled into the same surface; the drill spindle, with its entire mechanism is mounted upon a heavy cast iron arm, which swings horizontally upon the frame of the machine; the arm may be lowered or raised to suit the work, and the spindle carriage can be moved in or out on the arm, to suit conditions.

THE MILLING MACHINE.

The *Milling Machine* may be classed as a combination of several other machine tools used for cutting metals; the work that can be done on this machine is not limited to either straight or curved surfaces, or drilling of holes; in general construction this machine does not differ greatly from an ordinary drill press, in fact it can often be used in its place.

In this machine the table upon which the work is held is movable in all directions, without disturbing

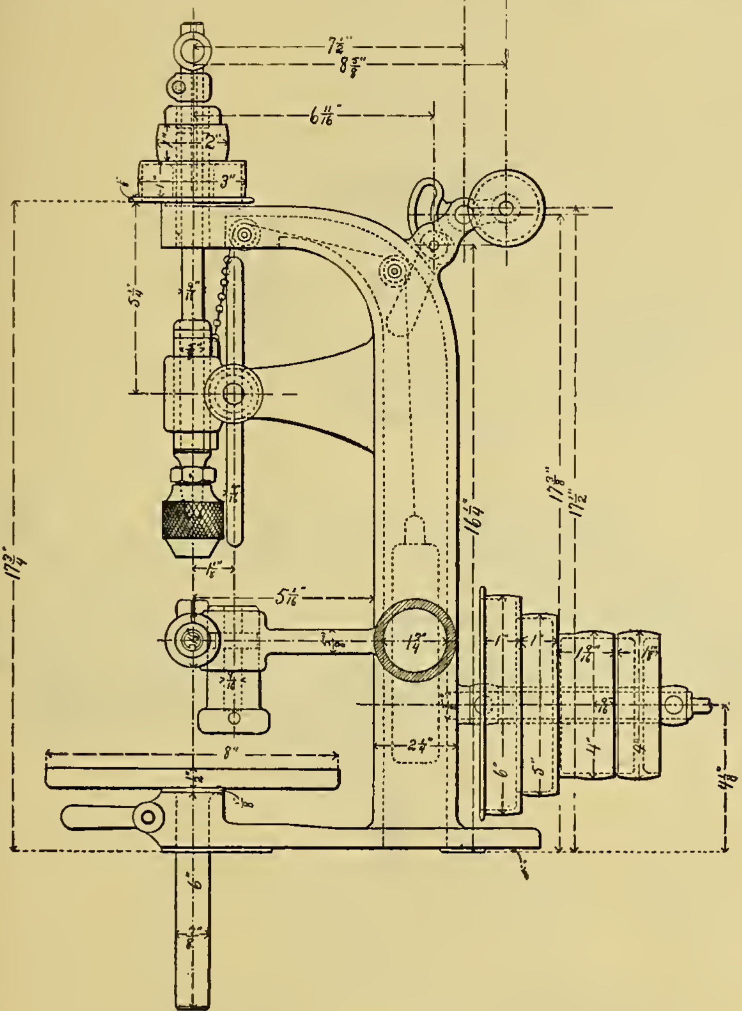


FIG. 472.

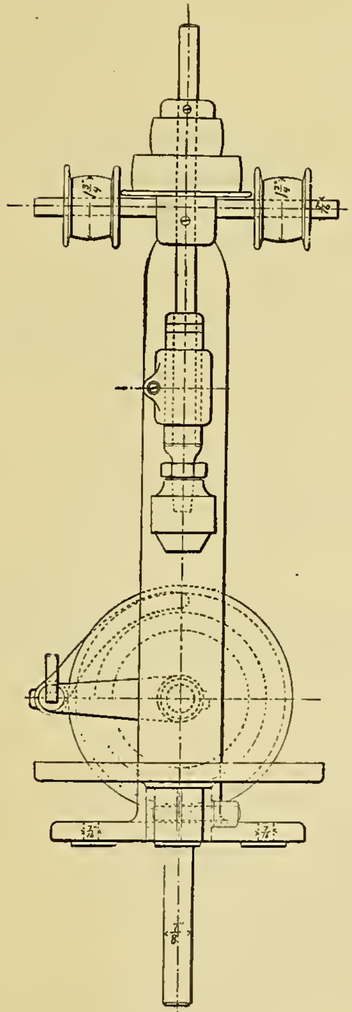


FIG. 473.

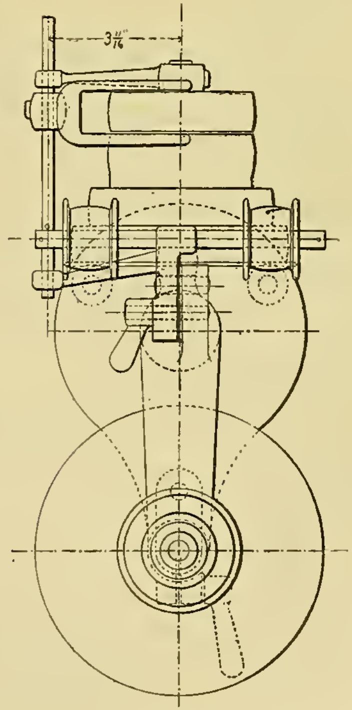


FIG. 474.

the adjustment of the work, which is fed either automatically or by hand feed, while the rotating cutter removes the superfluous metal.

In illustrations Nos. 475 and 476 are illustrated an approved form of a vertical spindle milling machine.

Fig. 475 shows the front view of this machine, and Fig. 476 shows the side elevation. The whole machine is an advanced type of a modern milling machine and produces an impression of strength and neatness of design.

The vertical spindle of this machine is made fully 3″ in diameter; the lower end of the spindle is provided with a thread for large mills, working in a horizontal plane.

The platen as well as *the saddle* of this machine are 51½″ long. All feed screws are provided with *dials*, thus enabling accurate work in a most convenient manner.

The largest distance between the spindle and the platen is 21½″. The extreme distance between *the rotary table* and *the vertical spindle* is 16″. There are fully eight changes of feed for the table and sixteen changes for the rotary attachment.

The dimensions of this machine over all, are as follows: Height 81″, width 65″ and depth 88½″.

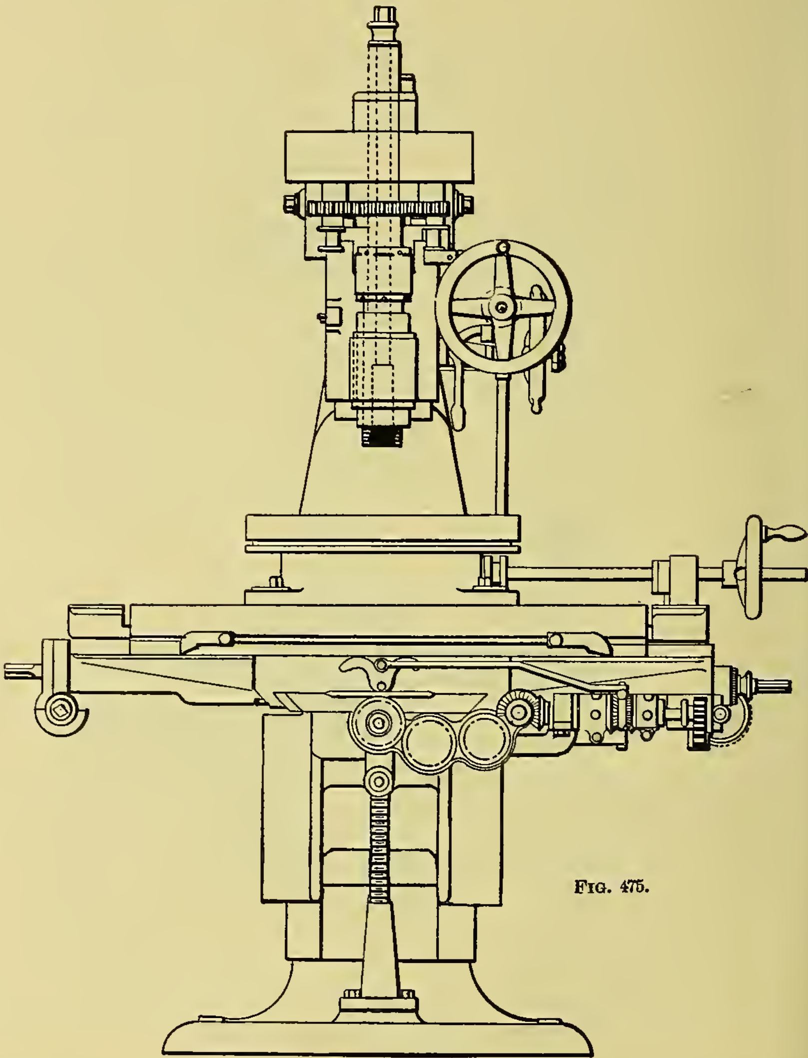


FIG. 475.

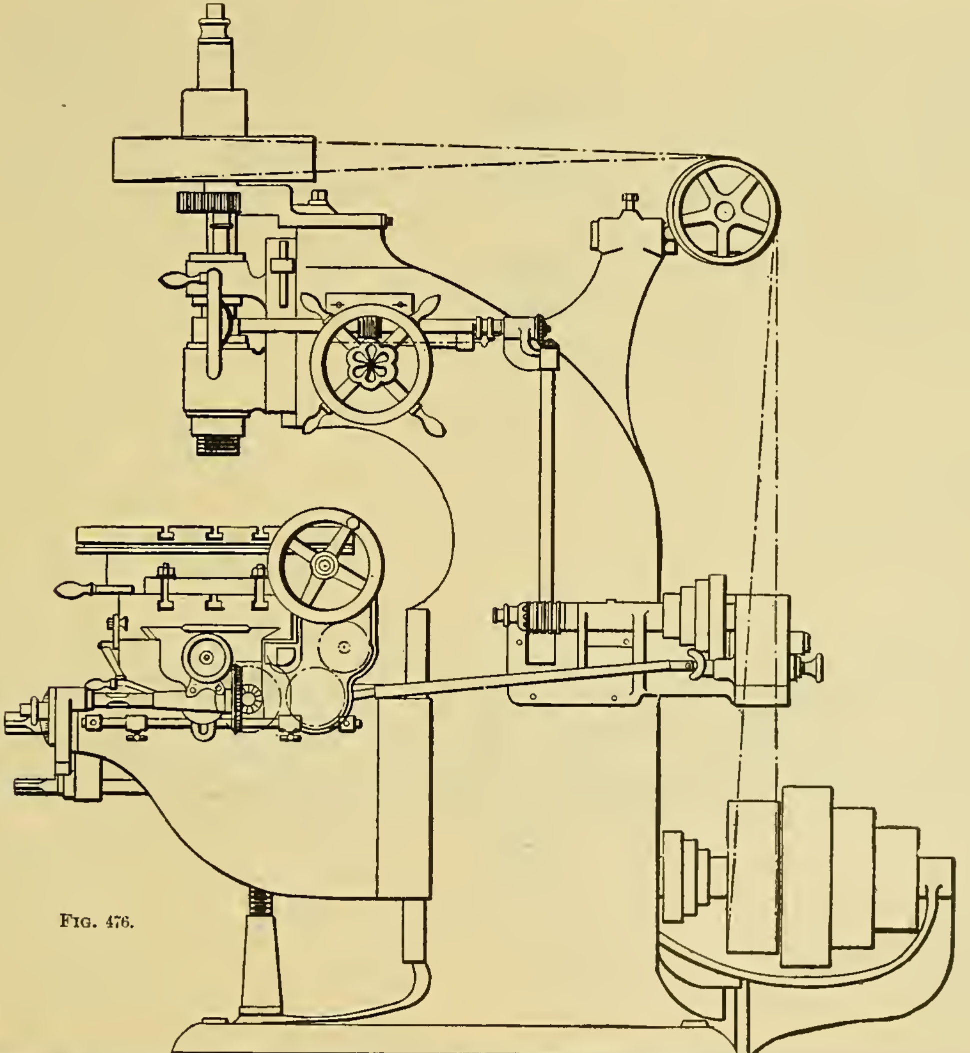


FIG. 476.

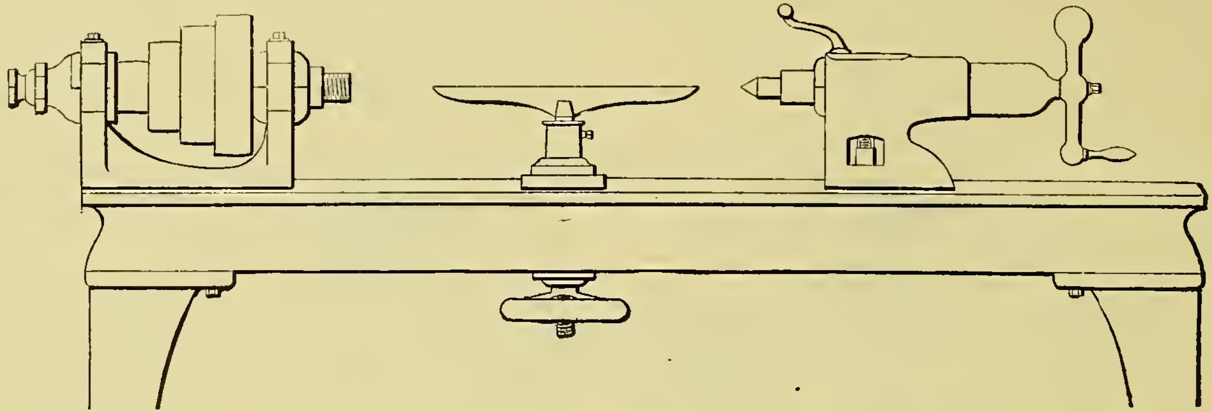


Fig. 477.

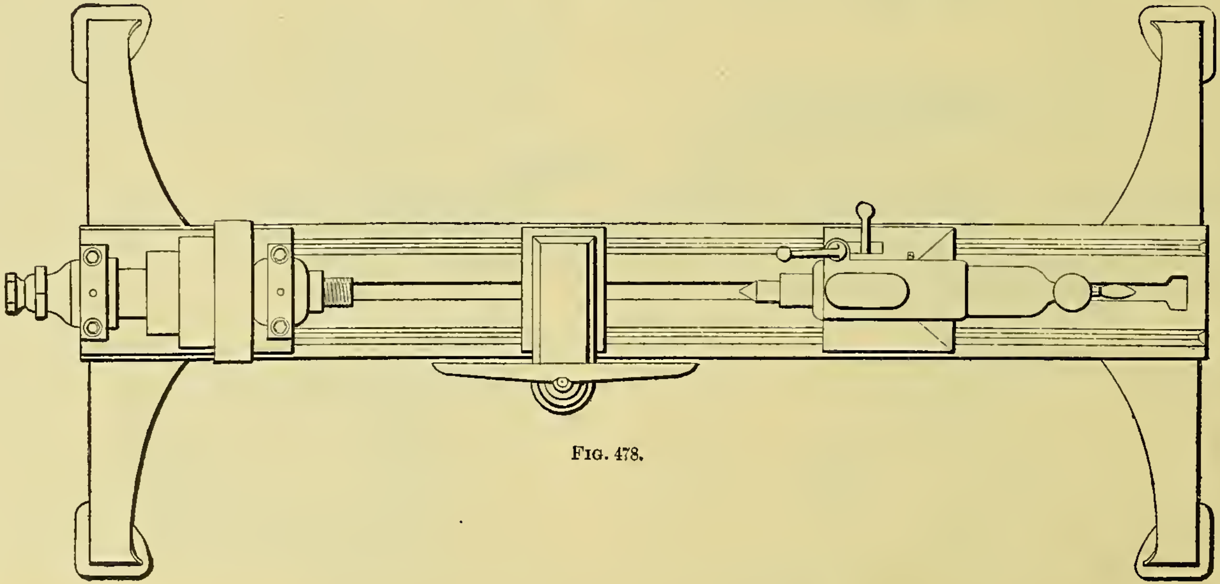


Fig. 478.

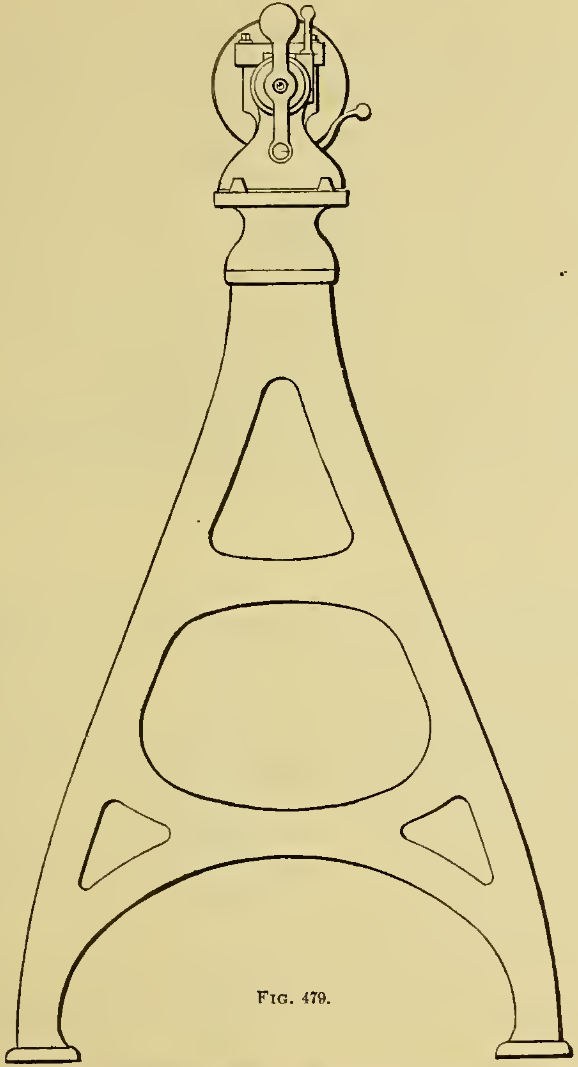


Fig. 479.

THE LATHE.

The most important machine tool in a shop is undoubtedly the lathe. It is used for a great variety of purposes and for this reason it is made in many different special forms and designs.

The simplest kind of a lathe is shown in Figs. 477 to 479. It is called a *speed lathe* and is used for small work which can be run at a high speed.

The lathe is composed of the following principal parts:

1. The bed.
2. The legs or supports.
3. The head stock.
4. The tail stock.
5. The tool rest.

By means of *the steps* in the *cone pulley* on the head stock different changes of speed of the spindle can be obtained. The *tool rest*, Figs. 480 and 481, is adjustable in all directions, but it is not provided with automatic feed connections.

The ordinary engine lathe, used for heavier and more accurate work, has the same main parts as the speed lathe. In this lathe, however, the carriage with its tool support is moved over *the shears of the bed* by the *lead screw* and its connections. The lead screw is splined and the feed mechanism is driven from a collar which has a *feather* engaging the spline and slides over the lead screw. The form of thread used on lead screws is somewhat similar to a square thread with sides forming an angle of 14½ degrees.

The lead screw is driven from the spindle of the head stock by gear wheel connections.

The head stock of an engine lathe, in two views, is shown in Figs. 482 and 483. Fig. 482 shows an elevation of the head stock, and Fig. 483 represents its plan or top view, the back gears being plainly shown.

Large engine lathes are also provided with a separate feed shaft besides the lead screw; this shaft is driven by a belt and cone pulleys, from the *stud*, and is splined lengthwise; a splined worm is fitted upon this shaft in such a manner that it can slide on it lengthwise, but is held by two projections on the *apron of the carriage*, so that it will slide with the carriage and at the same time turn with the feed shaft.

This worm engages in a worm-wheel, connected by a clutch to a gear, which meshes with a rack under the front edge of the lathe-bed. By means of this clutch the feed can be engaged or disengaged. The worm-wheel also connects with a clutch, which will operate the cross-feed of the tool. Both clutches are operated by knobs at the front of the apron.

Fig. 484 shows the longitudinal section and Fig. 485 is a cross or lateral section of the tail-stock of a lathe of the usual form. All *back-geared lathes* can be run with the back gears idle, by locking the cone with the spindle gear; in this way the spindle has only the changes in spindle speed depending upon the steps of the cone pulley as in the speed lathe. The gear wheels at the back of the head stock reduce the speed of the spindle and a double number of changes in speed can thus be obtained.

Figs. 486 and 487 show the manner in which the spindle gear may be connected with the lead screw gear, for producing different feeds.

CHANGING GEARS FOR SCREW CUTTING.

The problem of cutting a screw on a lathe resolves itself into connecting the spindle of the lathe with the lead screw by a number of gears in such a manner that the carriage, moved by the lead screw, advances exactly one inch during the lapse of time required for the lathe spindle to make a number of revolutions equal to the number of threads to the inch in the desired screw.

The lead screw has, nearly always, a single thread, and, therefore, to move the carriage for-

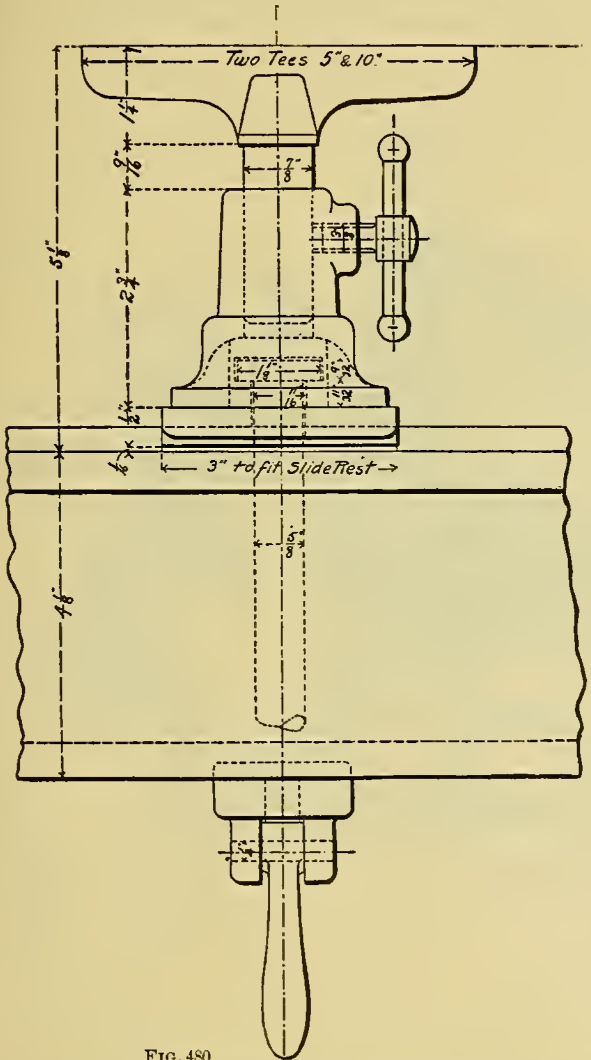


FIG. 480.

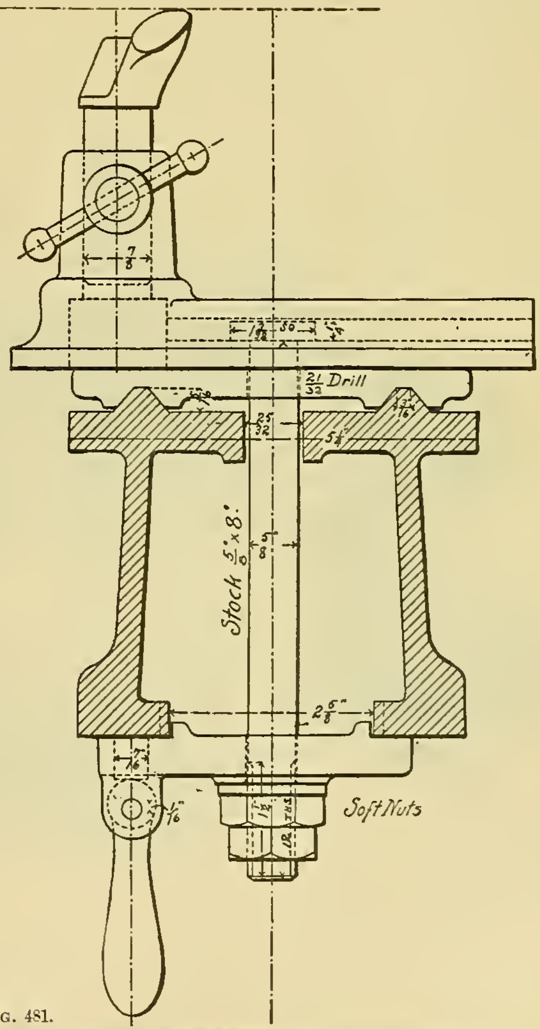


FIG. 481.

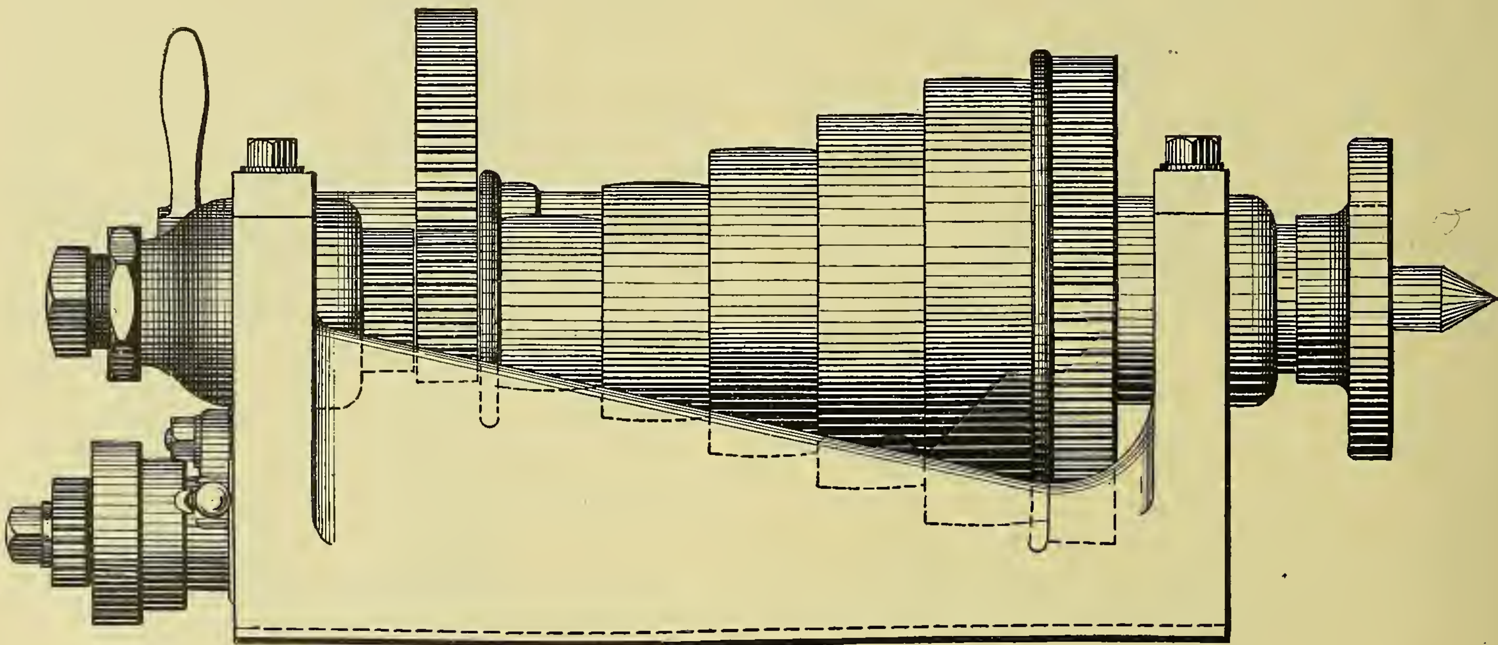


Fig. 482.

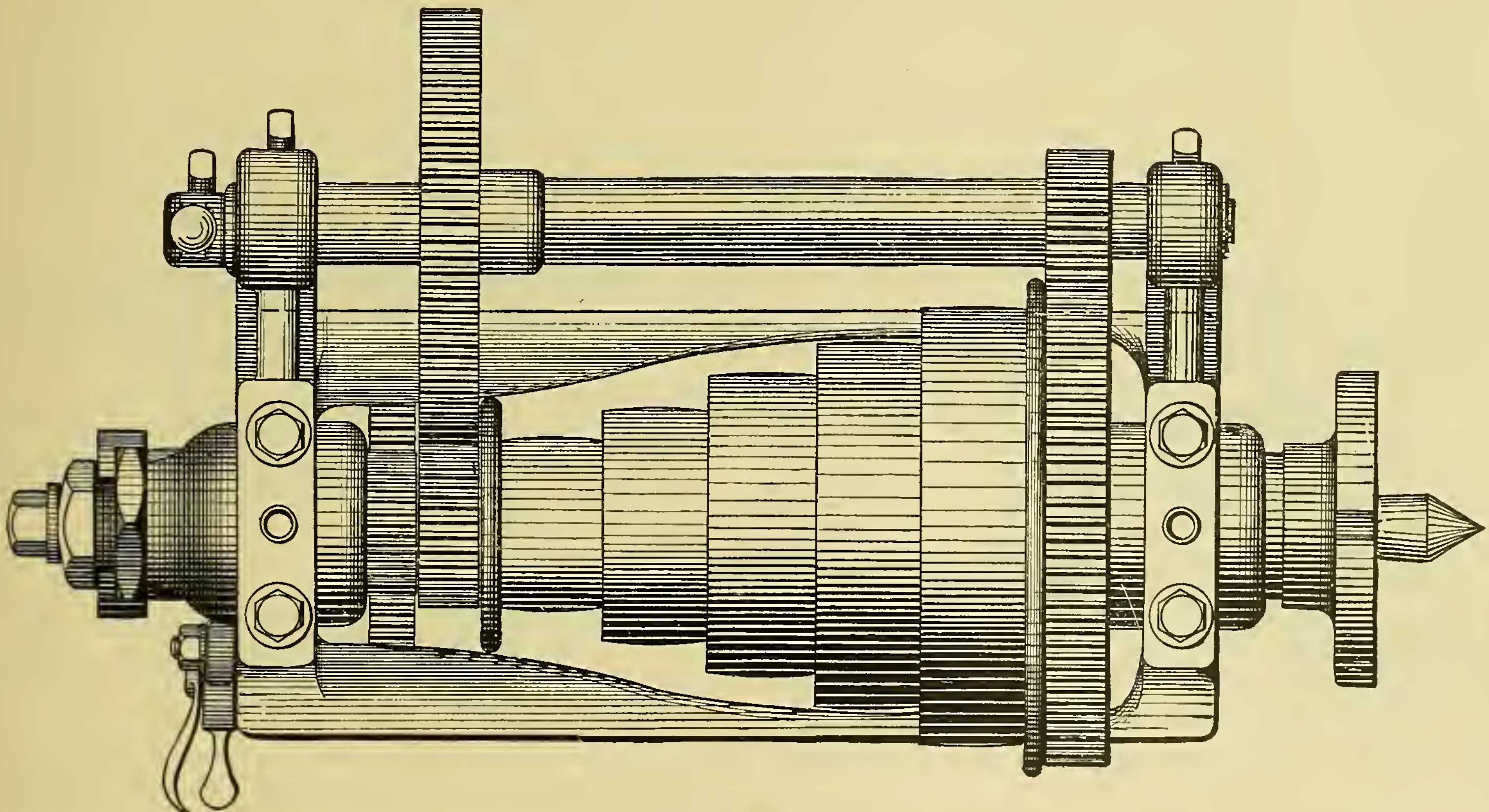


FIG. 483.

ward just one inch it must make a number of revolutions equal to its own number of threads per inch. It is, consequently, first of all necessary to know the number of threads per inch on the lead screw.

The spindle of the lathe is provided with a gear which transmits the rotary motion of the spindle to the stud gear, below the spindle, by means of intermediate gears, situated within the head stock. There are two of these intermediate gears, one being an idle gear, for the purpose of changing the direction of the motion of the stud and through this the lead screw.

The connection of the stud with the lead screw may be accomplished by *simple* or *compound gearing*.

In *simple gearing* the motion of the stud gear is transmitted either direct or by means of an intermediate gear to the gear on the lead screw. One or more intermediate gears, which simply transmit the motion received from one gear to another, do not affect the resulting ratio of a train of gears. Consequently, the intermediate gears in simple gearing will be disregarded in all calculations for screw cutting.

The stud gear is usually equal to the driving gear on the spindle; it may, however, be of a different size and in the following problem it will be assumed that the gear on the spindle has double the number of teeth than that on the stud.

The following formula will give the required ratio for the gears on the stud and on the lead screw:

$$\frac{\text{Number of teeth on stud gear}}{\text{Divided by number of teeth on lead screw gear}} = \frac{\text{Number of turns of spindle}}{\text{Number of turns of stud}} \text{ multipled}$$

$$\text{by } \frac{\text{Number of threads on the lead screw}}{\text{Divided by number of threads per inch on required screw.}}$$

Problem:

It is required to cut a screw with 16 threads to the inch; the lead screw has 8 threads to the inch and the spindle makes 20 turns to 40 turns of the stud.

Solution:

$$\frac{\text{Number of teeth on stud gear}}{\text{Number of teeth on lead screw gear}} = \frac{20}{40} \times \frac{8}{16} = \frac{1}{4}$$

The required ratio is one to four, *i.e.*, when the stud gear will have 16 teeth the lead screw gear will have $16 \times 4 = 64$ teeth; now if the stud gear will have 20 teeth the lead screw gear will have $20 \times 4 = 80$ teeth and so on.

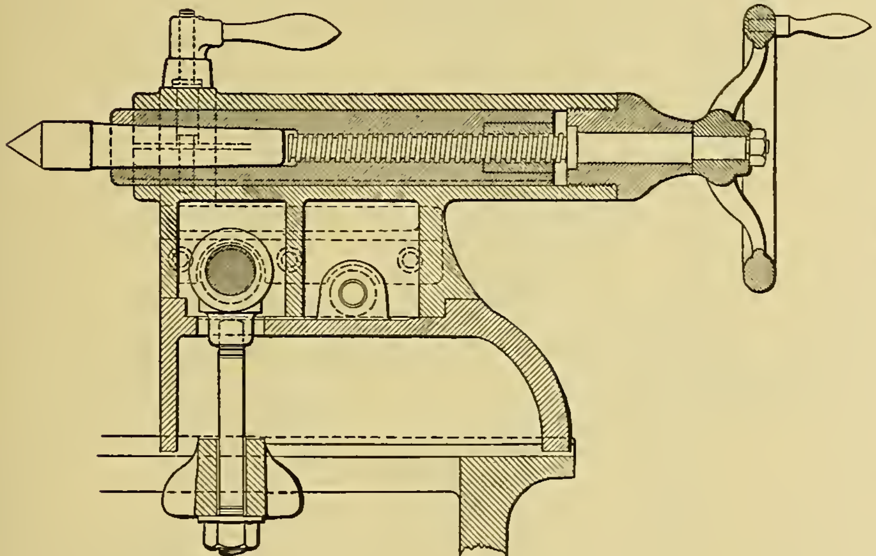


FIG. 484.

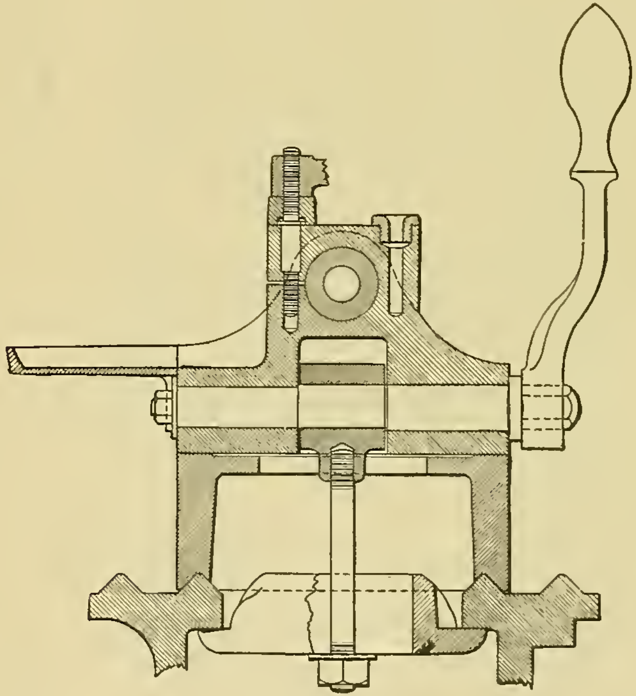


FIG. 485.

In *compound gearing*, as in Fig. 487, the motion of the stud gear is transmitted to the lead screw by two gears keyed together on an intermediate stud. In this case there are four changeable gears and consequently a wider range of changes than in simple gearing.

Of the two gears working together on the intermediate stud that one which works with the spindle stud is called the first gear and the other working with the lead screw gear is termed the second gear.

Now assuming that the spindle gear makes 20 revolutions to 40 revolutions of the stud gear and that the lead screw has 4 threads to the inch it will be necessary to find the velocity ratio between the stud gear and the lead screw gear for cutting a screw with 50 threads to the inch.

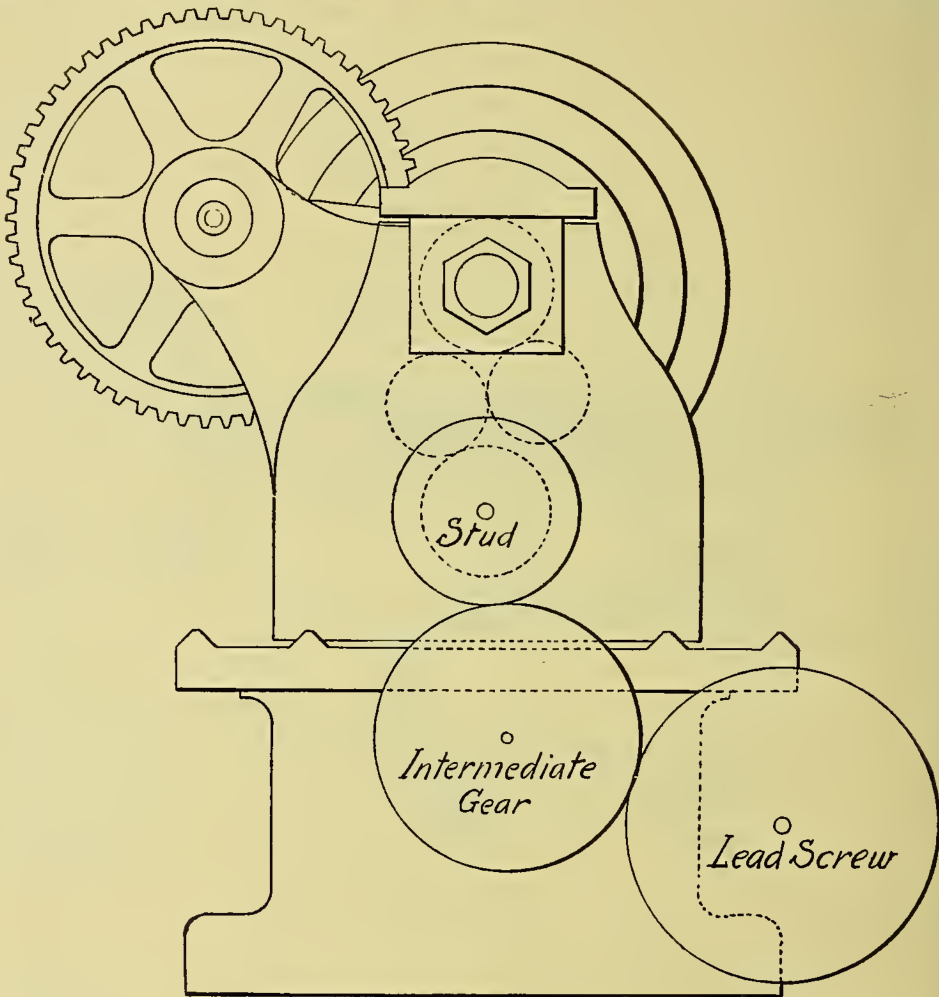


FIG. 486. *Simple Gearing.*

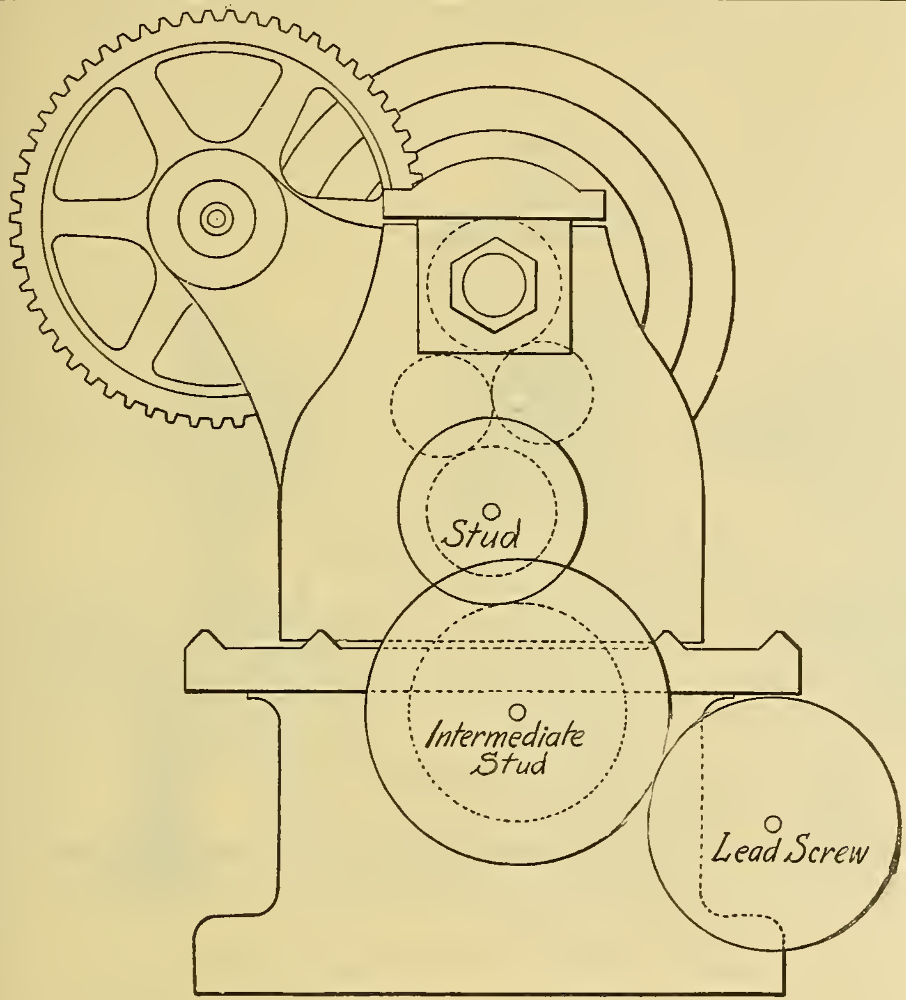


FIG. 487. *Compound Gearing.*

$$\frac{\text{Number of teeth in stud gear}}{\text{Number of teeth in lead screw gear}} = \frac{20}{40} \times \frac{4}{50} = \frac{1}{25}$$

that is, if the gear on the stud should have 16 teeth then the gear on the lead screw would have 400 teeth, or the required ratio for simple gearing. For compound gearing this ratio can be divided into factors, for instance, $\frac{1}{5} \times \frac{1}{5} = \frac{1}{25}$, that is the velocity ratio for the spindle stud gear and the first intermediate stud gear could be made equal to $\frac{1}{5}$, and the same velocity ratio for the two other gears. For instance, if the stud gear will have 16 teeth the first intermediate stud gear must have $5 \times 16 = 80$ teeth; the second intermediate stud gear could have 16 teeth and the lead screw gear 80 teeth. Or 15 and 75 could be taken for the first pair and 16 and 80 for the second pair, or in fact any pair of gears having the desired velocity ratio.

Figure 488 represents a modern shafting lathe, built by the Springfield Tool Company, and which can be used both for ordinary lathe work and especially for turning shafting.

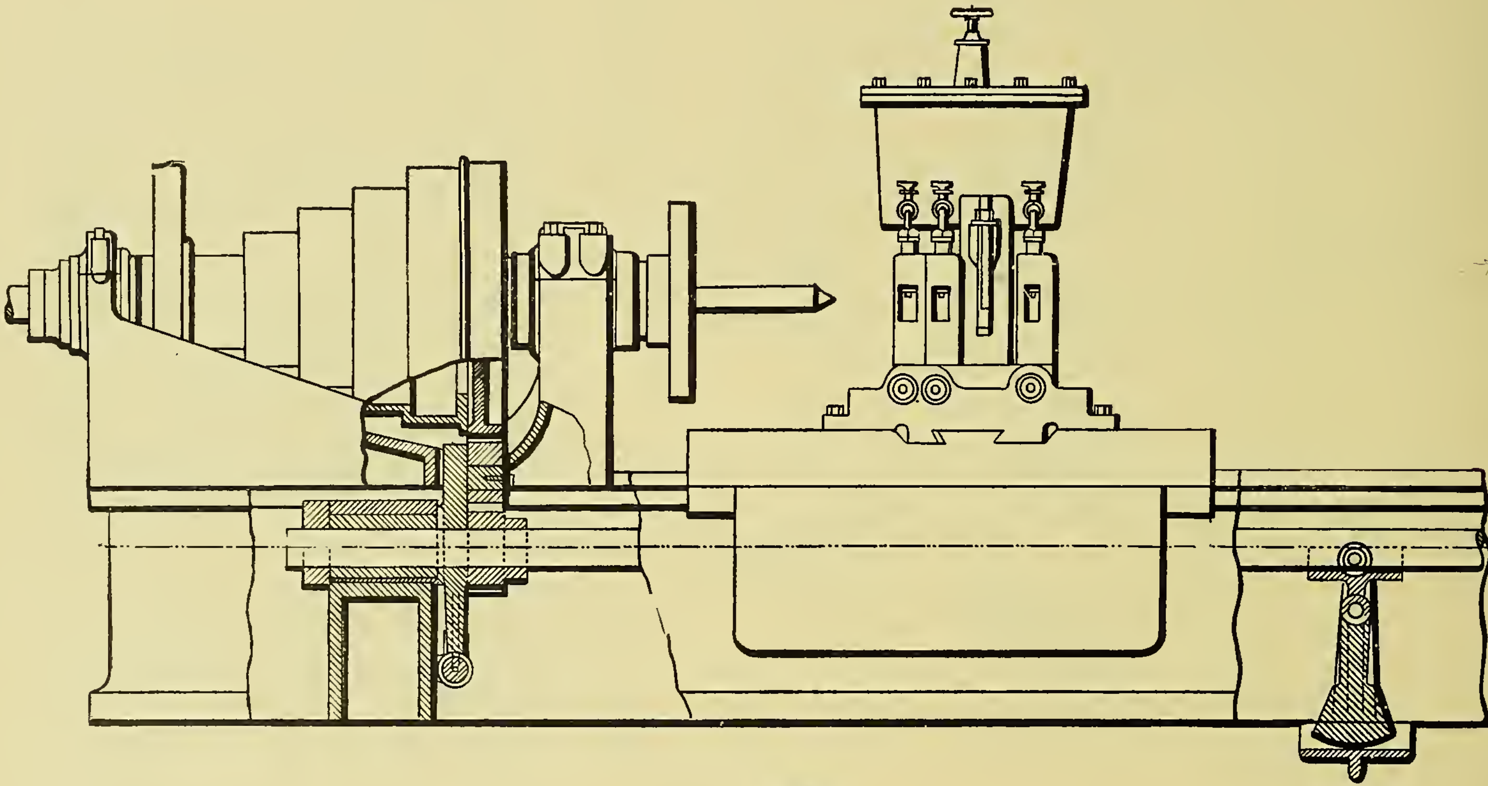


FIG. 488A.

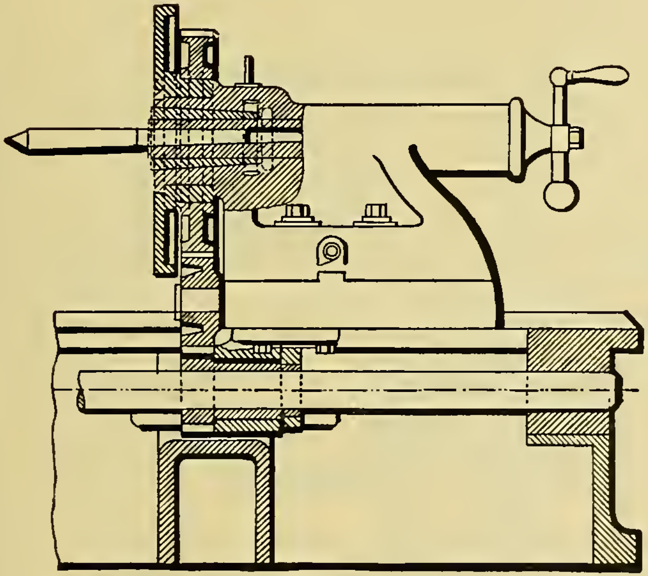


Fig. 488B.

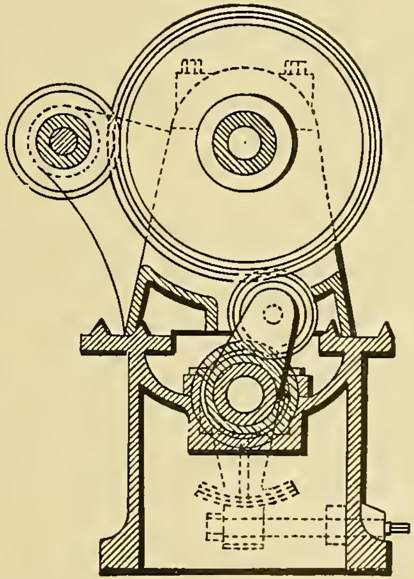


Fig. 489.

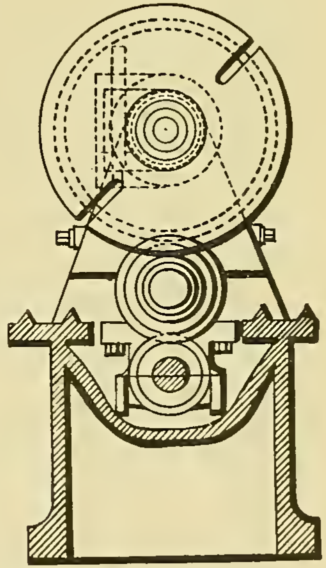


Fig. 490.

This lathe may be fed by a friction feed or by the lead screw. Slightly below and midway between the shears in the bed, passes a splined shaft, which drives the tail stock face plate by means of an intermediate gear, shown in Fig. 490. This small gear can be thrown out of action by the worm-wheel section shown in Fig. 489. The tail stock face plate is made for the purpose of driving the shaft by a dog, exactly as is done by the head stock. It is very convenient for turning the end of the shaft for which the head stock dog has to be removed.

The long centers are a necessity in this lathe in view of the fact that they must reach through a bushing in the rest. This bushing is depended upon to support the shaft during the cutting; it is made to fit the shaft exactly. The special rest for shafting slides into place on the saddle when the compound rest is removed. The pump and tanks for lubricants are carried by this rest. The pump is driven by a gear wheel seen in Fig. 491, which engages with a pinion sliding upon a shaft; this latter extends the entire length at the back of the lathe. Fig. 491 also shows the lower tank into which all the lubricant collects, from where it flows by gravity to the pump.

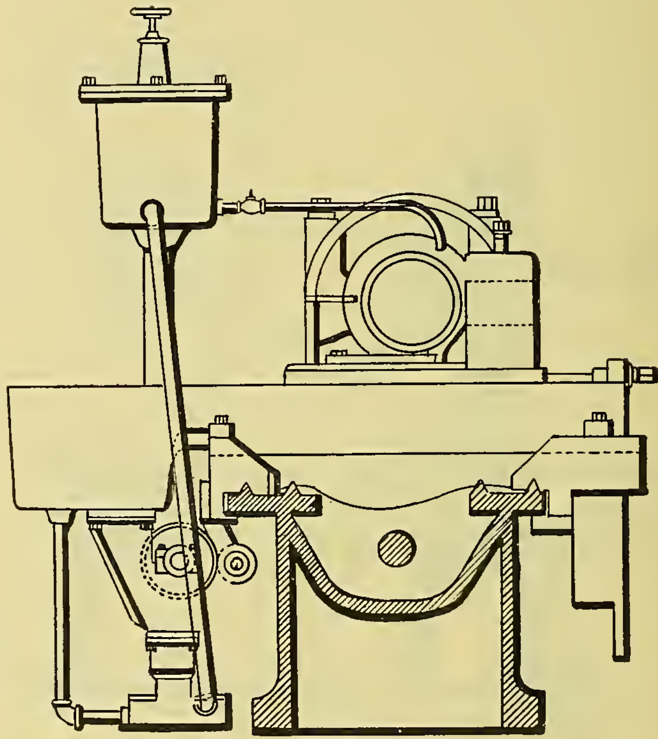


Fig. 491.

ENGINES AND BOILERS.

The study of the steam engine involves an acquaintance with the sciences of heat, of chemistry, and of pure and applied mechanics, as well as a knowledge of the theory of mechanism and the strength of materials ; many other things are needed to be known, as the student will find as he progresses in his researches, the first of which should relate to the safe and economical production of the steam itself.

Nearly the whole of the Eighteenth Century passed in experiments made to reduce the energy, latent in coal and other fuels, to the service of mankind ; at its earliest point of progression the boiler and the engine were substantially one and the combined engine and boiler were known as *the fire engine.* At a little later period when scientific research had shown clearly the source of the power which gave vitality to the newly invented mechanism the name changed to *the heat engine*, it having become known that heat accomplishes work only by being let down from a higher to a lower temperature, a certain amount of *heat disappearing* when changed into *work.*

The modern Steam Engine is now considered as apart from the Steam Boiler and the classification and variety of each and the successive steps of advancement, while full of interest are too voluminous to consider in this volume, but some account of their early history is given in the note below.

NOTE.—About the year 1710, Thomas Newcomen, ironmonger, and John Cawley, glazier, of Dartmouth, in the county of Devonshire, made several experiments in private, and in the year 1712 put up an engine, operated by steam, which acted successfully. The progress made was very rapid and it is recorded that in the year 1737 there was a pumping engine of the Newcomen construction working a succession of pumps each 7 inches in diameter and 24 feet apart, and making 6-feet strokes at the rate of 15 per minute, whereby water was pumped from cistern to cistern throughout the whole length of a shaft 267 feet deep, by steam at or near the atmospheric pressure.

The construction of the Newcomen engine was greatly improved by Smeaton, who designed and erected an engine for the Chase-Water mine, in Cornwall, which had a cylinder of 72 inches in diameter, with a 9-feet stroke, and worked up to 76 horse power. There were three boilers, each fifteen feet in diameter. This was the last effort on a system then about to pass away, for the engine was set up in 1775 no less than six years after the date of Watts' patent, and we are told that when " erected it was the most powerful machine in existence."

STEAM BOILERS.

A closed vessel in which water may be heated for the purpose of generating steam is called a steam boiler; the boiler is partially filled with water for this purpose, the level of the water in the boiler being called *its water line;* the space above the water line is termed *the steam space.*

That part of the surface of the boiler, exposed to the heat of the fire and of the hot gases, is called *the heating surface* of the boiler, and its measurement is usually given in square feet.

The space in which the heat is generated is called *the furnace;* the surface upon which the coal is laid is called *the grate surface,* and its dimensions are also given in square feet.

Steam boilers may be classified according to their construction and form, or according to their application. Thus, we have horizontal and vertical boilers, externally and internally fired boilers, plain cylindrical shell boilers, fire-tube and water-tube boilers.

Boilers may be *stationary* or *portable;* there are locomotive boilers and marine boilers *semi-portable,* etc.

The plain cylindrical boiler, Fig. 492, consists of a long cylinder called *a shell,* made of iron or steel plates riveted together, the ends of the cylinder being closed by flat plates called *the heads of the boiler.*

The furnace is arranged at the front end of the boiler, the fuel being placed on the grate through the furnace door, the ashes falling through the grate into *the ash pit* below. Behind the furnace is built a brick wall, called *the bridge wall,* which keeps the hot gases in close contact with the under-side of the boiler.

For long boilers of this class a second bridge wall often is built.

The hot gases flow from the furnace over the bridge walls into *the chimney.* Within the chimney is placed *a damper* regulating the flow of these gases. All portions of the brick work exposed to the action of the gases, are made of fire-brick. It is not desirable to allow the upper portion of the boiler to come in contact with the hot gases, and for this reason the boiler above the water line is lined with fire brick.

Water is forced into the boiler through *the feed pipe* leading to the lower end of the boiler, by the aid of *an injector* or a pump. To prevent the steam from rising above a certain pressure, *a safety valve* is placed at the top of the boiler.

From the highest part of the boiler also, *the main steam pipe* leads the steam to the engine or any apparatus for which the steam is to be used.

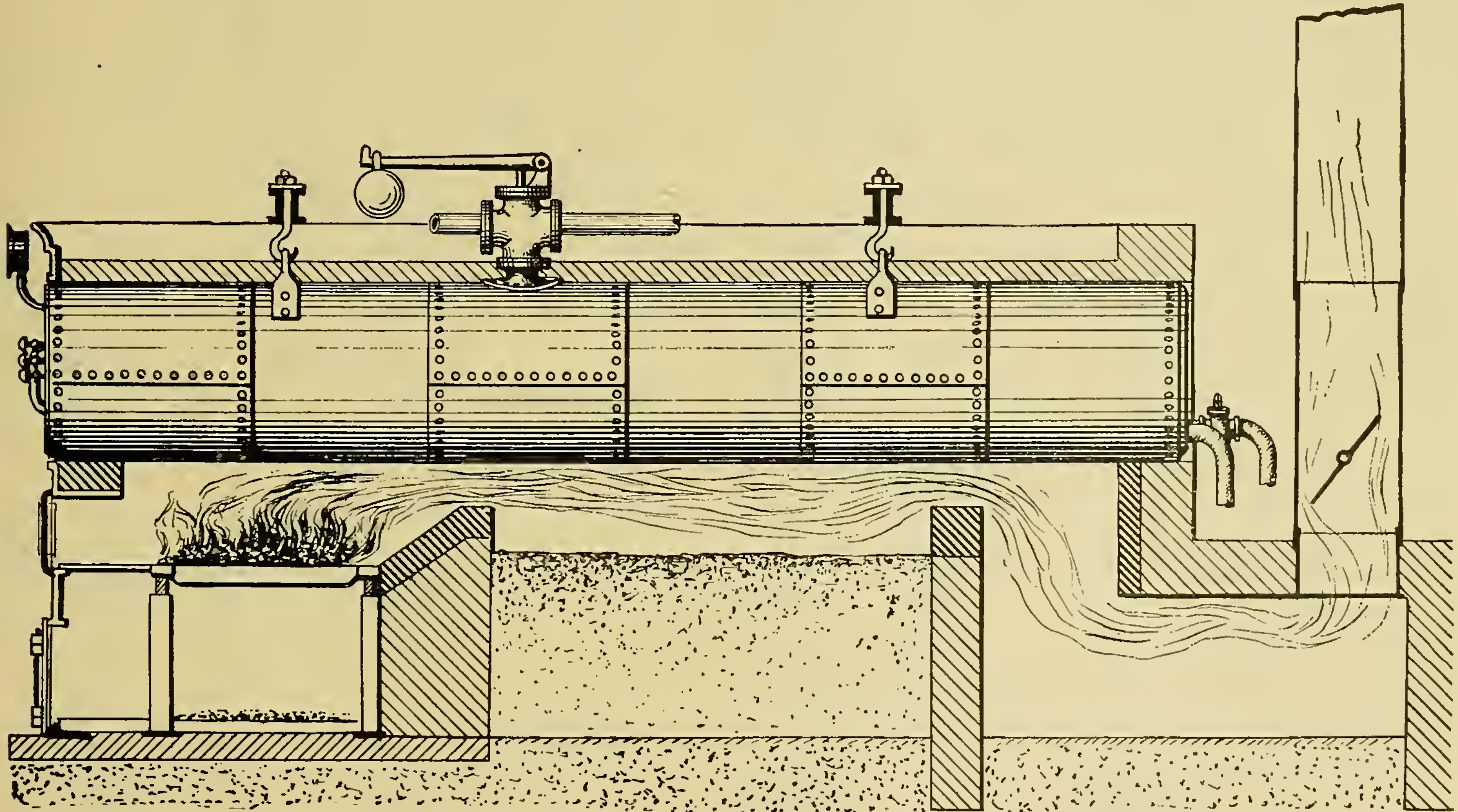


FIG. 492.

The pressure of the steam in the boilers is indicated by *the steam gauge*, Figs. 493 and 494, attached to a pipe which passes through *the front head* into *the steam space of the boiler*. To determine the water level, *gauge cocks* are placed in the front head of the boiler shell. There are, commonly, three of them

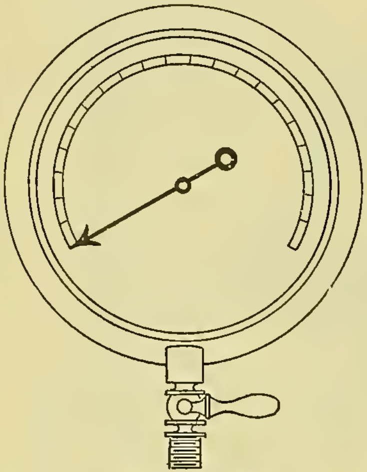


FIG. 493.

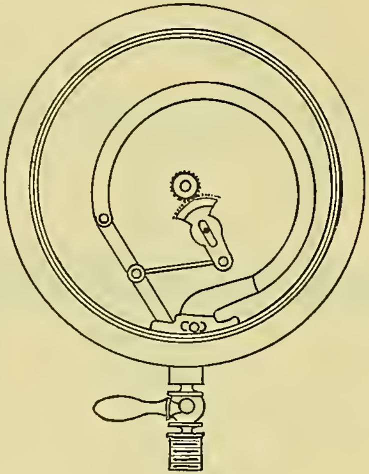


FIG. 494.

in one vertical line; the level of the water may be found approximately by opening these gauge cocks, shown in Fig. 495.

The level of the water may also be shown by a water glass, illustrated in Fig. 496. Valves at the top and bottom allow the steam to be shut off if the glass breaks or needs cleaning, and a *pet cock* at the

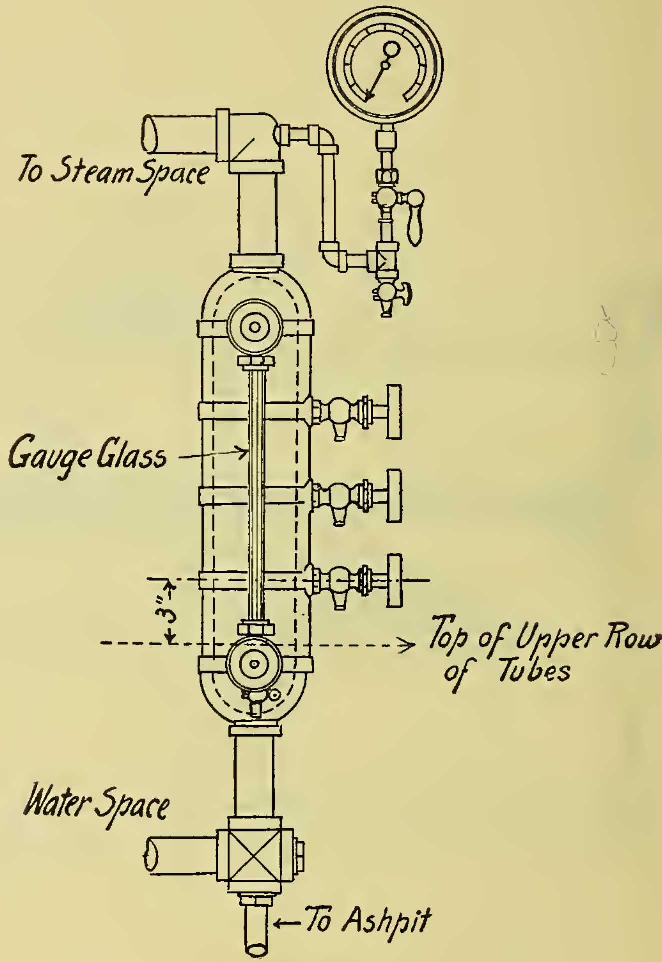


FIG. 495.

bottom allows the water to be blown out of it. The brass fittings of the water glass are often screwed directly into the boiler plates; when this cannot be done, the water glass may be put on a *water column* like that shown in Fig. 495.

The boiler must also be provided with a *blow-off pipe*, through which the water may be discharged; in Fig. 492 the feed pipe, as well as the blow-off may be seen at the rear of the boiler.

A *manhole*, Fig. 497, is constructed in the front head or on top of the boiler, to allow a person to enter for the purpose of cleaning, inspecting or repairing. At the lower side of the boiler a *handhole* is generally sufficient, as in Fig. 498, for cleaning it out and removing the accumulated sediment.

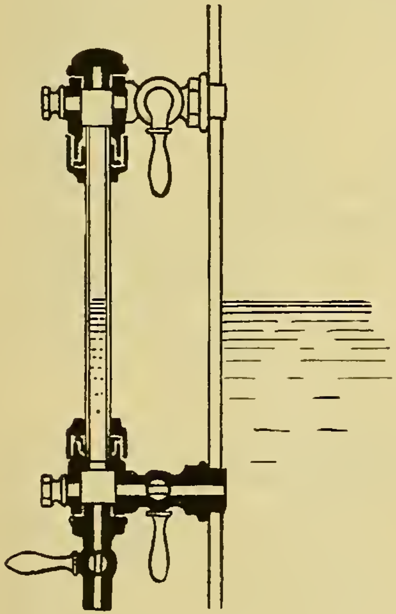


FIG. 496.

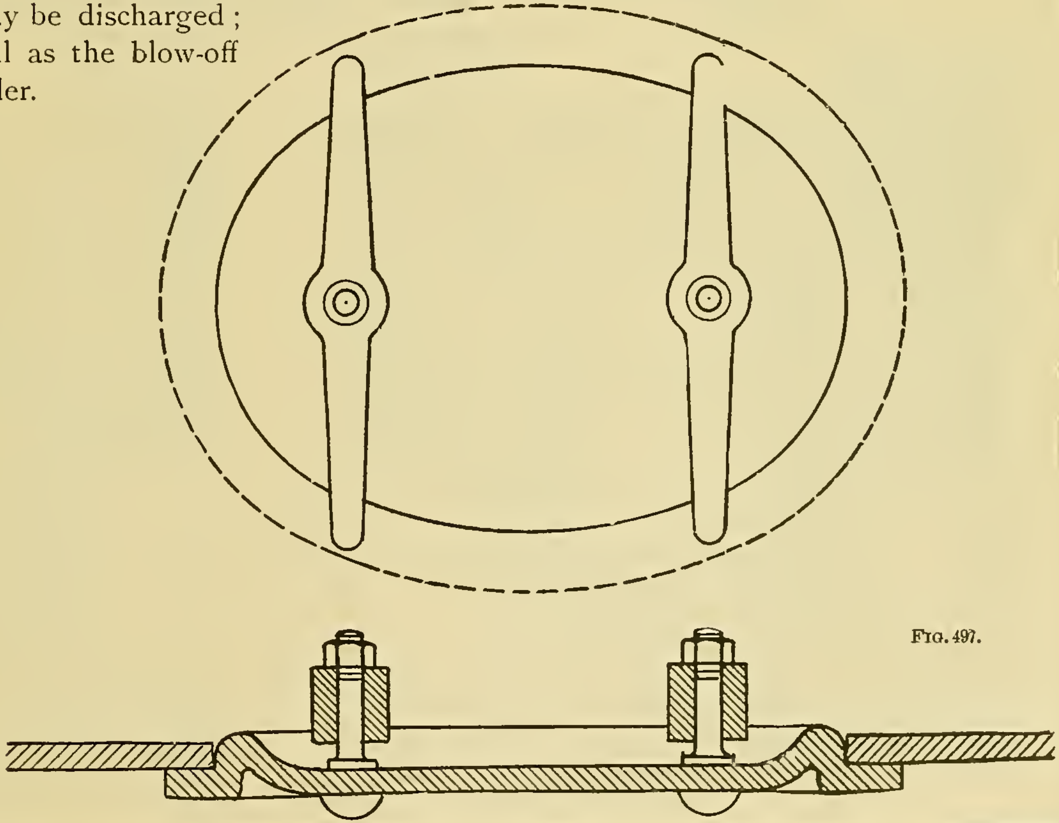


FIG. 497.

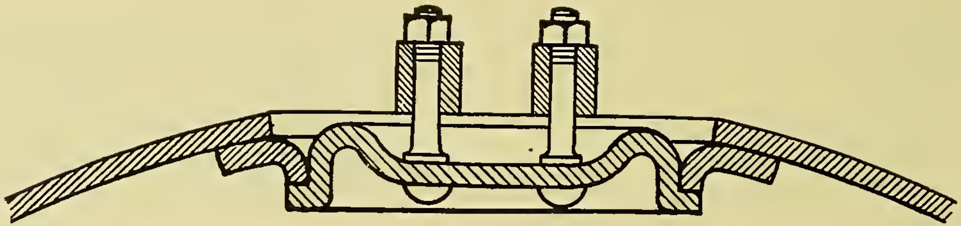


FIG. 498.

Plain cylindrical, or plain shell boilers, may be made from 30 to 40 inches in diameter and from 20 to 40 feet long; they are not considered economical on account of their small heating surface.

The *flue boiler*, Figs. 499 and 500, differs from the plain shell boiler in having one or more large flues running lengthwise through the shell, below the water level. The hot gases pass from the furnace over the bridge walls and then through the flues to the *smoke box* and chimney. This type of boiler is more economical than the plain shell boiler, as the flues considerably increase the heating surface. It is used wherever the water is bad, even though it may not be as economical as some other types of boiler.

The *cylindrical tubular boiler*, Figs. 501, 502, 503 and 504, is a development of the flue type. It consists of a cylindrical shell, closed at the ends by two flat tube plates and of numerous fire-tubes, usually having a diameter of three or four inches. About two-thirds of the boiler is filled with water; the other third being the steam space. The water level must be six or eight inches above the highest row of fire-tubes.

The *fire-tubes* hold the two ends of the boiler rigidly together, acting as stays, but as these are placed only below the water line the upper parts of the flat plates are braced by *through rods* or stays, or *diagonal stays*, similar to that shown in Fig. 505.

The boiler is supported by the side walls by means of brackets riveted to the shell, similar to the one shown in Fig. 506.

The *Cornish boiler* consists of a cylindrical shell with flat ends, through which passes a smaller tube or flue, containing the furnace as shown in Fig. 507. The furnace is terminated by the bridge wall built of fire brick. The hot gases flow over the bridge wall to the end of the furnace tube, then they return on both sides of the boiler shell through the flues on the side of the boiler and again pass to the back end of the boiler by the flue running along its bottom to the chimney. The figure shows a longi-

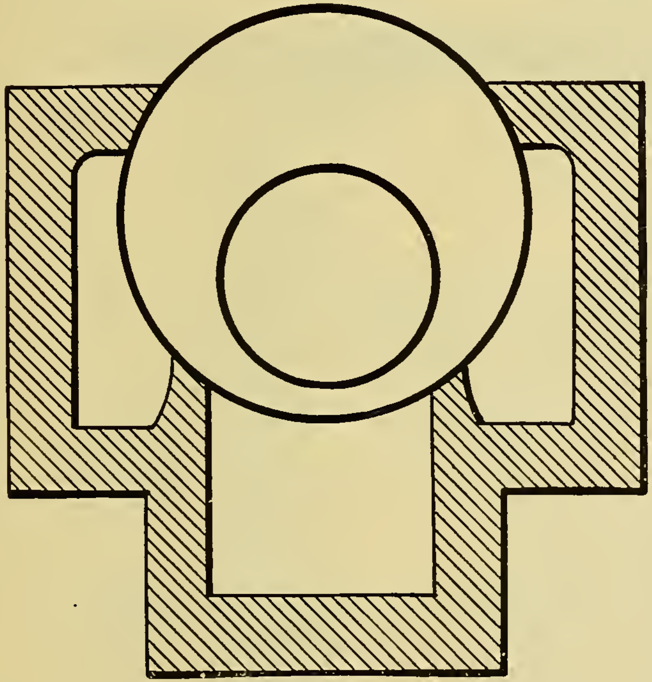


FIG. 499.

tudinal section of the boiler. The gases part with much of their heat before reaching the bottom of the boiler, and therefore are less liable to unduly heat the bottom plates where sediment usually collects. It has been found that this method of draft heated the plates unequally and thus weakened the boiler. For this reason the products of combustion are led through the bottom flue first and then only

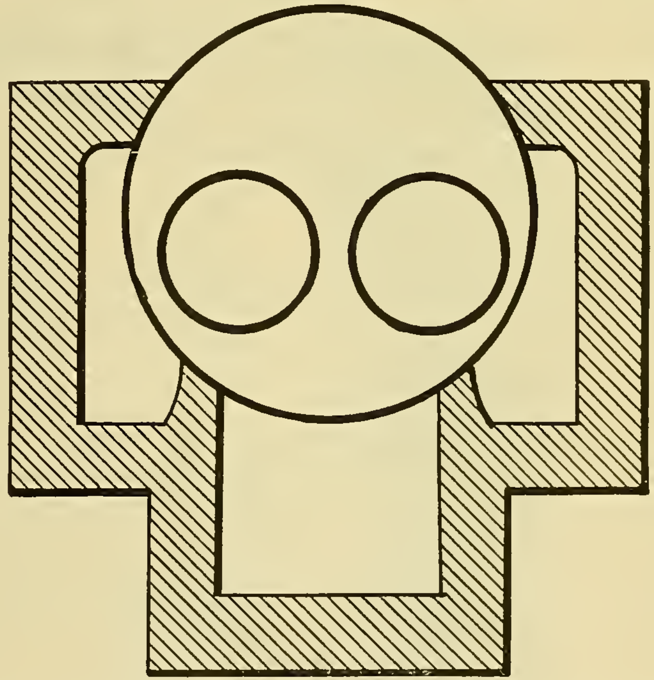


FIG. 500.

through the side flues, this method being called the *split draft*.

A Cornish boiler having two internal furnace tubes is called a *Lancashire boiler*.

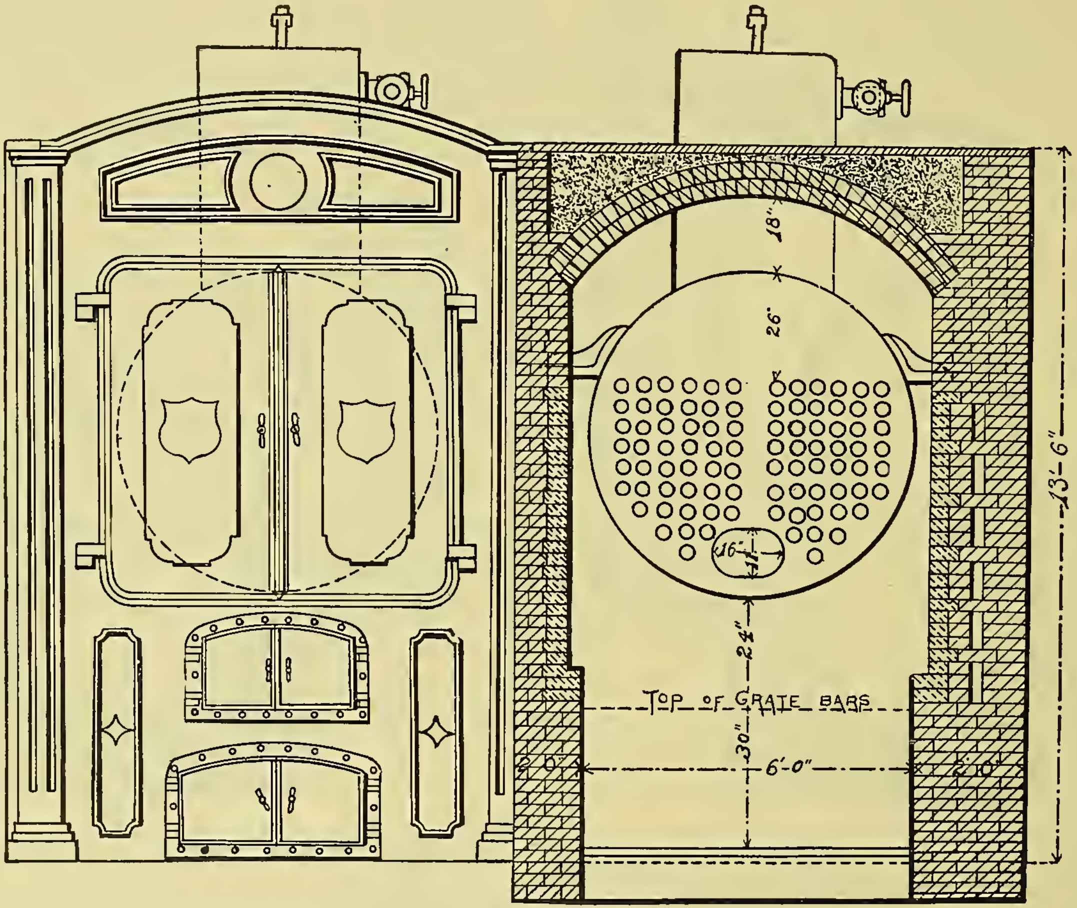


FIG. 501.

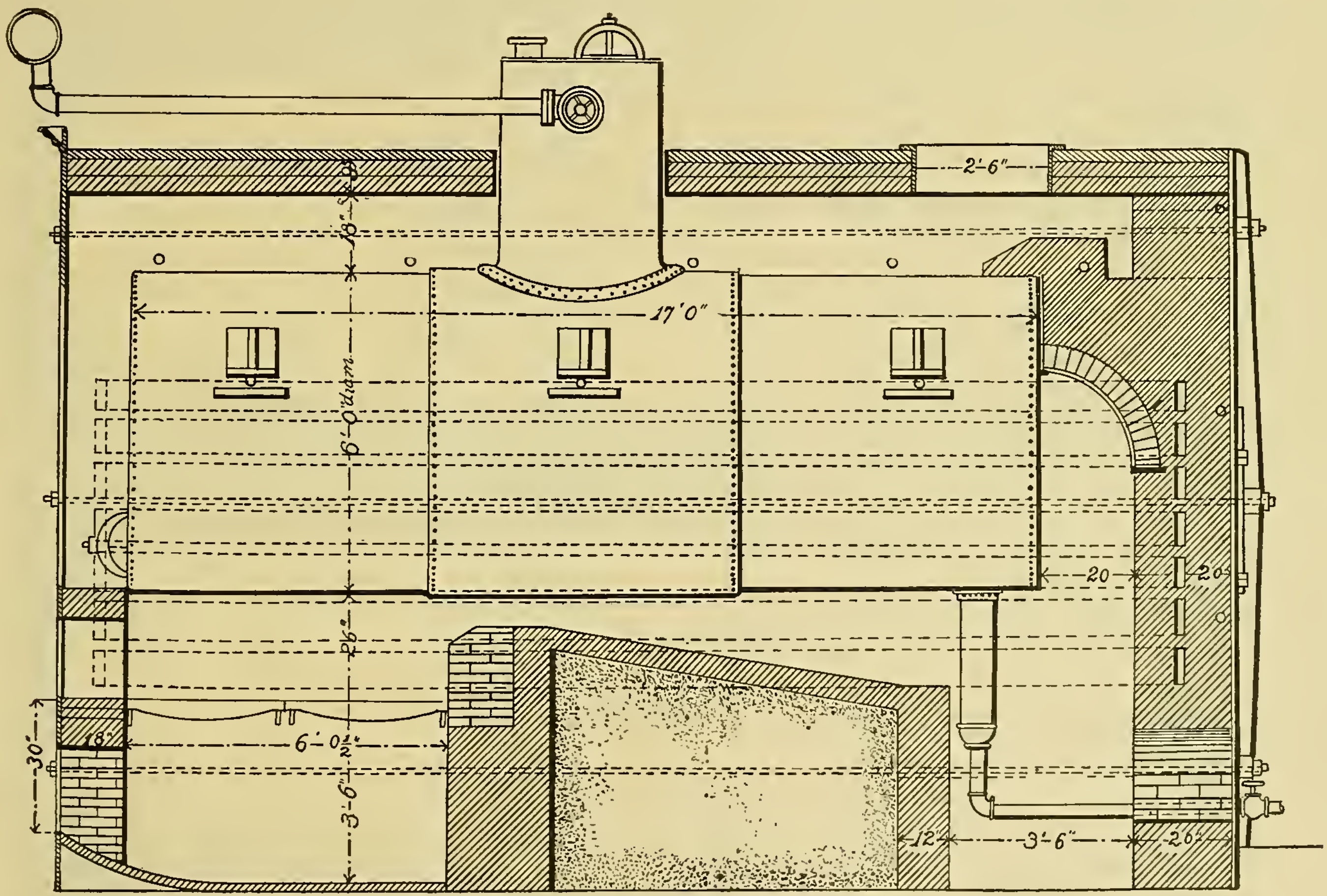


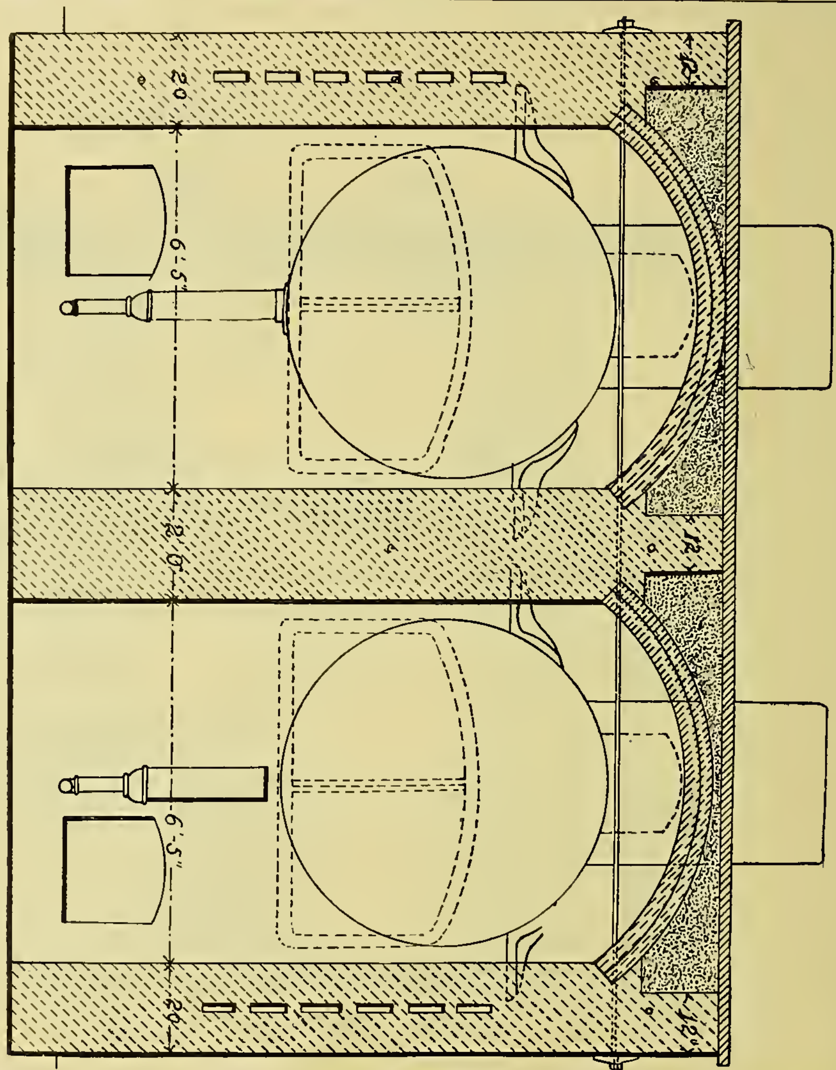
FIG. 502.

The *Galloway boiler* will be understood from the part section shown in Fig. 508. Here water tubes are placed within the furnace tube; holes are cut opposite each other in the furnace tube, and the joints made good by riveting the flanges of the water tube around the hole; they pass directly across the furnace tubes, so that the hot gases have a considerably increased heating surface to act upon.

Instead of extending through the whole length of the boiler, the two furnace tubes unite just behind the bridge wall in one large flue, which extends to the rear head of the boiler.

A *locomotive or fire box boiler* of a semi-portable character is shown in Figs. 509 and 510, which exhibit a half end elevation and half cross section through the fire box. The rectangular fire box which constitutes the furnace of this boiler is riveted to the front part of the cylindrical boiler. A space called the *water leg* is left around the fire box and the boiler shell; this space, which is usually from 2½ inches to 4 inches wide, is intended to be filled with water.

Fig. 508.



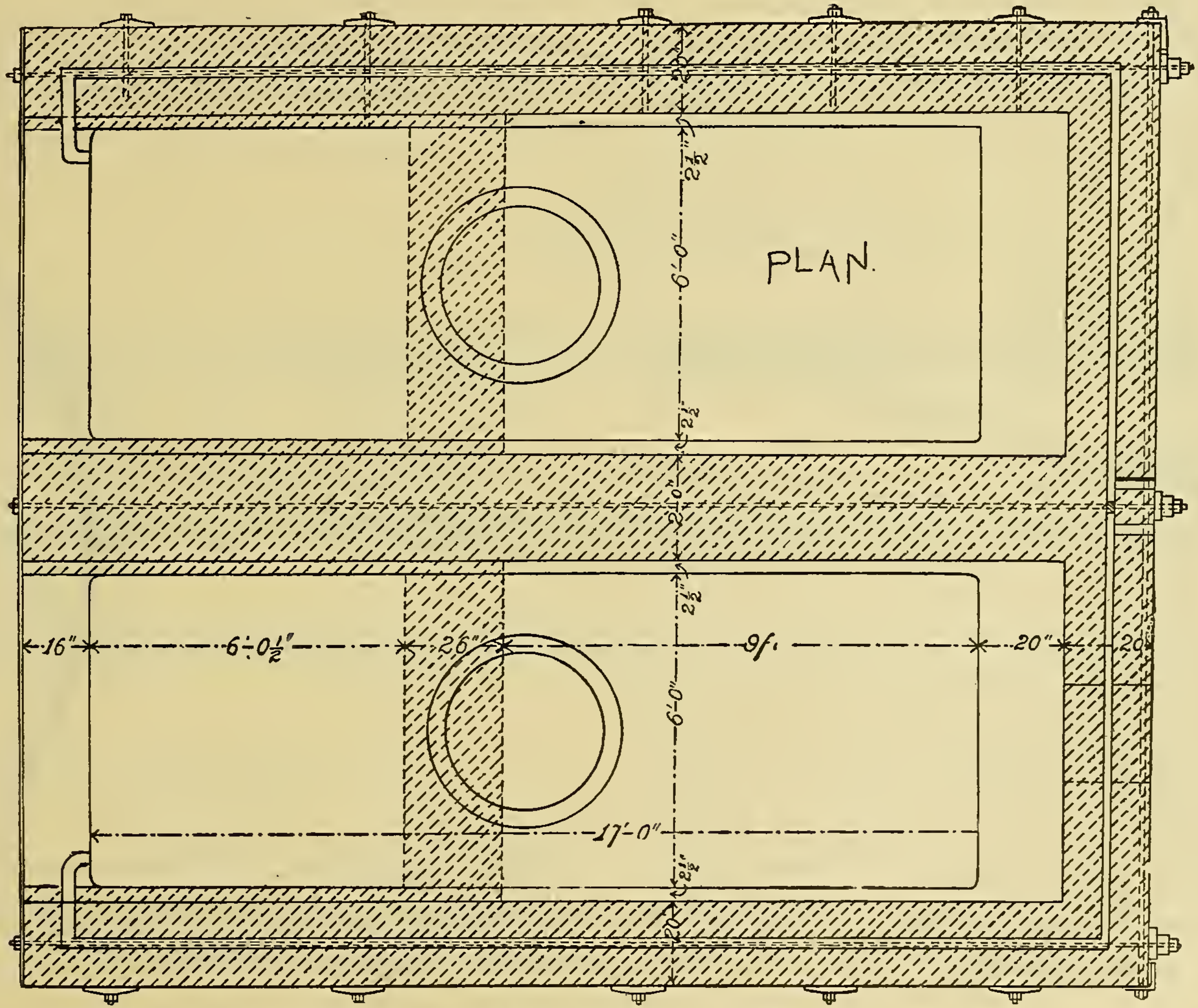


Fig. 504.

Since the flat sides of the furnace and shell are liable to bulge under pressure, they must be securely braced or stayed; the illustration shows the *stay bolts* which are there for that purpose. The top of the fire box is strengthened in a similar manner, as is seen in the longitudinal section of this boiler, Fig. 510; a large number of tubes pass through the boiler and are secured to a tube plate at the rear end

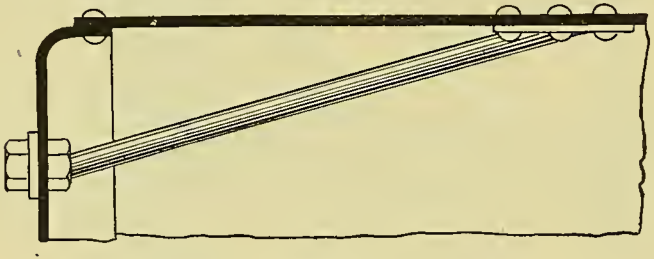


FIG. 505.

of the boiler and to the fire box at the front end; a cylindrical smoke box is fastened to the rear end of the boiler; the gases of combustion pass directly from the furnace through the tubes to the smoke box and thence to the smoke stack.

Vertical boilers have the advantage of taking up comparatively small floor space. They are made in a great many varieties of designs and are used particularly for fire engines, hoisting engines, etc., and wherever space is limited.

An interesting example of this type of boiler construction is shown in Figs. 511, 512 and 513; this design has given excellent economical results. It may be observed that there are no flat surfaces

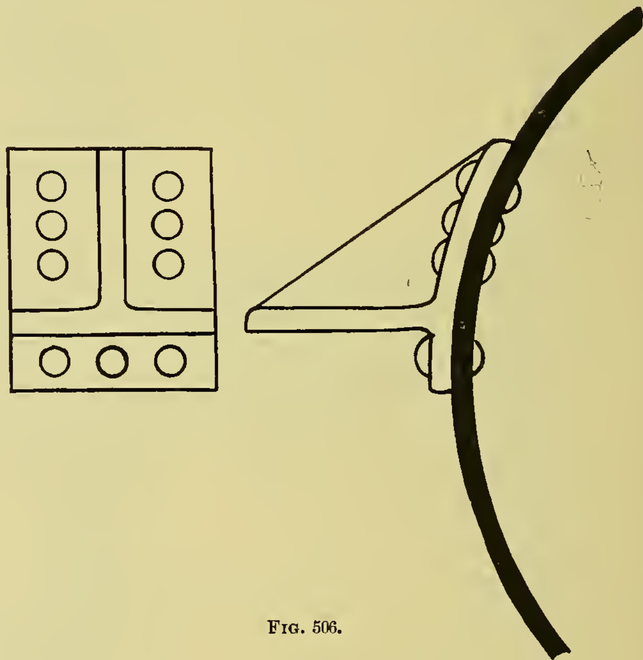


FIG. 506.

which require staying, the top of the shell, as well as the upper plate of the fire box, are of hemispherical shape, giving the maximum strength for a given weight of material.

The products of combustion pass from the fire box through the inclined oval-shaped flue, into a combustion chamber and thence through a very large number of horizontal tubes to the smoke box and thence to the chimney.

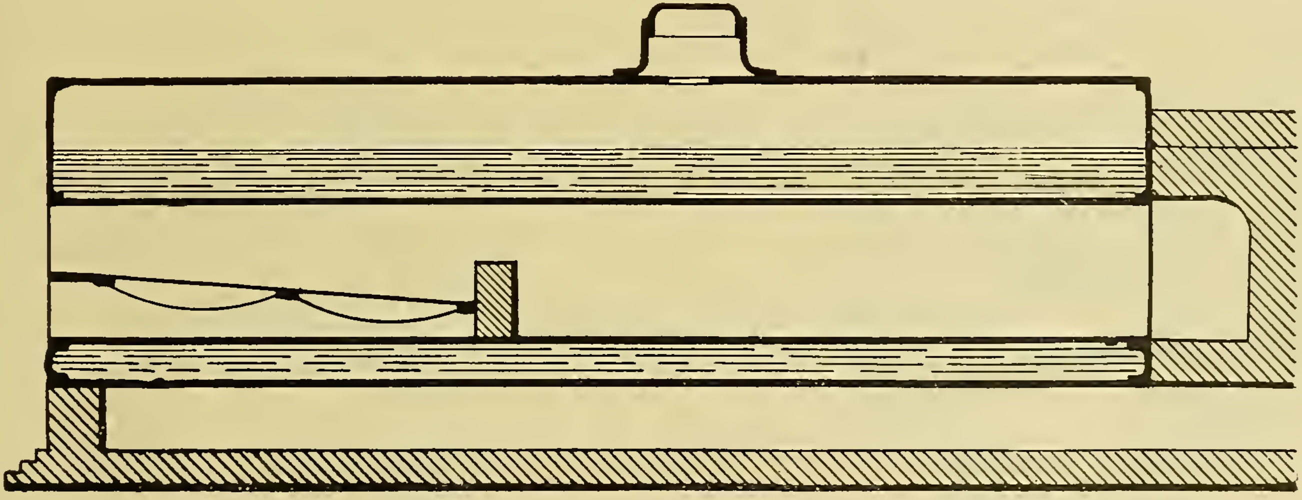


Fig. 507.

As may be seen in the illustration, the combustion chamber is lined with fire brick.

Whenever the generation of a large quantity of steam in a comparatively short time is required, water tube boilers are now extensively employed. In these boilers the steam space is limited to a cylindrical shell which forms only a part of the boiler. The water is contained in a large number of small lap-welded tubes, connected in various ways to each other, as well as to the cylindrical drum above them. The water fills all the tubes and a part of the drum. A furnace of the usual form is placed under the front end of the tubes, the products of combustion circulating around the tubes and the under side of the drum. An illustration of this type of boiler is shown in Figs. 514, 515.

In this type of boiler the drum for the steam space is made comparatively large, and is located parallel to and above the network of tubes, which are inclined, as well as the drum, at an angle with a horizontal plane, so as to bring the water level to about one-third the height of the drum in the front and about two-thirds of its height in the rear. The ends of the tubes are expanded into large water legs made of wrought iron, flanged and riveted to the shell, which is cut out for a part of its circumference to

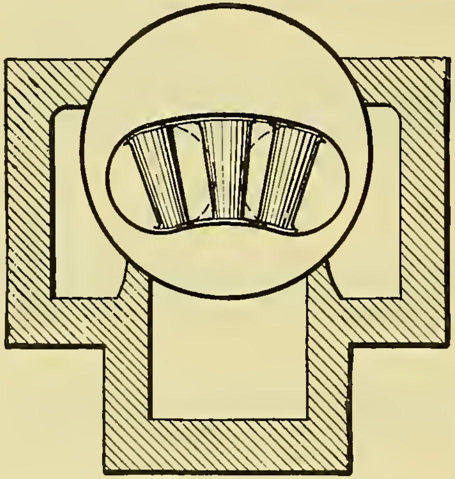


FIG. 508.

receive them. The two ends of the drum are of a hemispherical form and are not braced as is the case where flat heads are used. The water legs form the natural support of the boiler.

The boiler is entirely enclosed by a brick work setting; the furnace is situated below the front end of the boiler and is terminated by a bridge wall; air is admitted through a channel at the bottom of the space behind the bridge wall, and is heated in passing through the wall.

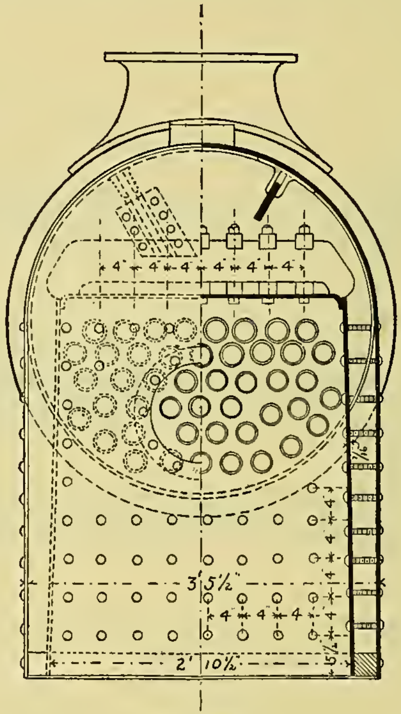
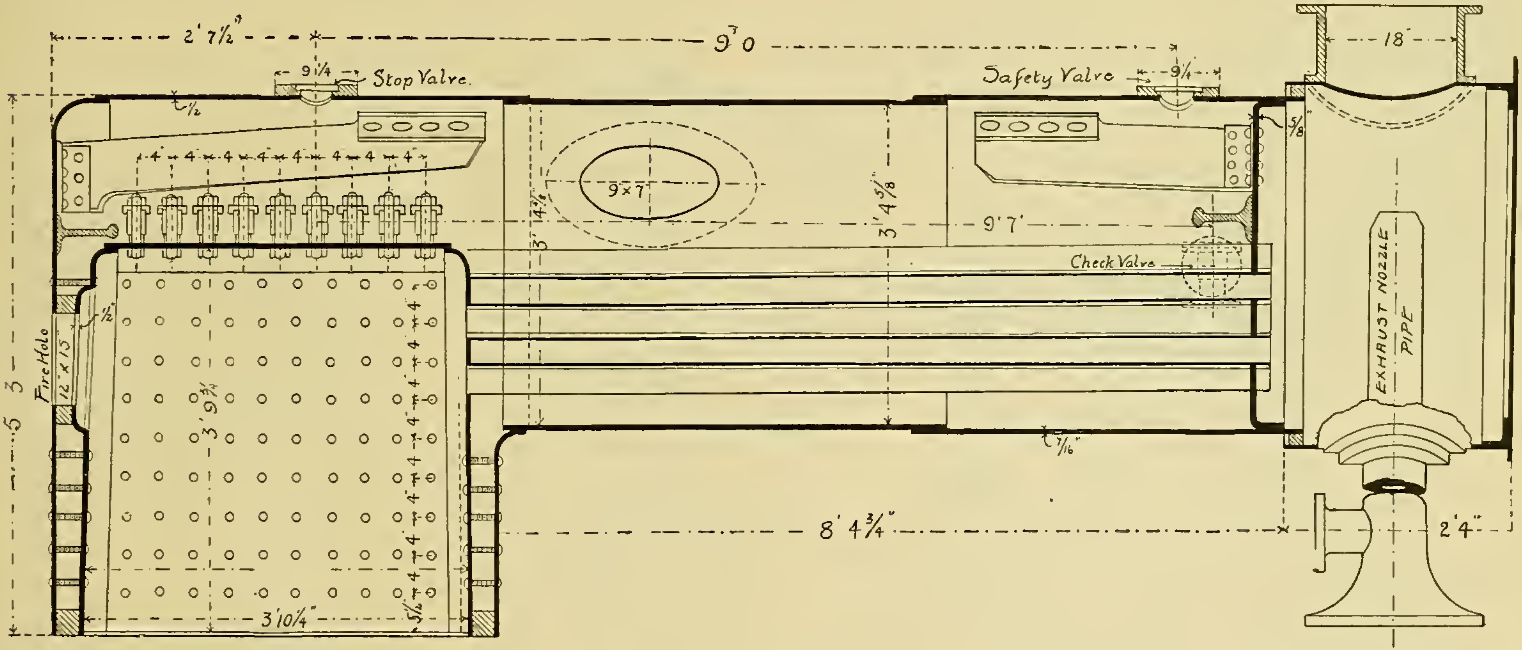


FIG. 509.

The feed water is brought through a feed pipe leading to the front head of the drum; within the main drum is suspended a *mud drum* below the water



2' 7½"
9' 0
9¼
Stop Valve
Safety Valve
9¼
18"
½
5/8
9 × 7
3' 4⅝"
9' 7"
Check Valve
EXHAUST NOZZLE PIPE
Fire Hole 12" × 15"
5' 3"
3' 9¾"
3' 10¼"
7/16"
8' 4¾"
2' 4"

FIG. 510.

line. The feed water enters the mud drum first, which is submerged into the hottest part of the water; in this manner the impurities of the feed water are largely extracted.

Between the horizontal rows of tubes are placed layers of fire brick, acting as *baffle plates*, forcing the hot gases to circulate back and forth between the tubes and finally flow out through the chimney placed above the rear end of the boiler; the upper part of the main drum is protected by a lining of fire brick.

When several of these boilers are used together, forming a battery of boilers, an additional steam drum is usually placed at right angles and above the steam drums already described.

TO DESIGN A STEAM BOILER.

In designing a steam boiler an engineer has to bear in mind the following considerations: 1, its required strength; 2, its durability; 3, its accessibility for inspection, cleaning and repairs; 4, its ability to perform the work; 5, the special laws of the locality in which the boiler is to be used, as well as the rules of insurance companies; and 6, the type best adapted to existing conditions.

The following example may serve to show how the parts of a boiler may be calculated.

Let it be required to design a 60 horse power horizontal multi-tubular boiler, to carry a working pressure of 150 lbs. per square inch, and which will be capable of sustaining a test pressure of 225 lbs.

Let the length of the tubes be 15 ft. and each tube have an internal area of 6.08 sq. in., *i. e.*, about 3 inches outside diameter. The heating surface should be about 37 times the grate surface.

Let the area of the grate in sq. ft. . . . . equal G
" the heating surface in sq. ft. . . . . " H
" the area of smoke passage through the tubes in sq. ft. " C
" the water space in cubic feet . . . . " W
" the steam space in cubic feet . . . . " S

According to the standard recommended by a committee of the American Society of Mechanical Engineers, it is customary to rate boilers by their horse power, *considering 30 pounds of water evaporated from feed water at 100° F., under pressure of 70 lbs. by the steam gauge, is equivalent to one horse power;* this is equivalent to 34½ lbs. of water evaporated from feed water at a temperature of 212° F., into steam at atmospheric pressure.

Now, as 34½ lbs. are evaporated for 1-horse power, for a boiler of 60 H. P. $34.5 \times 60 = 2{,}070$ lbs. must be evaporated to meet the conditions.

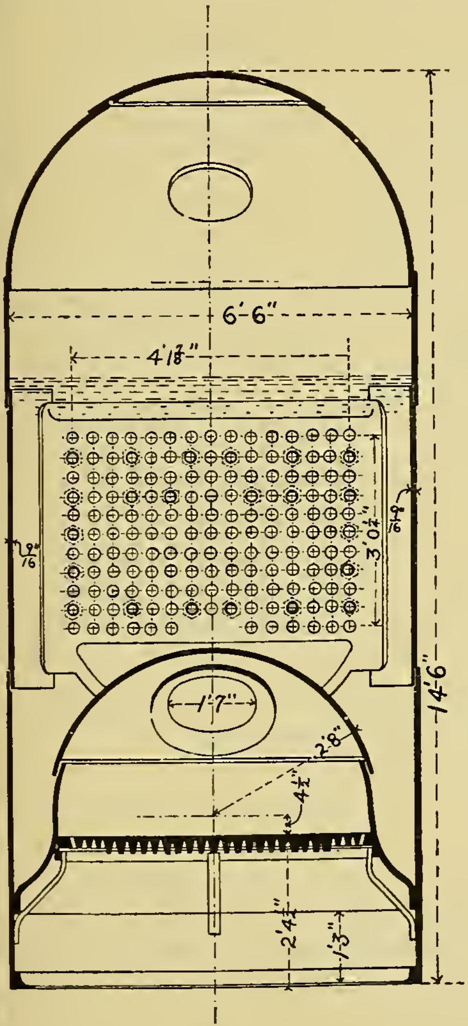


FIG. 511.

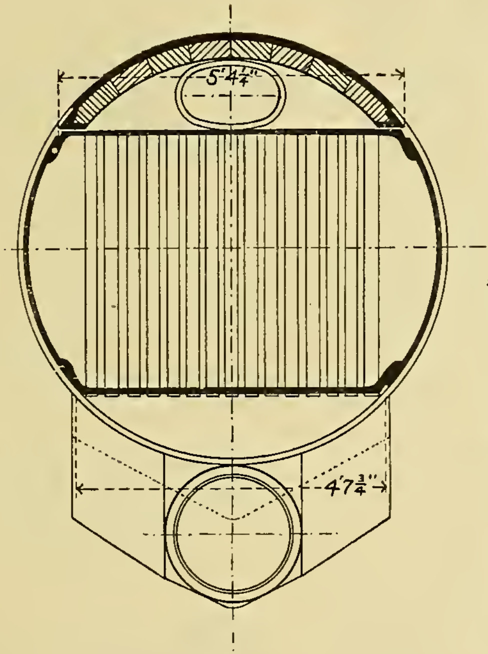


FIG. 512.

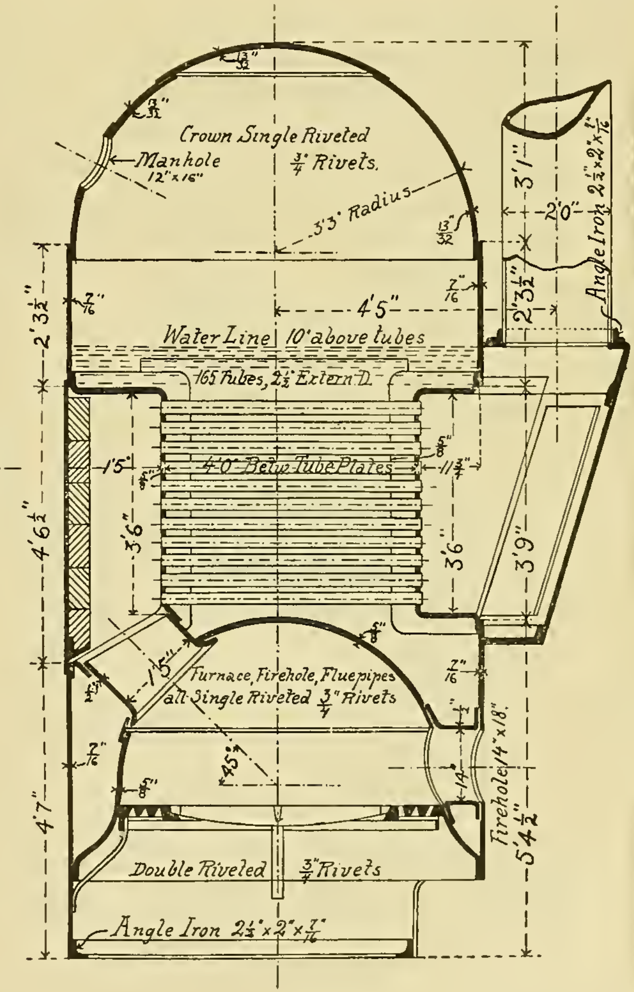


FIG. 513.

Evaporation per 1 lb. of coal: 1, depends on the quality of the coal; 2, the rate of combustion, and also, 3, the construction of a boiler. The following table illustrates the effect of the rate of combustion, according to tests with a boiler, which had a ratio of 25 to 1 of the heating surface to the grate surface.

Rate of combustion in pounds of coal per sq. ft. of surface.	Evaporation per lb. of coal.	Evaporation per sq. ft. of heating surface.
6	10.5	2.52
8	10.4	3.33
10	10.1	4.04
12	9.5	4.56
14	8.9	4.98
16	8.2	5.25

The evaporation per pound of coal that takes place in the different types of boiler, according to Prof. Hutton, is as follows:

Plain Cylindrical	5 to 8
Vertical	5 to 10
Water-tube	5 to 11
Cornish	6 to 11
Multi-tubular	8 to 12
Locomotive Boiler	8 to 13

The area of heating surface of each type of boiler is nearly always in a constant ratio to the grate area Below is given a table showing *the ratio between the grate surface and the heating surface*, generally observed in the several types of boiler:

Style of Boiler	Ratio of Grate Surface to Heating Surface
Plain Cylindrical	12 to 15
Cornish	15 to 30
Cylindrical Flue	20 to 25
Cylindrical Tubular	25 to 35
Locomotive Tubular	50 to 100

For the boiler which we have taken as an example, we will assume that 12 pounds of coal can be burned per square foot of grate, and that one pound of anthracite coal will evaporate about 9 pounds of water at 212° F.

As we have found, 2,070 pounds of water will have to be evaporated in this boiler to give us the required 60 H. P.

Now, as 1 pound of coal will evaporate 9 pounds of water, the coal contained in 1 square foot of grate surface, 12 pounds, will evaporate $12 \times 9 = 108$ pounds of water. Dividing the number 2,070 by 108 gives *the required area of grate.*

$$\frac{2070}{108} = 19.16 \text{ sq. ft. of grate surface.}$$

The area of smoke passage through the tubes to the grate area, C : G, is according to good practice, made equal to 1 : 8 for this type of boiler. The number of tubes, each 3″ in diameter may be found in the following manner:

$$\frac{19.16}{8 \times 6.08} \times 144 = \text{about } 56 \text{ tubes.}$$

Here 6.08 is the internal area of one tube.

Suppose our boiler is designed for a steam engine which is to use 40 pounds of steam at a pressure of 70 pounds per horse power per hour, and that the steam space shall hold enough steam to supply the engine 30 seconds; the absolute pressure is nearly 85 pounds and the specific volume of steam at this pressure is 5.125. The space which will be taken by steam required for one horse power is,

$$\frac{40 \times 30}{60 \times 60} \times 5.125 = 1.706 \text{ cubic feet.}$$

Let us assume that this amount of space is taken up by the steam required for one horse power; then the total space required to contain the steam for the 60 H. P. will be

$$1.706 \times 60 = 102.36 \text{ cu. ft., say } 103 \text{ cu. ft.}$$

That is, the steam space, S, should hold 103 cu. ft. As the water space may be taken to equal two times the steam space, the water space, W, will equal $2 \times S$, or $2 \times 103 = 206$ cu. ft.

NOTE.—The steam space required by a given boiler depends upon the purpose for which the steam is to be used. Where the steam is under high pressure and comparatively small quantities of it are withdrawn at very frequent intervals, the steam space need not be so large as in cases where large quantities are withdrawn, even though less frequently. Where the boiler supplies a steam engine, it is the general practice to have the steam space of such dimensions that it shall contain sufficient steam to supply the engine for about a half a minute.

Adding the steam space and the water space together, we get 309 cu. ft., for the volume of both; this volume would determine the capacity of the shell, were there no tubes passing through it and taking up part of the space within; in this case, therefore, the space taken up by the tubes must be added to the above volume.

We have already found that the boiler will contain 56 tubes. The outside area of one tube of the given size, is 7.107 sq. in., consequently

$$\frac{56 \times 7.107 \times 15}{144} = 41.45 \text{ cu. ft.} = \text{the space}$$

taken up by the tubes. Adding this to the volume found above, 309 cu. ft. plus $41.45 = 350.45$ cu. ft., the entire volume of the shell.

As the shell is to be 15 feet long, the area of its head must be $\frac{350.45 \times 144}{15} = 3362.3$ sq. in. Dividing this by 0.7854, we get the square of the diameter of the shell; $D^2 = \frac{3362.3}{0.7854} = 4281.$ sq. in. Allowing for the space occupied by the stays, etc., we may take D equal to 67″.

One-half of the outside surface of the shell equals $\frac{67 \times 3.14 \times 15}{12} = 131.4$ sq. ft. The inside surfaces of the tubes equal $\frac{8.74 \times 56 \times 15}{12} = 611.8$ sq. ft.

Allowing for the heating surface, one-half the surface of the shell, and all of the inside surfaces of the tubes, we have 131.4 + 611.8 = 743.2 sq. ft.

H. = 743.2 sq. ft.

We have already found the grate surface to be equal to 19.16 sq. ft. Dividing the heating surface by the grate surface, we are to get, according to the conditions given in the problem, the ratio of 37.

$$\frac{743.2}{19.16} = 38.7,$$ or very nearly as required.

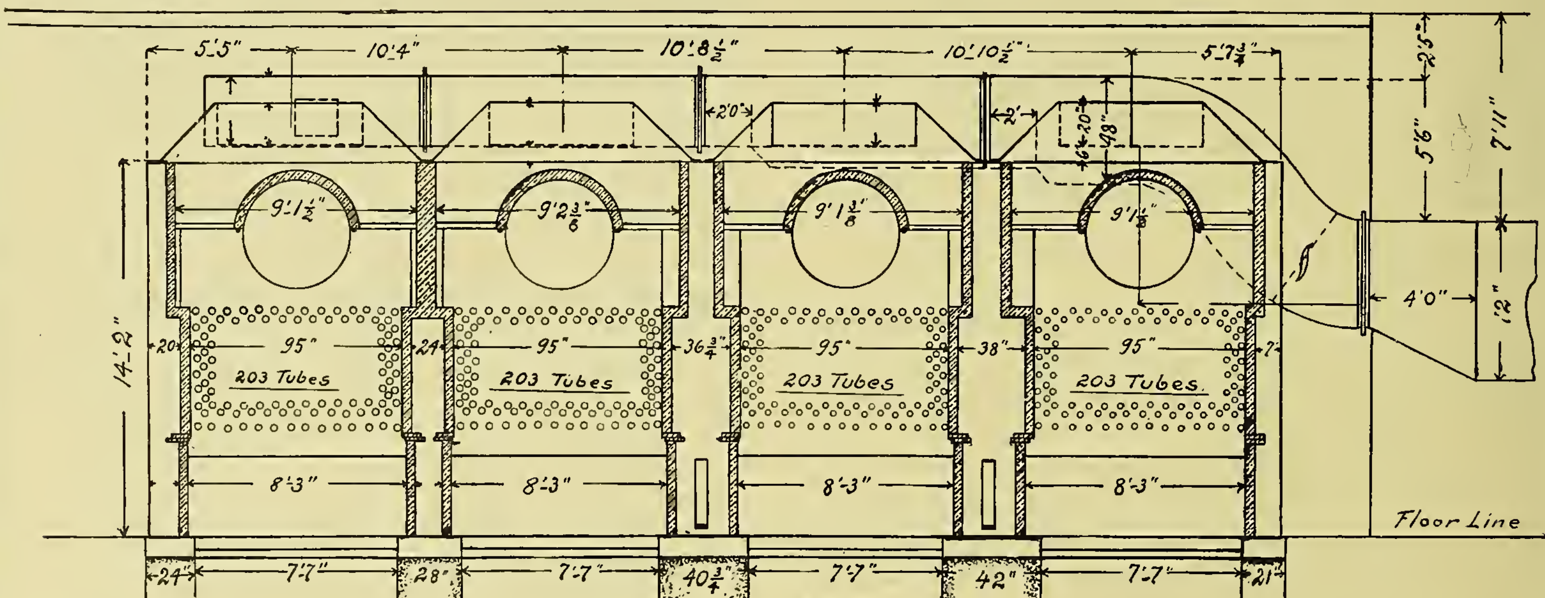


FIG. 514.

HORSE POWER OF THE STEAM BOILER.

As was stated before, the evaporation of 30 lbs. of water per hour, from a feed water temperature of 100° F. into steam at gauge pressure of 70 lbs. is the value of a commercial horse power, adopted by the A. S. M. E. Different boilers will generate steam at different pressures, receiving also the feed water at different temperatures. In order to compare properly the performances of different boilers, their actual evaporation must be reduced to an equivalent evaporation from and at 212° F. The problem may be stated differently as follows: It is necessary to find what would be the evaporation if the feed water would be at 212° F., and the delivered steam at 0 gauge pressure.

To find the equivalent evaporation of a boiler, proceed as follows:

RULE: *From the total heat of steam at pressure of actual evaporation, subtract the observed temperature of the feed water and add 32; multiply the result by the actual evaporation and divide by 966.1.*

EXAMPLE: If a boiler generates 2,000 lbs. of steam per hour at a pressure of 100 lbs., and if the temperature of the feed water is 70°, what is the equivalent evaporation of the boiler?

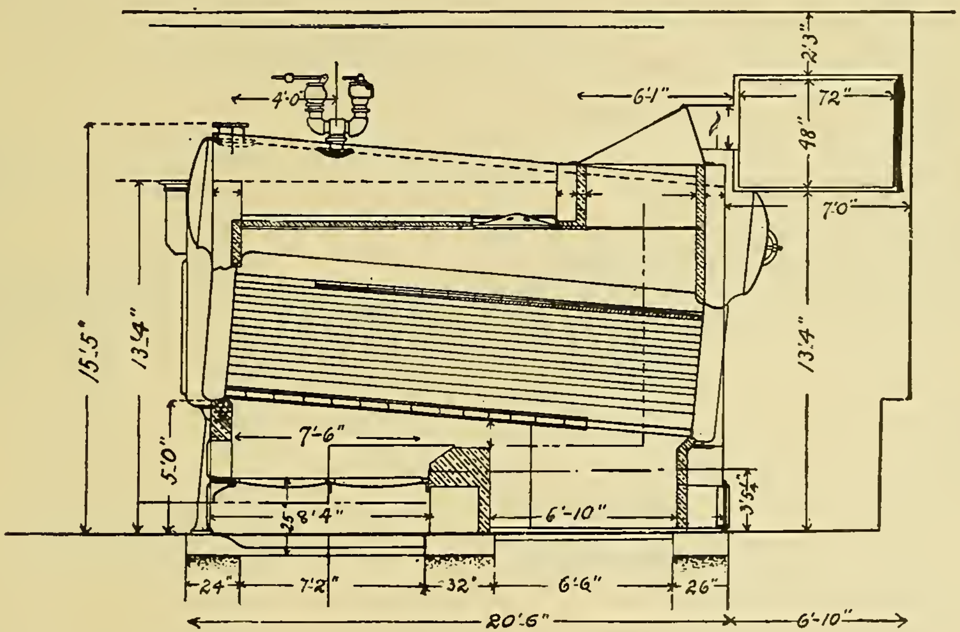


FIG. 515.

From the steam pressure table given below, the total heat corresponding to a pressure of 100 lbs. gauge is 1184.5; consequently the equivalent evaporation is $\frac{(1184.5 - 70 + 32) \times 2,000}{966.1}$

To find the horse power of the boiler, divide the equivalent evaporation by 34.5. In this case, the horse power $= \frac{(1184.5 - 70 + 32) \times 2,000}{966.1 \times 34.5} =$ 68.8 nearly.

Let W equal the actual evaporation
H " total heat
t " observed temperature of the feed water; then, according to the above rule, the equivalent evaporation is equal to $\frac{(H - t + 32) \times W}{966.1}$

or $\frac{H - t + 32}{966.1} \times W$

The quantity $\frac{H - t + 32}{966.1}$ which changes actual evaporation to equivalent evaporation from and at 212° F. is called the factor of evaporation.

The equivalent evaporation is equal to the actual evaporation of the boiler, multiplied by the factor of evaporation; knowing the actual evaporation, and having a table of factors of evaporation, we are easily able to calculate the equivalent evaporation, or the horse power of the boiler.

TABLE OF GAUGE PRESSURE AND TOTAL HEAT.

The following is a table of steam pressures; the table gives the pressure of the steam by gauge and *the corresponding total heat* required to generate one pound of steam from water at 32° F. under constant pressure.

Pressure by Gauge	Total Heat	Pressure by Gauge	Total Heat
0	1146.1	85	1181.4
5	1150.9	90	1182.4
10	1154.6	95	1183.5
15	1157.8	100	1184.5
20	1160.5	105	1185.4
25	1162.9	110	1186.4
30	1165.1	115	1187.3
35	1167.1	120	1188.2
40	1169.0	125	1189.0
45	1170.7	130	1189.9
50	1172.3	135	1190.7
55	1173.8	140	1191.5
60	1175.2	145	1192.2
65	1176.5	150	1192.9
70	1177.9	155	1193.7
75	1179.1	160	1194.4
80	1180.3		

SAFETY VALVE RULES.

The safety valve provides for the safety of boilers, by allowing the steam to escape when its pressure exceeds a certain limit. The valve is kept in its seat, either by a weight at the end of a lever, as in Fig. 516, or by a heavy weight placed directly over

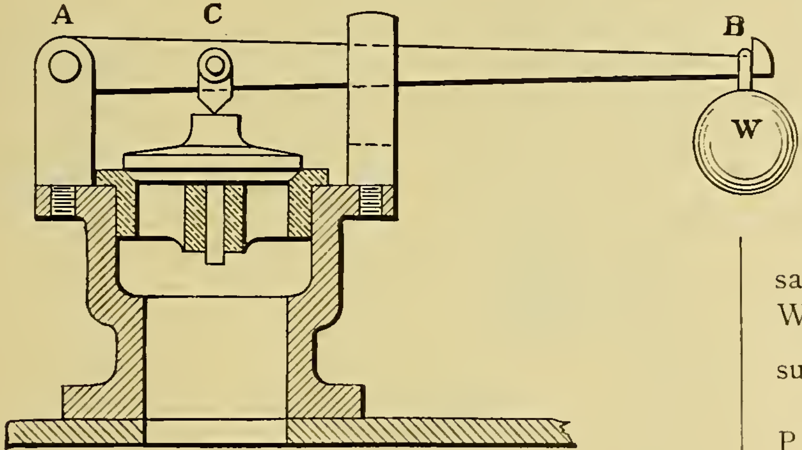


FIG. 516.

the valve, or by a strong spring. A good safety valve must allow all excess of steam to escape as fast as it may be generated.

The valve shown in Fig. 516 rests on a circular seat. To find the weight, W, or the length of the lever, AB, for a given pressure of steam:

Let AB represent the length of the lever in inches.
" AC " the distance between the center of valve and A, also in inches.
" W " the weight in pounds.
" w " the weight of the lever in pounds.
" P " the pressure of the steam per sq. in.
Let a " the area of the valve in sq. in.
" V " the weight of the valve in pounds.

If the weight of the lever and valve be neglected, we have, when the steam reaches the limit of pressure, for which the valve is intended, a downward pressure of $W \times \frac{AB}{AC}$ and at the same time an upward pressure equal to $P \times a$. When the valve is just about to lift, these two pressures may be considered equal; then $W \times \frac{AB}{AC} = P \times a$; from this, $W = P \times a \times \frac{AC}{AB}$ in pounds.

Taking into consideration the weight of the valve, which should be done for accurate practice, we have a downward pressure of $W \times \frac{AB}{AC}$, the pressure due to the weight W, plus $w \times \frac{AB}{2AC}$, the pressure due to the weight of the lever, assuming that the weight of the lever acts downward in its middle, and plus V, the weight of the valve.

The upward pressure remains, as before, P × a.

Here again, $W \times \frac{AB}{AC} + w \times \frac{AB}{2AC} + V = P \times a.$

EXAMPLE: Let it be required to find the weight, when the lever AB is equal to 36 in., AC equals 4 in., w equals 5 lbs., V. equals 3 lbs., P equals 80 lbs. and a equals 6 sq. in.

The weight of valve and lever must be taken into account. According to the above formula,

$$W \times \frac{36}{4} + 5 \times \frac{36}{2 \times 4} + 3 = 80 \times 6, \text{ or}$$

$$W \times 9 + 4.5 \times 5 + 3 = 480, \text{ or}$$

$$W = \frac{480 - 25.5}{9} = 50.5 \text{ lbs.}$$

THE STEAM INJECTOR.

The injector is an instrument, by the aid of which, the energy of a jet of steam from the boiler, is utilized in forcing a stream of water into the boiler.

The injector has largely replaced other appliances for feeding steam boilers, for when the work of an injector is compared with that of a steam pump, we come to the conclusion that even if the injector may consume a little more steam than the pump, the heat is returned to the boiler, by being imparted to the feed water.

A boiler is tapped at the highest point of the steam space, and a pipe leading downward is inserted into the opening. To the open end of this pipe is attached the injector, which again is connected with the lower part of the boiler, into which it is to force the feed water which it receives through a special pipe from the source of water, be it a tank, well, etc.

The live steam which enters the injector and is given the shape of a pointed jet, forms a partial vacuum within a chamber in the injector just above the feed water pipe, allowing the water to enter the chamber, where it acquires a velocity equal to that of the jet of the entering steam, and being thus enabled to overcome the pressure within the boiler, by its momentum, it is forced through an opening and a check valve, into the boiler.

While the pressure within the boiler may be taken to be pretty nearly equal in all its parts, the partial vacuum caused by the condensation of the jet of steam meeting the colder water in the injector, compels the jet of steam to rush into the injector at a much higher velocity than if it were discharged into

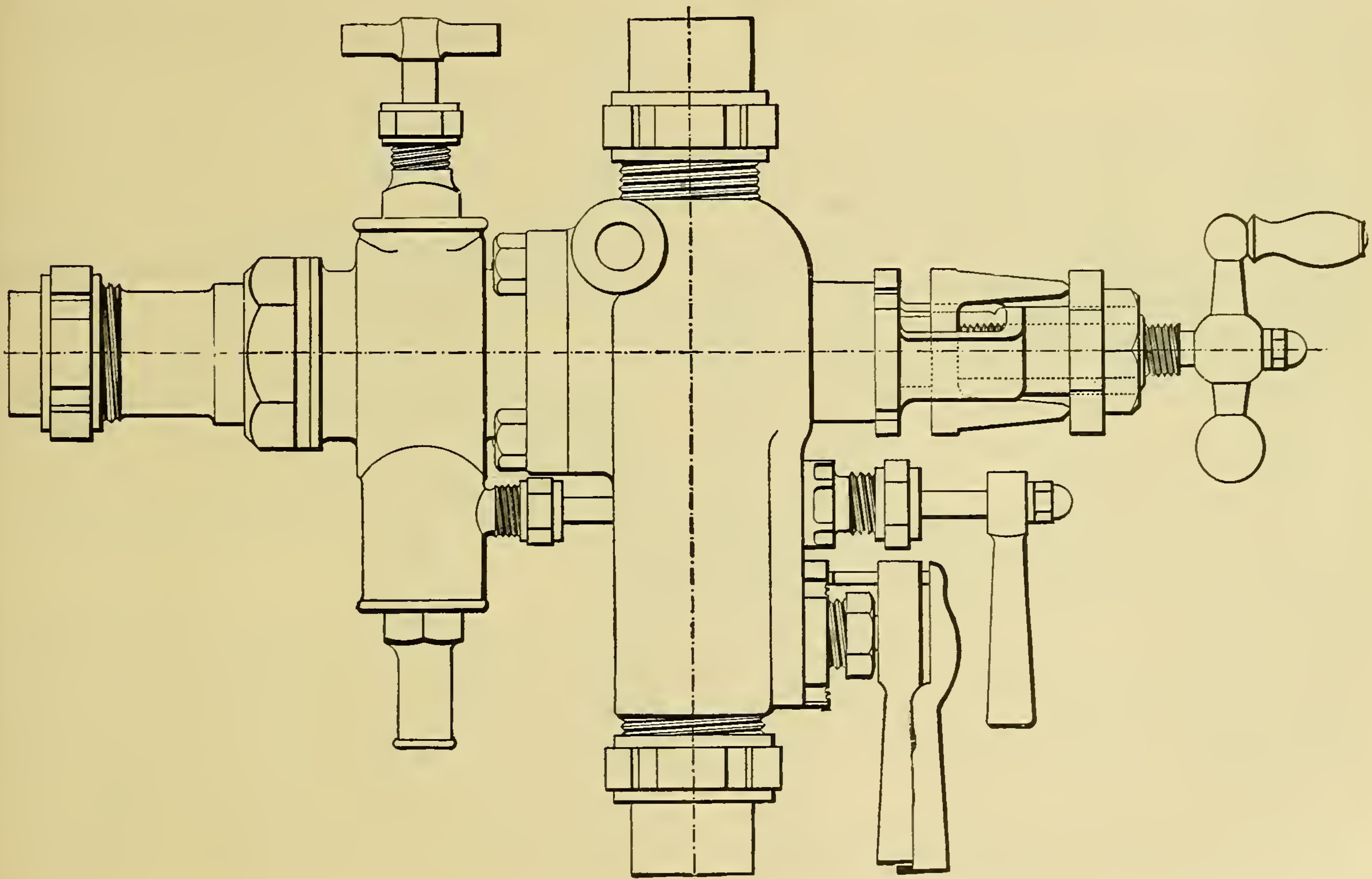


FIG. 517.

the atmosphere. Consequently the high velocity and the resulting momentum of the entering feed water.

The accompanying illustrations, Figs. 517 and 518, show an outside view and a longitudinal section of an injector. Referring to the sectional view, it will be seen that the injector consists of a case with a steam inlet at its upper part, water inlet directly below the steam inlet, delivery outlet to the boiler and an overflow opening at the bottom of the injector. Separate handles are provided to regulate the flow of steam, of feed water and delivery.

The nozzles within the injector may be termed, according to their purpose:

(1.) The steam nozzle, through which the steam enters into the chamber of the injector. It is bored out straight in the middle and slightly conical towards its ends.

(2.) The combining nozzle is nearest to the steam nozzle; here the steam and the feed water come together. This nozzle is placed in line with the first one.

(3.) The condensing nozzle, is the next one; it forms the vacuum, upon which is based the velocity of the feed water; from this nozzle the water is driven into the (4) delivery nozzle, through which it enters the boiler. The delivery nozzle is usually made with the smallest bore of all the nozzles. The diameter of the bore in the delivery nozzle determines the volume of water which may be forced through it into the boiler. The size of an injector is always given by the diameter of the smallest part of the bore in the delivery nozzle, expressed in millimeters; thus a No. 6 injector has an opening of 6 millimeters in diameter.

To start the injector, open the water valve first. When the water appears in a solid stream in the overflow, open the steam valve, situated directly above the jet, and close the jet valve. The steam valve must always be opened slightly before closing the jet valve, so as not to break the vacuum of the injector.

It will be noticed that the injector is put together in such a manner as to render feasible all repairs within by unscrewing the connected parts. The nozzles may have to be replaced from time to time, as they have to withstand the great velocity of the flow of water, which because of its impurities, occasions considerable wear on the nozzles. On account of this, all nozzles are made of a special hard metal.

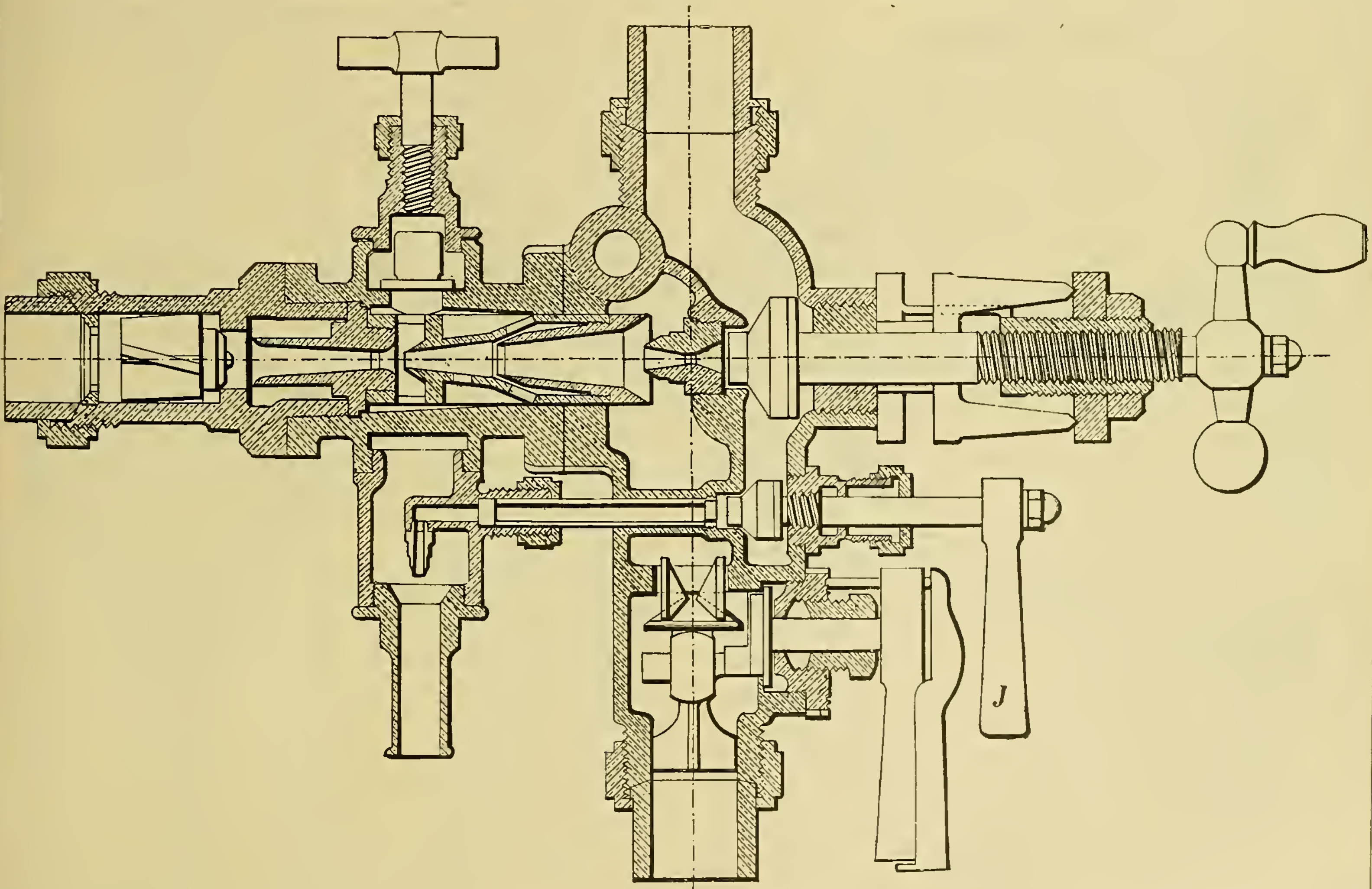


FIG. 518.

STEAM ENGINE.

The steam engine is a machine designed to transform the energy of steam, under pressure, into actual energy in the form of continuous rotation.

For this purpose the steam is made to move the piston in the steam cylinder backward and forward, by bringing the steam into the cylinder, alternately from one side of the piston and then from the other, thus imparting a reciprocating motion to the piston.

The mechanism which regulates the direction of the steam into the cylinder is called the *valve mechanism* or valve gear of the steam engine.

When the piston, or the area which receives the pressure of the steam, travels in a circular path continuously in one direction, the engine is termed a *rotary steam engine or the steam turbine.*

The *reciprocating steam engine*, in which the piston travels *back and forth*, is the ordinary form of this important motor. It has been found to be the most convenient and most economical design, hence we shall take up for illustration and explanation this form, only, of the steam engine.

The reciprocating motion of the piston may be transformed into a continuous rotary motion in various ways; the crank motion is the most popular form of mechanism adopted for this purpose; the motion of the *piston* is transmitted by the *piston rod*, which is fastened firmly at one end to the piston, to the *crosshead*, from which the *connecting rod* leads to the *crank pin* of the *crank;* this forms a solid structure with the main shaft of the engine.

The *main shaft*, receiving in this manner the rotary motion, serves as the source of rotary power, used for the many purposes of modern industry.

The length of the cylinder is made equal to the travel of the piston, which itself is equal to twice the effective length of the crank, plus the thickness of the piston, to which must be added the allowance for clearance at each end, so that the piston shall not strike the head of the cylinder, and at the same time will provide the necessary space for the steam to get behind the piston when the latter is at the end of its stroke.

The length of the piston rod must be sufficient to permit the piston to return the full length of its stroke and still leave enough of the rod outside the cylinder to fasten it to the crosshead. To avoid leakage of steam through the hole in the cylinder head, through which the piston rod protrudes, a *stuffing* box is attached to the cylinder head. It is evident that the extreme length of the stuffing box must be added to the length of the piston rod.

The crosshead is guided in its rectilinear path by close-fitting rods, bars or blocks, which are securely

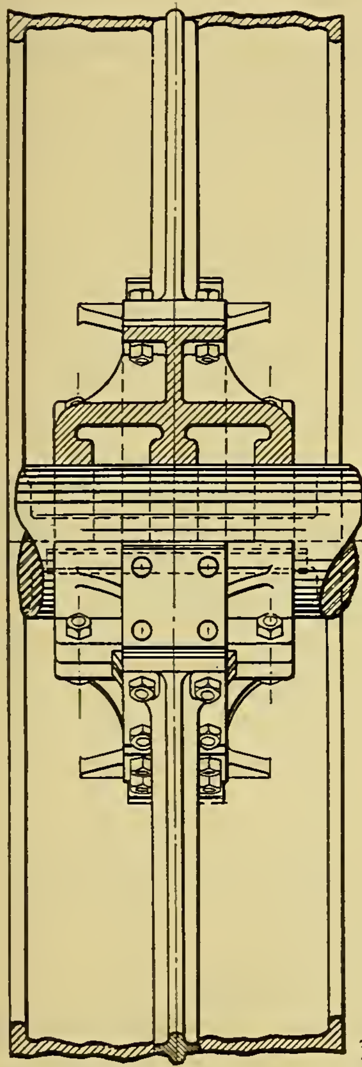


Fig. 519.

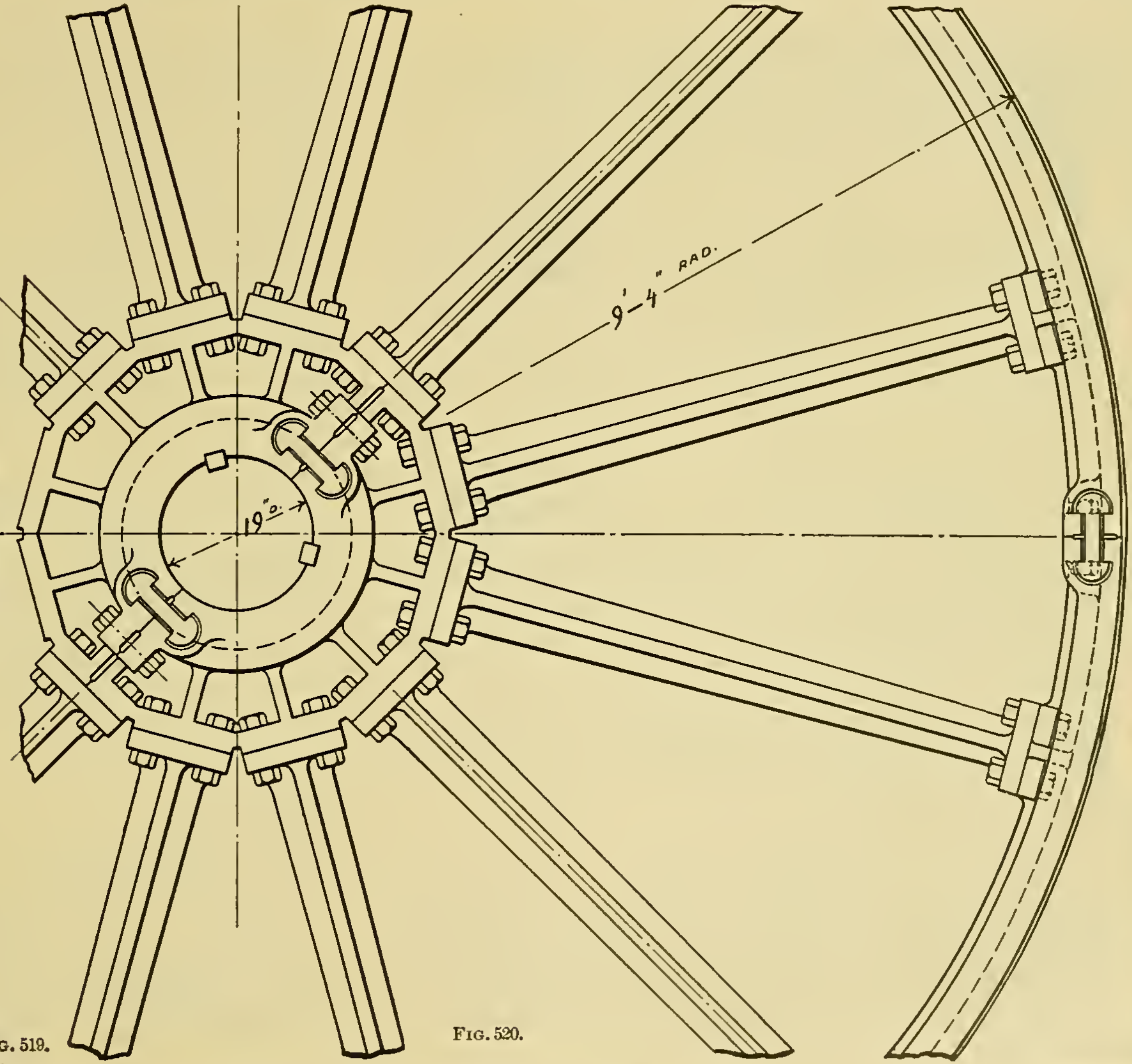


Fig. 520.

fastened to the engine bed, or form a part of the bed casting, in one piece, and which are called the *crosshead guides*; these must be set absolutely parallel to the axis of the cylinder.

The *steam cylinder*, as well as all other parts of the steam engine mechanism, is fastened to a heavy casting called the *engine bed*, which is rigidly held upon a solid masonry foundation by means of *anchor rods*, whenever the engine is of the stationary type; in marine engines the bed plate is fastened to extra heavy frames forming part of the hull.

When the crank is in a horizontal position, in the plane of the piston rod, and the crank-pin lies in a line drawn through the center line of the cylinder, the piston being at one of its extreme positions of the stroke, the engine is then said to be on its *dead center*, as the pressure of the steam upon the piston will not result in rotation of the crank. The rotating shaft is usually supplied with a heavy fly wheel, intended to store up the energy of rotation, and one of the functions of the fly wheel is to carry the engine mechanism past the dead centers.

Fly wheels are of many different constructions, varying from a solid cast iron wheel of small diameter, to *built up wheels* of over 30 ft. in diameter. In modern practice the rim of the wheel is made wide enough to carry the belt which transmits the motion from the engine to the machinery. Such wheels are usually called *belt wheels* in distinguishing them from the old-style narrow rimmed fly or balance wheel, which was constructed independent of the pulley carrying the belt.

In Figs. 519 and 521 are shown two views of a belt wheel of modern construction, 18 ft., 8 in. in diameter. It is unnecessary to show the entire wheel, as it would be simply a repetition of similar parts. In most cases only a quadrant of the wheel is shown, accompanied by a partial section like that shown in Fig. 519.

It will be noticed that the outline of the belt wheel hub is a regular dodecagon, its sides forming the planed surfaces, to which the arms are attached by means of flanges and bolts. The other ends of the arms are also flanged and connected to the different rim sections as shown in Fig. 520. The hub in this case is made in two sections and the rim in six sections, to each of which latter two arms are flanged.

The sections of both hub and rim are held together by bolts passing through projecting flanges, as shown in Fig. 520 and in partial detail in Figs. 521, 522 and 523. Where extra strength is required, the reinforcements shown in Fig. 520 are often made use of. These consist simply of I-shaped

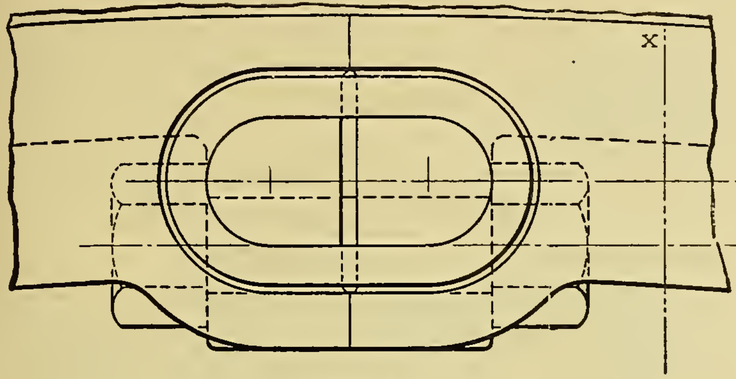


Fig. 521.

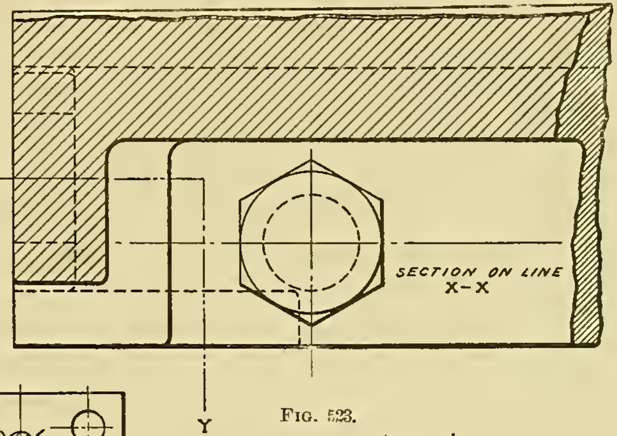


Fig. 523.

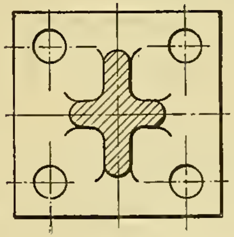


Fig. 524.

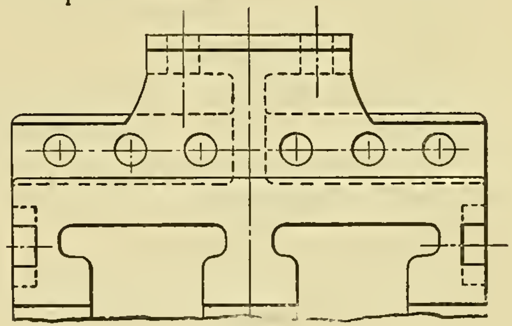


Fig. 525.

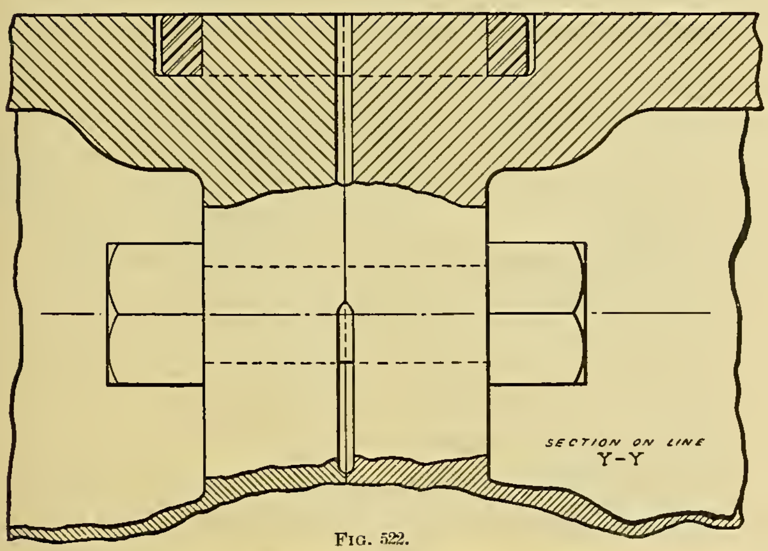


Fig. 522.

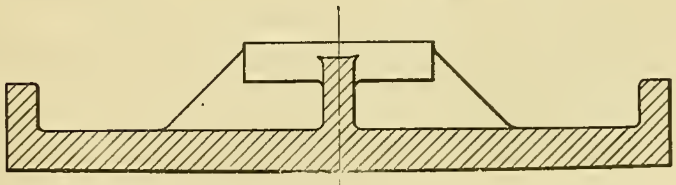


Fig. 526.

pieces made of mild steel, which are shrunk into recesses of similar shape, making a rigid joint.

A different type of reinforcement is illustrated in detail in Figs. 521, 522 and 523. Here, instead of the I-shaped piece, a wrought iron link is substituted, which is shrunk over bosses cast into the castings for this purpose. These bosses are cast so that they will not project beyond the surface of the rim, as shown in Fig. 522, leaving them flush so the wheel may be faced off after mounting. This method of reinforcement is rapidly finding favor for permanently connecting parts of heavy machinery, such as large sectional engine beds, etc.

It is very difficult, however, to disconnect such fastenings, for, when heating the link to expand it for removal, the lugs will also be heated and expanded, necessitating in most cases cutting and destruction of the link.

In Fig. 524 is shown a section through an arm of the wheel, and Fig. 526 illustrates a section through the rim, close to one of the flanges to which the arms are attached.

Fig. 525 represents part of the hub, showing the face of the joint.

The design of a fly wheel is one of the most difficult tasks that an engineer may meet and requires judgment and much practical experience. Oftentimes the success of an engine depends upon the fly wheel, for even a good and active governor would be unable to steady the motion of an engine with a variable load, were the fly wheel not able to carry the crank past the dead centers, as well as those points during the revolutions, where but little rotary motion is supplied by the driving parts.

Great care must also be taken to have the material in the rim evenly distributed, for if the wheel is not balanced, the centrifugal force will have a tendency to bend the shaft, besides causing severe vibration.

The rim speed of *a cast iron fly wheel* should never exceed one mile, 5,280 feet per minute, for the centrifugal force has a tendency to burst the rim and this tendency increases as the speed increases. *This danger is not overcome by increasing the thickness of the rim, for while the extra thickness adds strength to the rim, the extra weight increases the centrifugal force.*

Two or more cylinders are often used in one steam engine ; when two cylinders are used, they are usually arranged so that the two cranks of the separate cylinders are at an angle of 90° to each other. When three cylinders are used the cranks will be at angles of 120° to each other.

Such *multi-cylinder engines* do not require as heavy a fly wheel as a single cylinder engine of the

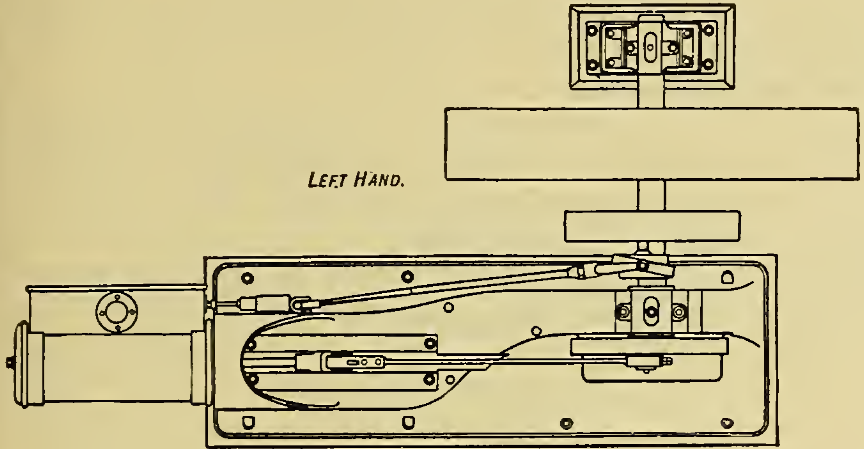


FIG. 527.

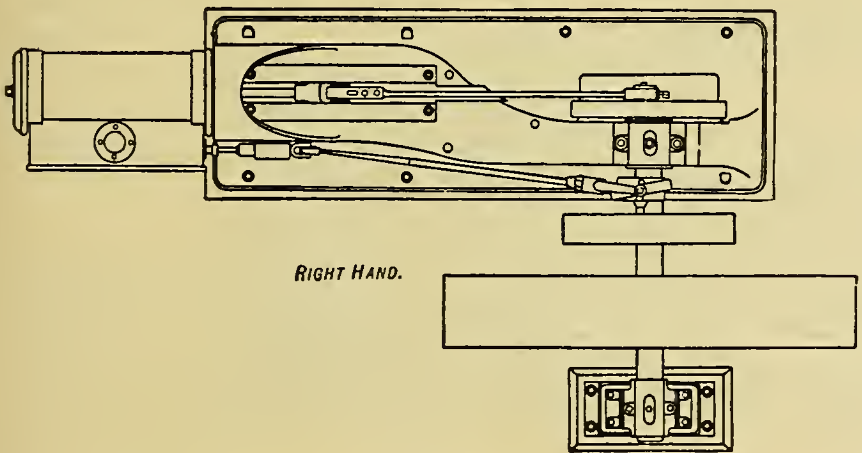


FIG. 528.

same power, as the cranks will assist each other over the dead centers; at the same time they act so that one cylinder develops its maximum power, while the others are nearing completion of the stroke.

The connecting rod of an engine is usually made from four to six times the length of the crank.

The top view of a horizontal engine is shown in Fig. 527. The same engine is shown in Fig. 528.

One illustration shows a right hand and the other illustrates a left-hand engine. *A right-hand engine is one in which the fly wheel is to the right of the observer as he stands at the head end of the cylinder looking towards the main bearing of the engine.*

The size of the engine is commercially rated by the length and diameter of the steam cylinder.

When an engine produces a rotary motion of the fly wheel and crank, so that the crank when starting from its inner dead center rises above the axis line, or descends below it, upon the beginning of the stroke, the engine is said to "run over" or "run under," Fig. 529. It is, as a rule, desirable to have an engine run over, because the pressure of the connecting rod is then always downward, and is taken up by the guides and bedplate.

An example of proportioning the main parts of an engine is given in Figs. 530 and 531.

A vertical engine for small power is shown in Fig. 532; it shows a section through the cylinder and

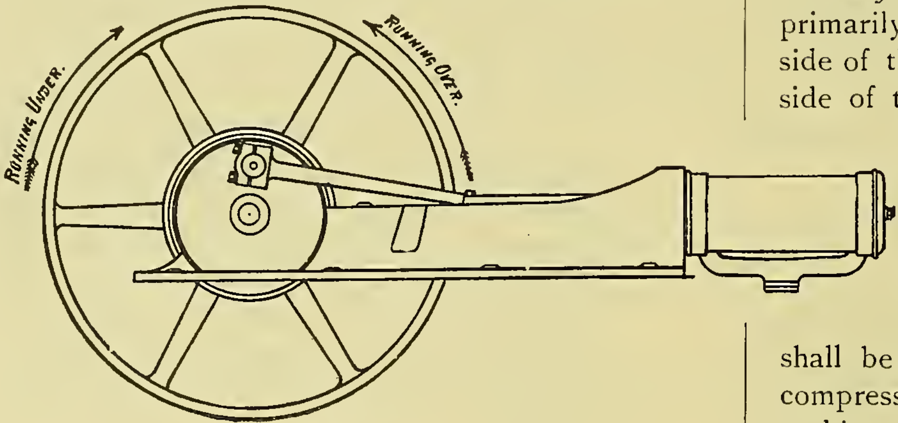


FIG. 529.

valve chest, while Fig. 533 exhibits a section on a plane at right angles to that of the first section.

The avoidance of cylinder wear, and still more the small floor space required by the vertical engine, have made its use practically universal for crowded power plants, steamships, etc. The support of such engines, however, is commonly not sufficiently rigid to prevent undesirable vibration of the moving parts.

The section of the vertical engine shown in Fig. 532 shows a type of a steam distributing valve, called the *slide valve*, one of the oldest and up to the present most reliable valve gears.

The functions of a valve on a steam cylinder are primarily to admit the steam from the boiler to one side of the piston, while the steam filling the other side of the cylinder is allowed to escape through the exhaust pipe, and second to stop the admission of steam at a certain point, for the purpose of producing its desired expansion and finally to close the exhaust opening at such a point in the return stroke, that a certain volume of steam shall be left in the other side of the cylinder to be compressed behind the piston, to serve as an elastic cushion.

NOTE.—The horizontal position of the engine is by far the most popular for factories, power plants, etc., where there is considerable floor space. To have all the parts of an engine easily accessible and a solid support for the engine, as offered by a large bed, are the great advantages offered by a horizontal engine; while on the other hand, the tendency of the cylinder to wear unequally is a disadvantage which cannot be denied.

Diagram of HORIZONTAL ENGINES.

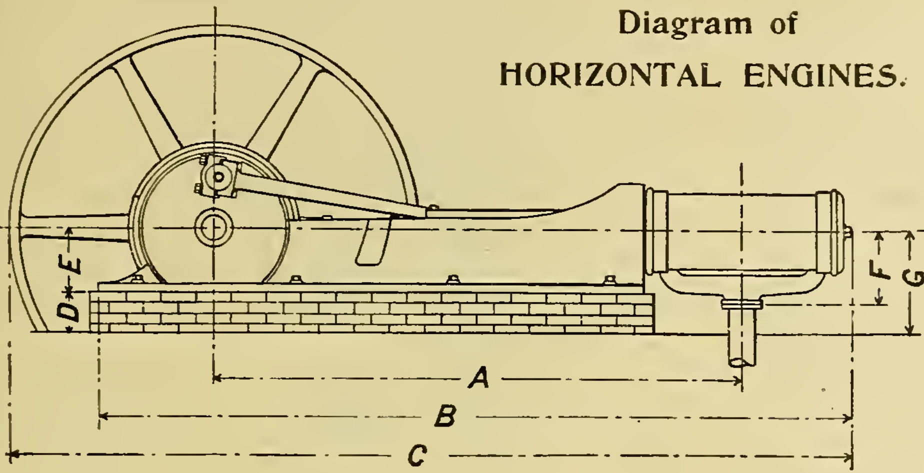


Fig. 530.

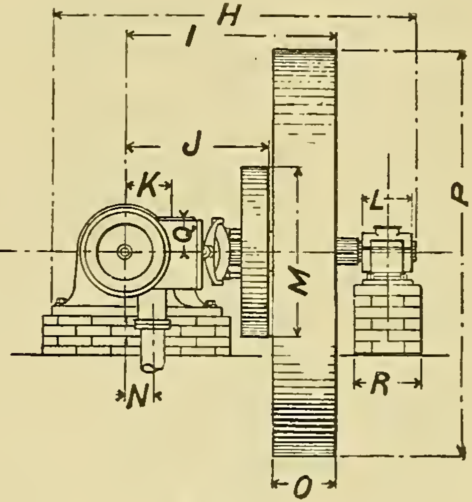


Fig. 531.

Table of Dimensions Reference being had to above Diagram.

SIZE OF ENGINE	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
12×24	10-4 3/16	14-8 3/8	16-5 3/8	9	15	17	24	7-5 5/8	4-0 1/8	2-10 1/8	10	12	3-4	6 3/8	13	8-0	7 1/4	16
13×24	10-4 3/16	14-8 3/8	16-5 3/8	9	15	18	24	7-5 5/8	4-2 1/8	2-10 1/8	10	12	3-4	7	15	8-0	8 3/8	16
15×24	10-7 1/2	15-3 3/8	18-0 3/8	13	15	20	2-4	8-3 1/2	4-7 1/2	3-2 1/2	11	15	4-0	9	16	10-0	9 5/8	19
16×28	12-5 1/8	17-9 7/8	20-1 5/8	15	18	22	2-9	9-5 1/2	5-3 7/8	3-6 7/8	12	16	4-10	9 1/8	20	10-0	10	20
18×28	12-5 7/8	17-11 3/8	20-3 1/8	15	18	23	2-9	10-3 1/8	5-10 3/4	3-9 3/4	13	18	4-10	11 1/8	24	10-0	11 1/4	22
20×30	13-6 1/2	19-9 3/8	22-6 3/8	20	20	25	3-4	12-0 1/8	7-2	4-9	15	20	6-0	11	28	12-0	12 5/8	24
22×30	13-7 1/2	19-11 1/2	22-8 1/2	20	20	27	3-4	12-10 1/2	7-9 1/2	4-10 1/2	15	22	6-0	12	34	12-0	13 3/4	26

It is evident that the opening or closing of the steam inlets or outlets of the cylinder must be carefully timed to produce the required pressures in the different parts of the cylinder at the proper time.

The valve is generally moved back and forth within the steam chest by the action of an *eccentric*, one type of which is shown in Fig. 536; this is securely fastened to the main shaft so as to turn together with it. In some rare cases, the eccentric is forged solid on the shaft, but the general practice is to fasten it by keying it on; the eccentric is usually placed just outside of the bearing which holds the main shaft.

This mechanism consists of two parts; the eccentric proper or sheave, Fig. 536, and the eccentric strap, Figs. 534 and 535. The eccentric strap is made to fit in a groove in the face of the eccentric, or the eccentric fits in a groove in the strap.

To the *eccentric strap* is attached the *eccentric rod*, which is connected to the valve rod, this finally connecting to the valve.

The eccentric is a form of crank, the difference between them being that in the eccentric the crank pin is so large that it embraces the crank shaft. This is shown in Figs. 536 and 537. *Twice the distance between the center of the crank shaft and the center of the crank pin is the length of a stroke produced by the crank. The same is true for the eccentric.*

The slide valve which has been used most extensively is the plain three-ported slide valve. Its form and action will be understood by reference to the illustrations shown in Figs. 538 and 539; here the slide valve is shown in its most elementary form, as a box open on its under side sliding over a plane surface on the outside of the steam cylinder. This surface is supplied with openings called *steam ports*, leading into the cylinder; these ports, usually rectangular in section, are indicated in the illustration by the letters S_1 and S_2.

The third opening over which the slide valve moves, indicated by the letter E, is the *exhaust opening*, through which the steam escapes from the cylinder. It will be seen that, when the valve is in its middle position, its two edges cover the two steam ports, while the hollow part of the slide valve is over the exhaust port. When the valve no more than covers the steam ports when in its middle position, the eccentric must be placed 90° in the advance of the engine crank.

The illustration shows the piston at the left end of the cylinder, with the valve moving toward the right and about to open the steam port S_1 to permit the steam to pass through this port into the cylinder, thus forcing the piston to the right. During this same time, the steam port S_2 and the exhaust port E will be connected by the hollow part of the valve,

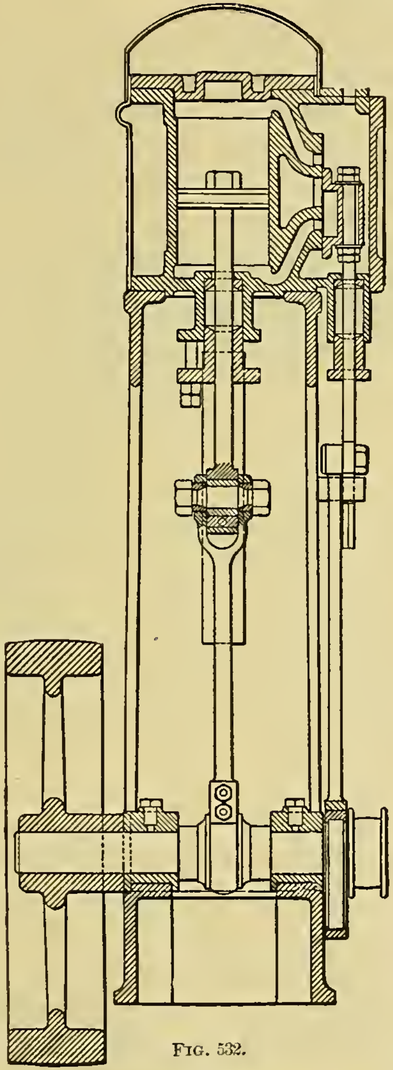


FIG. 532.

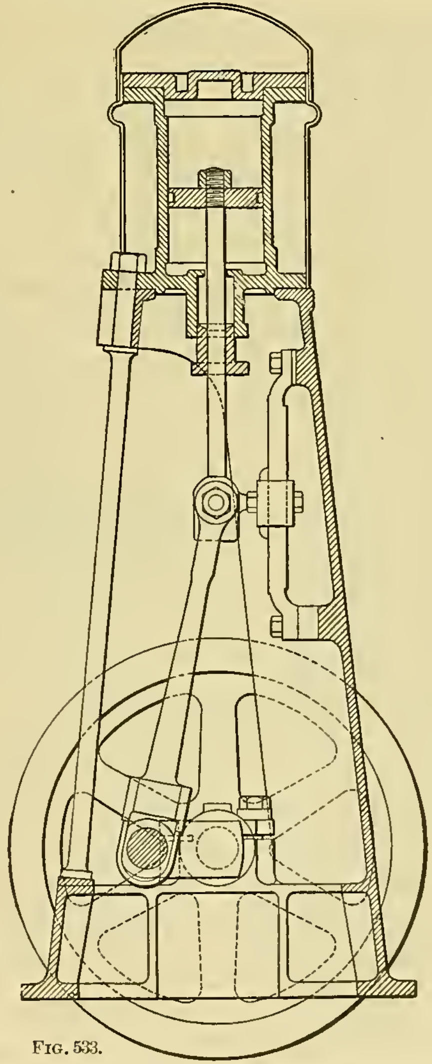


FIG. 533.

and the steam, which is contained to the right of the piston is allowed to escape into the exhaust. The valve will have moved to its extreme right position when the piston has reached the middle of the cylinder, and when the piston has reached its extreme right position, the valve will be in the middle of its return stroke. Without this arrangement there would be no expansive working of the steam, as one end of the cylinder is left open for the admittance of live steam during the whole stroke of the piston, while the other end is open during the same time to the exhaust. To produce expansion, the valve must more than cover the steam ports when in its middle position. The amount which the valve projects outside of the steam ports, when the valve is in its middle position, is called the *outside lap of the valve*, and the amount which the valve projects on the inside of the steam ports in the direction of the exhaust ports, is called the *inside lap*, Fig. 540.

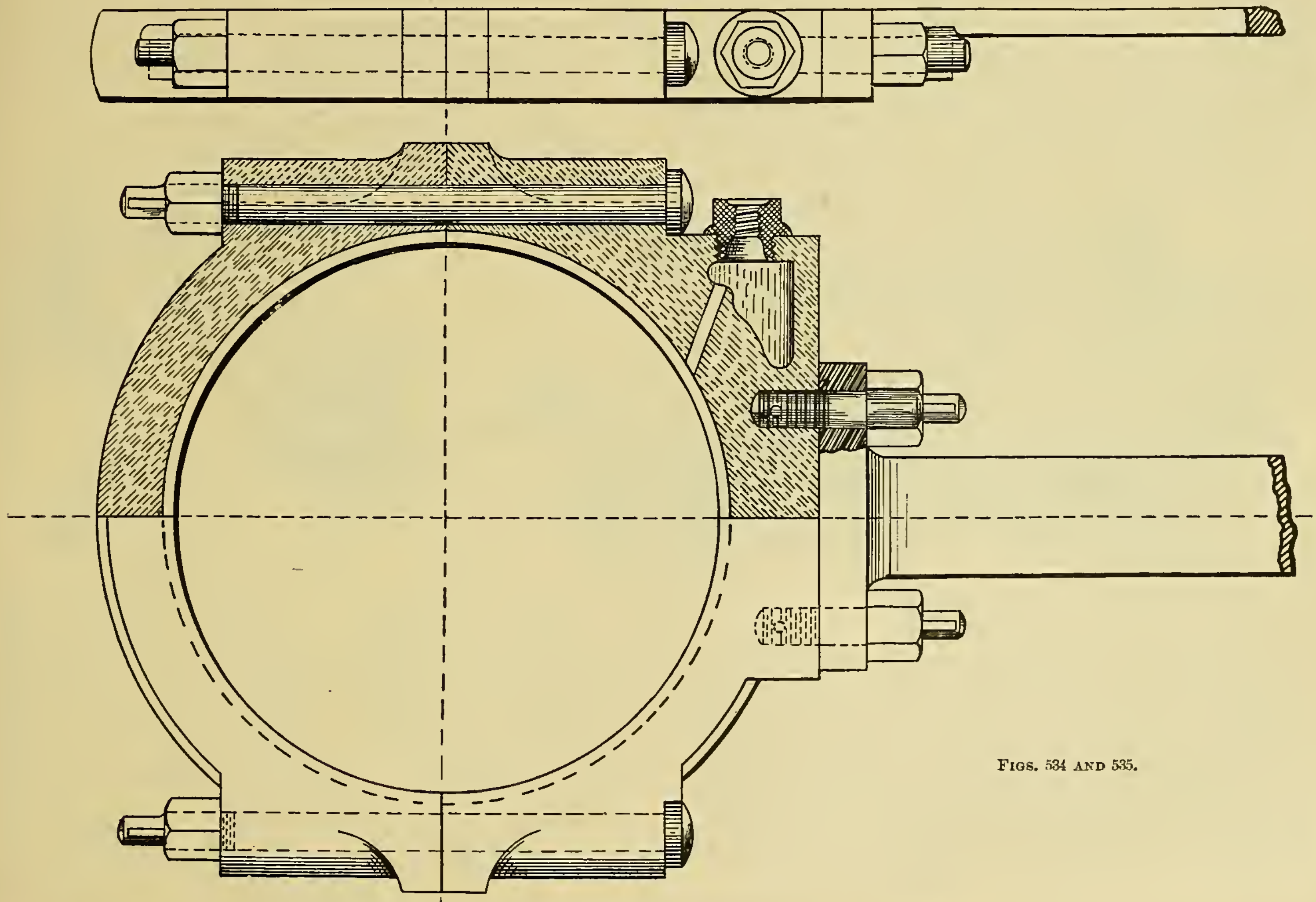
The addition of laps necessitates a change in the angle of advance between the crank and eccentric, because the valve must be on the point of opening the steam port when the piston is at the beginning of its stroke, and therefore the valve must be away from its middle position, *by a distance equal to the outside lap when the piston is at the beginning of its stroke.* The angle between the eccentric and the crank must then be more than 90°.

The correct position of the eccentric in relation to the crank is found by the construction illustrated in Fig. 541. Here AO represents the crank, while the circle CDE is the path of the center of the eccentric. On AO set off OB equal to the outside lap of the valve. Draw BD perpendicular to OB cutting the circle at D. Then OD is the position of the eccentric sheave, if the motion is in the direction of the arrow. If opposite, then OE is the right position of the sheave. The angle COA is a 90° angle, and the acute angle COD is called the angle of advance.

When it is desirable to partly open the steam port just as the piston is beginning its stroke, the valve must be given a *lead.* The amount of such opening of the steam port at the beginning of the stroke, is called the *lead of the valve.*

To produce the valve lead, the angle of advance of the eccentric must be increased, so as to make OB, in the above figure, equal to the outside lap, plus the lead.

Let the circle ABCD in Fig. 542 represent the path of the center of the eccentric sheave. When the valve is in its middle position, moving toward the left, the eccentric will be in the position OC, moving in the direction indicated by the arrow. Let P be one position of the eccentric; drop from the point P a line PM perpendicular to AB. Then

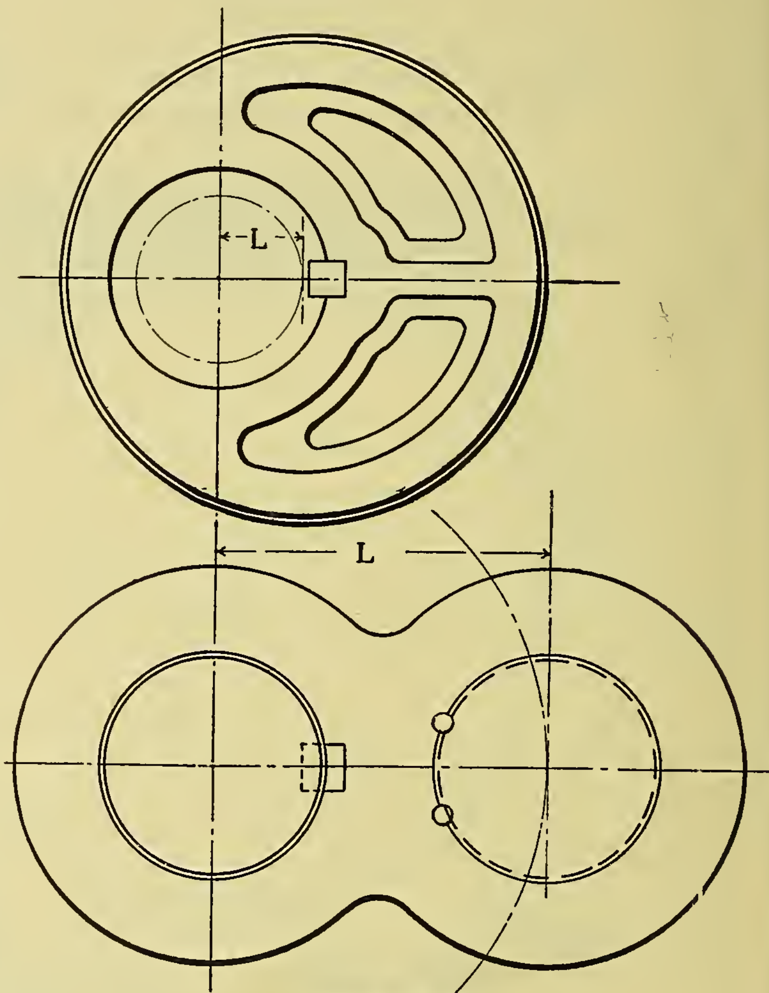


FIGS. 534 AND 535.

the distance OM will correspond to the distance the valve has moved from its middle position. Make QO equal to MO. If more positions of the eccentric are taken, and for each one a similar construction employed, the points corresponding to the point Q, found above, will, when joined, produce a curve which will have the form of the two circles, AQON and OSBT. These circles are described on AO and OB as diameters. By means of these two circles the position of the valve may be readily found for any position of the eccentric. For instance, if OR is the position of the eccentric, the valve will be at a distance OS from its middle position.

To find the position of the engine crank for any given position of the eccentric, say for the position OP, make the angle POL equal to the angle between the eccentric and the crank, equal to a right angle plus the angle of advance; then OL will be the required position of the crank.

If the distance OQ, equal to MO, be set off on OL instead of OP, and a similar operation gone through for a number of positions of the crank, it will be found that the different positions of the point Q, when joined, will form a curve just coinciding with the two circles described on OE and OF, Fig. 543, as diameters, the diameter EOF making the angle COE, equal to the angle of advance.



FIGS. 536 AND 537.

From this diagram the position of the valve for any position of the crank may be found. If the crank is in position OL, Fig. 543, then the valve is a distance OQ from its middle position.

We can also find any position of the crank for a given position of the valve. For instance, when the valve is just on the point of opening or closing, it will be at a distance equal to the outside lap, from its central position. If an arc be described with the center O and a radius equal to the outside lap, $O6_1$ will be the position of the crank when the steam is admitted, and $O6_2$ its position when the steam is cut off. The position of the piston can easily be found from this.

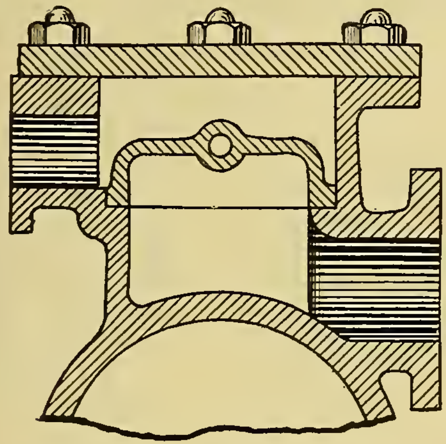


FIG. 538.

To determine whether the valves are set correctly, by means of diagrams taken of the steam pressure from each end of the cylinder and by observing and comparing the respective positions of the points of admission, cut-off, release and compression, the apparatus called the *steam engine indicator* is used.

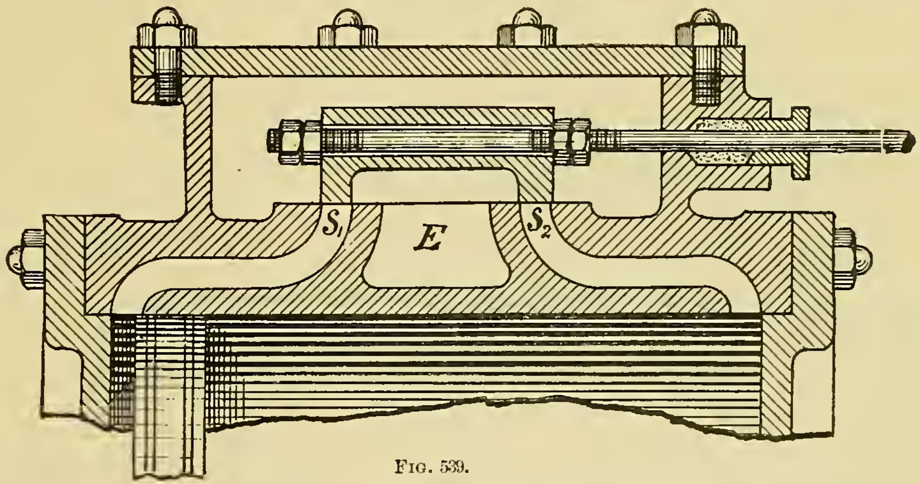


FIG. 539.

A description of the indicator and its use, together with a study of its diagrams, can not be classed with mechanical drawing, and would cause us to drift too far from our subject. A very interesting and thorough treatise on the indicator is "Hawkins' Indicator Catechism," and the student who desires to take up the field of steam engineering, is respectfully referred to this work.

Fig. 544 shows a *valve diagram*, as well as a theoretical form of an indicator diagram. The radius of the eccentric equal to one-half the travel of the valve, is equal to the distance AO in the diagram. The outside lap equals OC, the lead equals b d, the angle of advance is equal to the angle EOC; the

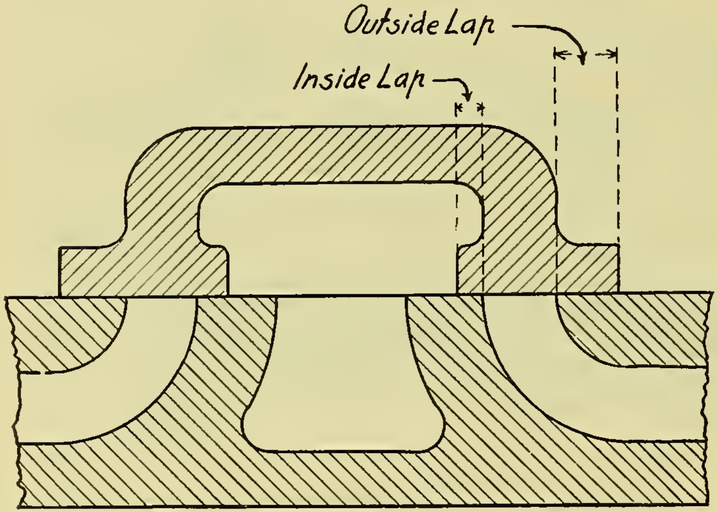


FIG. 540.

inside lap is equal in length to Og, the width of the steam port is given by MK, which is equal to gh. When the steam is admitted, the crank is in the position indicated by the line $O6_1$. When the steam is cut off the position of the crank is $O6_2$. When the steam is released the crank is in the position $O6_3$. Compression begins when the crank is in the position $O6_4$; the port is completely open while the crank moves through the angle q o r, and it is completely open for exhaust while the crank moves through the angle tOs.

To find the indicated horse power of a steam engine, *multiply the mean effective pressure in lbs.*

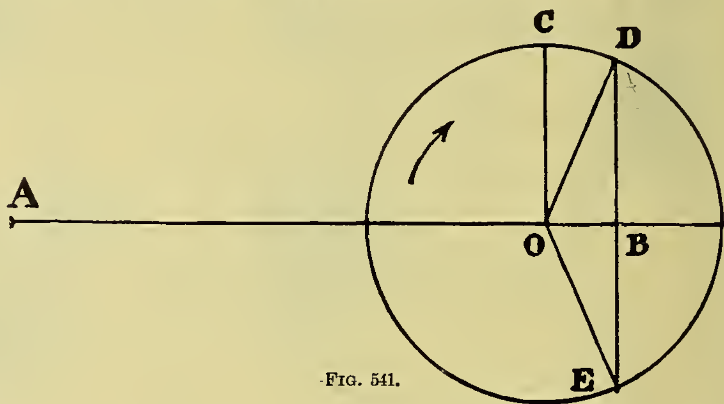


FIG. 541.

per sq. in. on the piston during one stroke, by the length of the stroke in feet, then by the area of the piston and by the number of strokes per minute and divide the result by 33,000.

$$\frac{P \times L \times A \times N}{33000} = \text{Indicated H. P. of engine,}$$

where P is the mean pressure; L, the length of the stroke; A, the area of the piston; and N, the number of strokes per minute. The actual horse power may be taken as about ¾ of the indicated horse power.

To find the area of the piston *multiply the square of its diameter by 0.7854.*

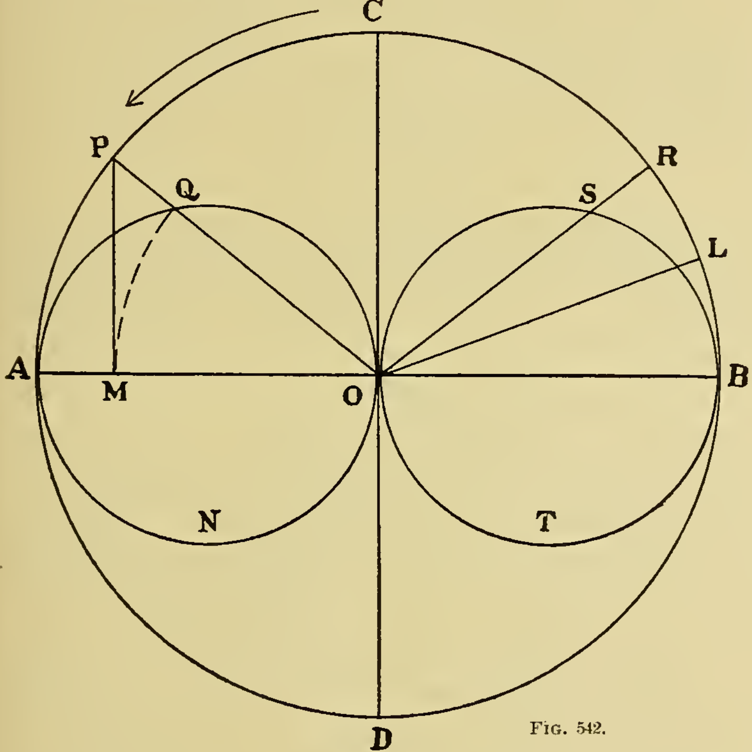


Fig. 542.

To find the mean effective pressure, *divide an indicator diagram of the engine into any number of equal parts, say 10, then measure the height of each part, half-way between the division lines, as shown by the dotted lines in* Fig. 545. *Add the length of all the dotted lines, and divide by the number of divisions, in this case 10.*

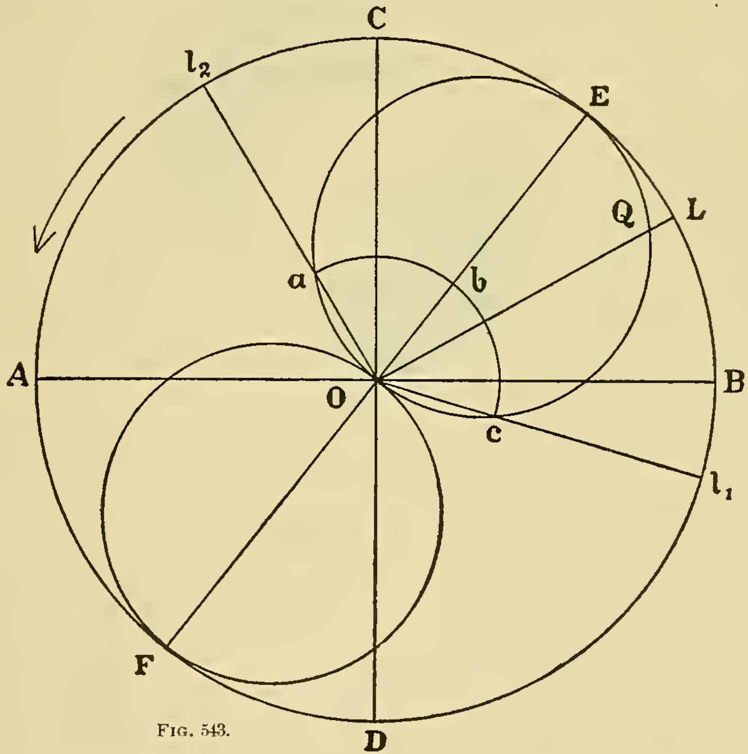


Fig. 543.

The mean effective pressure may also be found by *measuring the area of the diagram* by means of a planimeter and *dividing it by the length of the dia-*

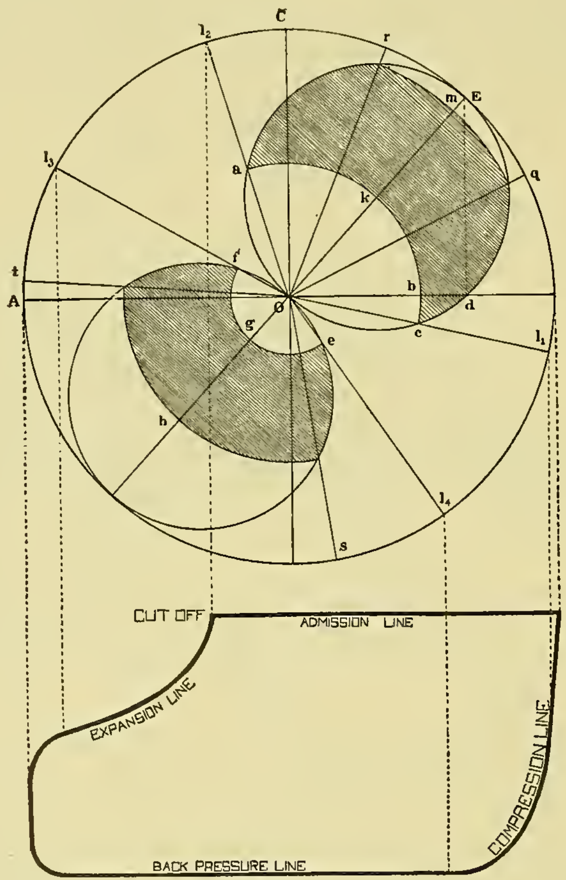


Fig. 544.

gram; multiply this result by the scale of the indicator spring, and the product will be the mean effective pressure.

Example: Find the horse power of an engine when L equals 4 ft.; diameter of cylinder equals 32 inches, P equals 40 lbs. per sq. in. and N equals 40 per minute.

$$\text{H. P.} = \frac{40 \times 4 \times 804.25 \times 40}{33000} = 756 \text{ nearly.}$$

From the above formula, the proportions of a cylinder may be determined, when the horse power, pressure and number of revolutions per minute are given.

$L \times A = \frac{HP \times 33000}{P \times N}$; here A is the area of piston, and L the length of stroke.

The area may be expressed by the diameter of the piston in the following manner: $A = .7854 \times D^2$; consequently the above formula may be written

$$L \times .7854 \times D^2 = \frac{HP \times 33000}{P \times N}$$

If we make L equal to d, as is often done, we have from the above formula, $d = 79.59 \sqrt[3]{\frac{HP}{PN}}$ from which we may find the required diameter of cylinder, for an engine which shall have a given horse power, mean pressure and number of strokes per minute. For the completed thickness of the walls of the steam cylinder, Prof. Reauleaux gives the following formula:

$$\text{Thickness} = \tfrac{1}{8}\ \text{inch} + \frac{d}{100}$$

EXAMPLE: If the diameter of the cylinder is 48 in., the thickness of its wall should be

$$\tfrac{1}{8} + \frac{48}{100} = .125 + .48 = .605$$

For the thickness of the heads of cylinders of ordinary size, when the heads are not stiffened by radial ribs, the thickness

$$= 0.003 \times d \times \sqrt{\text{boiler pressure per sq. in.}}$$

EXAMPLE: If the diameter of the cylinder equals 40 inches, and the boiler pressure 150 lbs., then the thickness of head $= 0.003 \times 40 \times \sqrt{150} = 1.46$ in. Having found a convenient thickness of the head and flange of the steam cylinder, upon which the head is to rest, the diameter of the bolts which fasten the cylinder head should be one-half the width of the flange. The number of required bolts may be found from the following formula:

Number of bolts equals 0.7854 × square of diameter of cylinder, multiplied by the boiler pressure and divided by 5,000 times the area of a single bolt of the assumed diameter.

EXAMPLE: Let the diameter of the cylinder be equal to 32 inches; the boiler pressure 81 lbs. per sq. in., and the assumed diameter of bolt equal to ¾ in. The area of a ¾ in. bolt equals 0.442 sq. in., then

$$\text{Number of bolts} = \frac{0.7854 \times 32 \times 32 \times 81}{5000 \times 0.442} = 30.$$

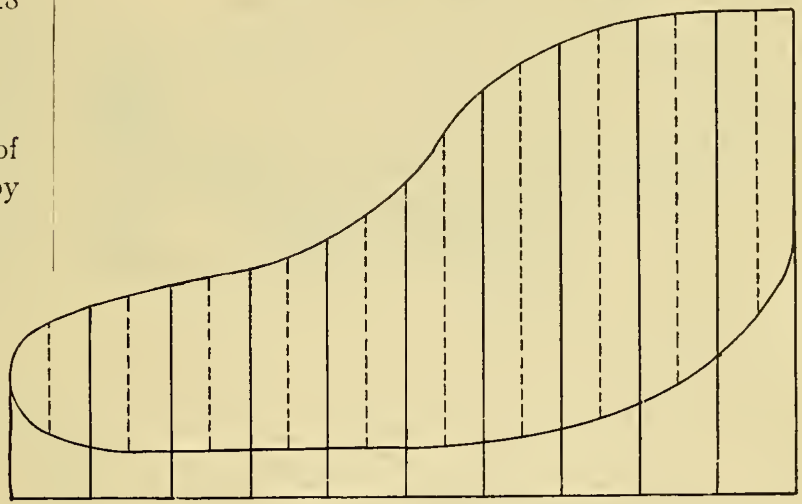


FIG. 545.

The steam chest must be made as small as the dimensions and travel of the valve will permit. It usually has the form of a square box, surrounding the valve face. The steam chest cover, as well as the sides of it, are usually made of the same thickness as the cylinder walls. The size of the steam ports depends upon the quantity of steam which is to be admitted through them, and upon the speed of the piston. It is a good practice to make the area of the ports equal to $\frac{1}{10}$ of the piston area when the speed of the piston is about 600 feet per minute.

Thickness of piston $= \sqrt[4]{\text{length of stroke in in.} \times \text{diameter of cylinder in in.}}$

EXAMPLE: If the diameter of the cylinder is 30 in. then the required thickness of piston is

$$\sqrt[4]{30 \times 30} = \sqrt[4]{900} = 5.4 \text{ in. nearly.}$$

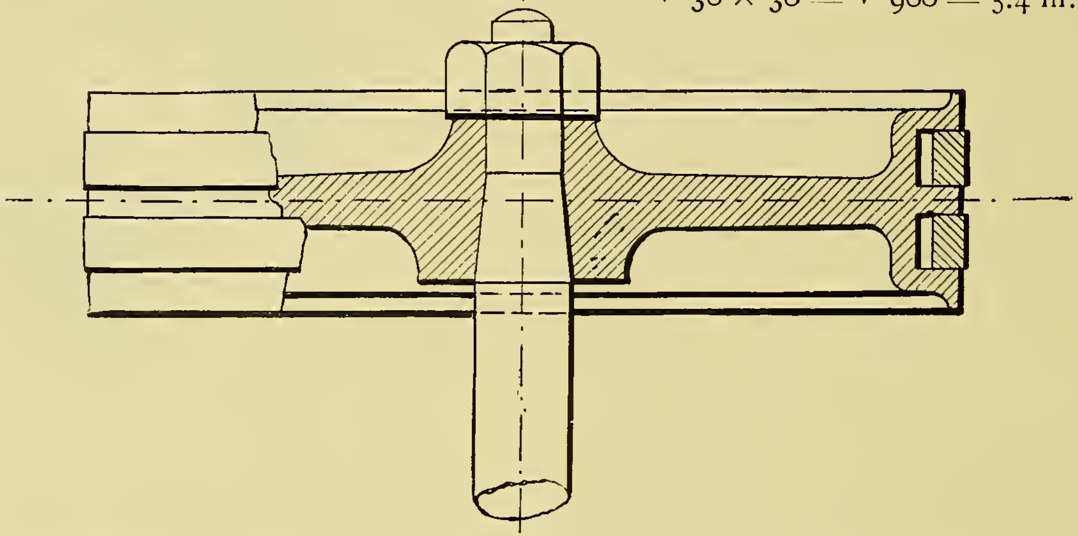


FIG. 546.

When the speed of the piston is higher or lower, the size of the ports is increased or diminished proportionately. To find the speed of the piston, multiply the length of stroke by double the number of revolutions of crank per minute.

A practical formula for the thickness of the piston, shown in Fig. 546, is:

The piston rod may be made of wrought iron, or still better of steel. It is generally keyed to the crosshead and fastened to the piston by a strong thread and nut or by wedge.

The diameter of a wrought iron piston rod may be found by the following rule:

Divide the diameter of the cylinder in inches by

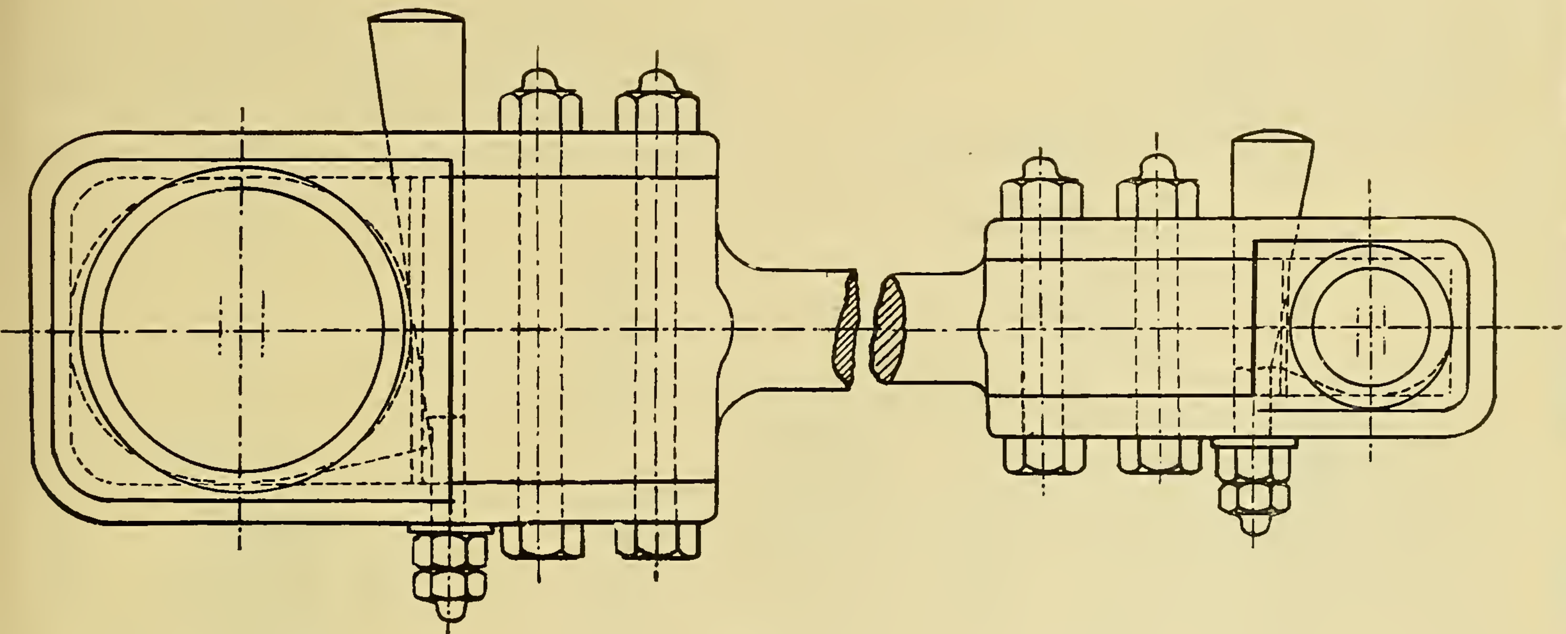


FIG. 547.

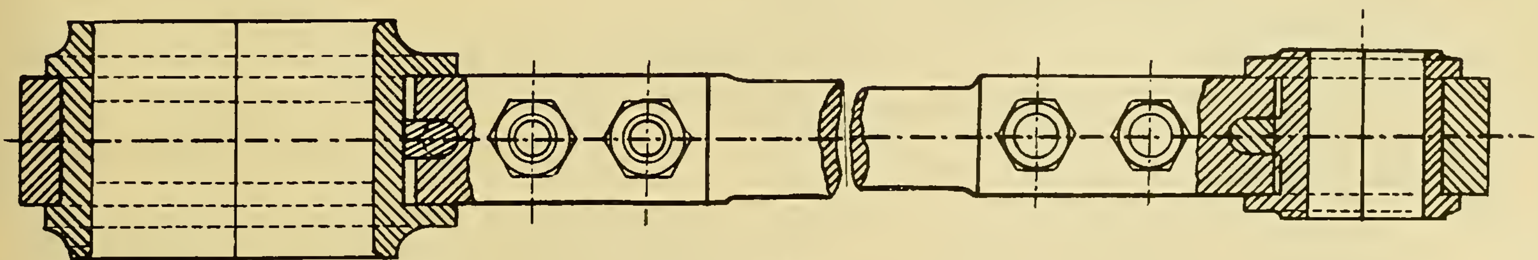


FIG. 548.

60 and multiply the quotient by the square root of the initial steam pressure.

Diameter of *wrought iron rod*

$$\frac{\text{diam. of cylinder}}{60} \times \sqrt{\text{initial pressure.}}$$

Diameter of *steel rod*

$$= \frac{\text{diam. of cylinder}}{69} \times \sqrt{\text{initial pressure.}}$$

To find the pressure of the crosshead upon the guide, in pounds, the following may be used :

$$\text{Pressure} = \frac{396000 \times \text{HP}}{\sqrt{n^2-1} \times L \times N}$$

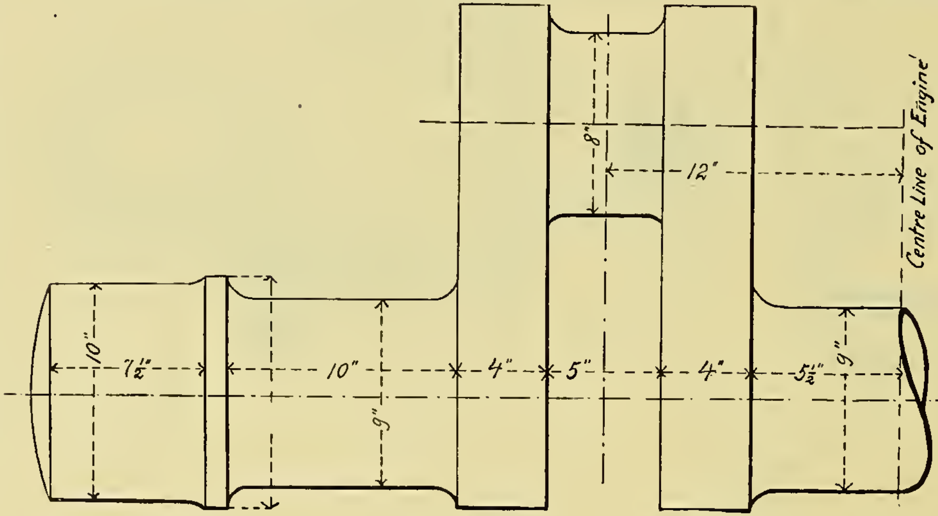


FIG. 549.

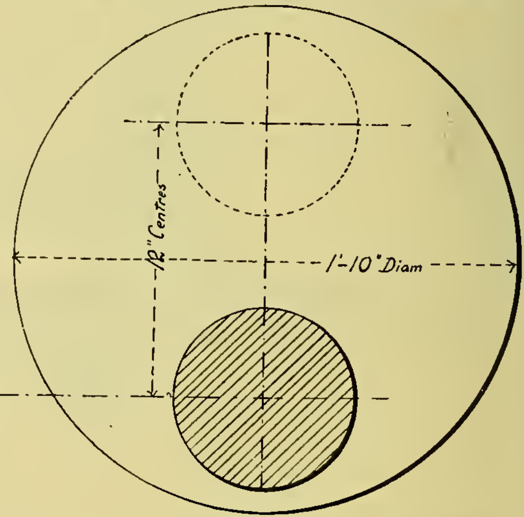


FIG. 550.

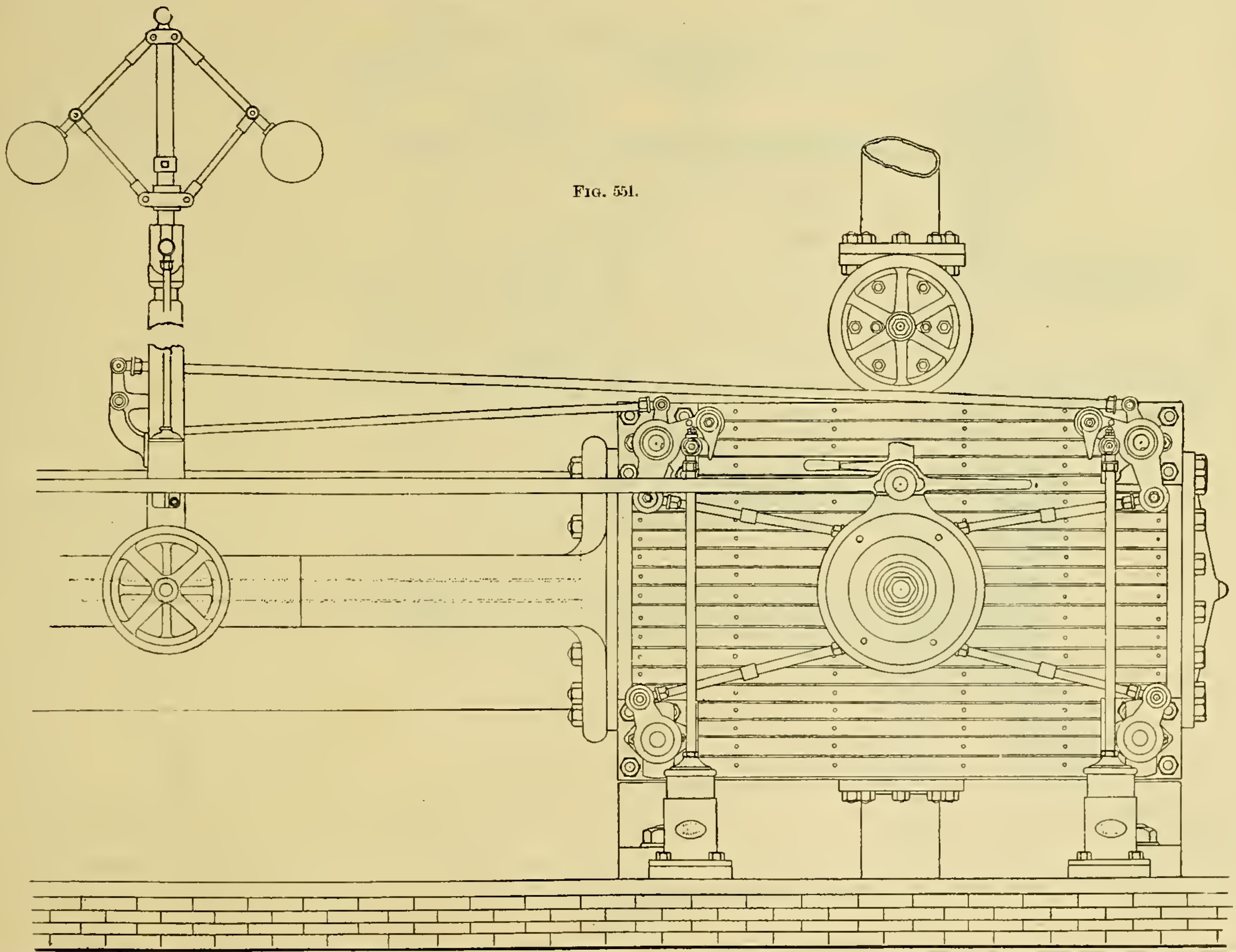
In this formula N equals the length of the connecting rod divided by the length of the crank. The other letters represent the same values as in former examples in this chapter.

Let the total area of the shoe of the crosshead be equal to A square inches, and let the pressure allowed upon a sq. in. be equal to p ; then,

$$A = \frac{\text{pressure of crosshead upon guide}}{p}$$

If the pressure of the crosshead be found to equal 6,568 pounds, and if the pressure per sq. in. of slide allowed be equal to 125 lbs., then,

Fig. 551.



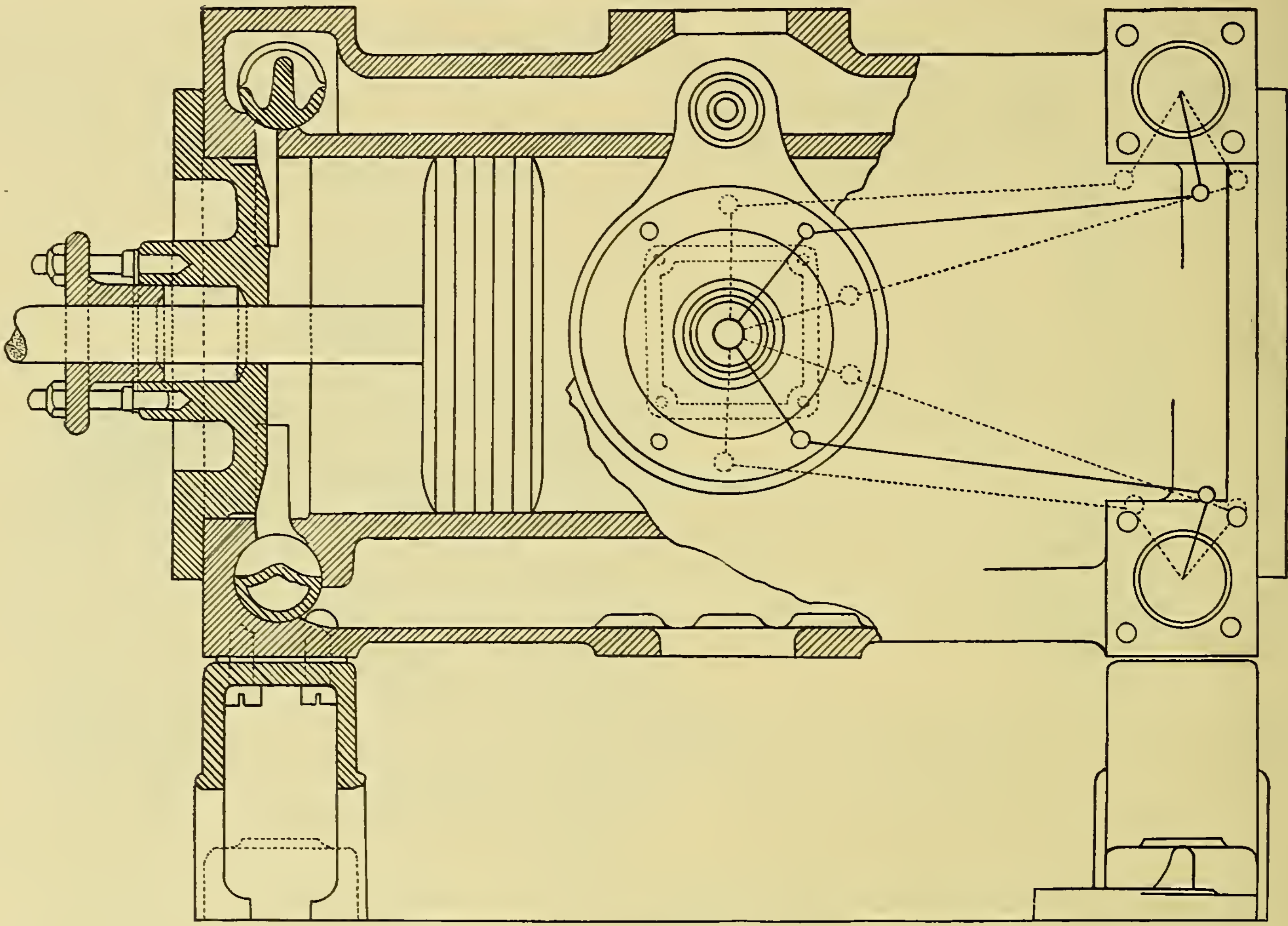


Fig. 552.

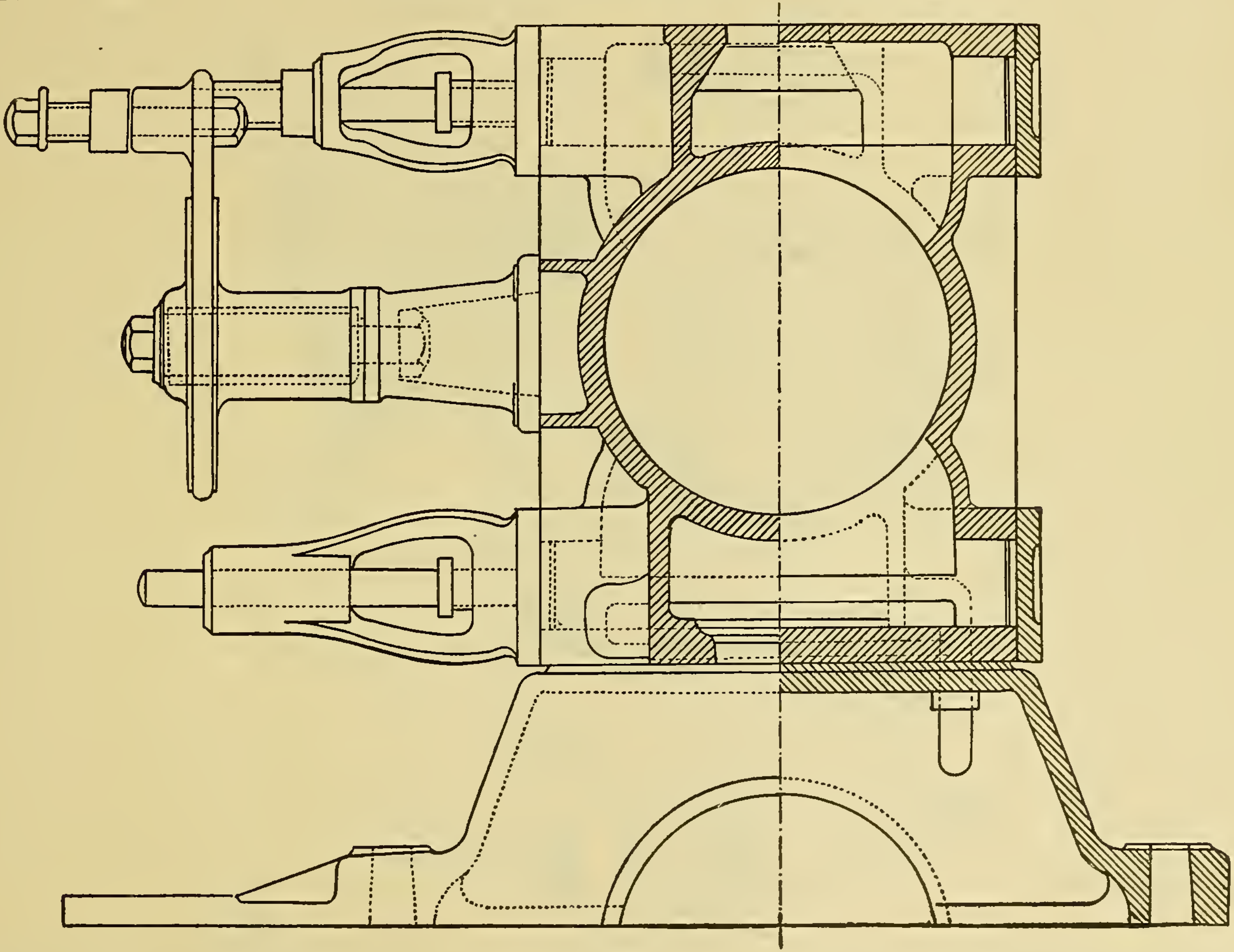


Fig. 553.

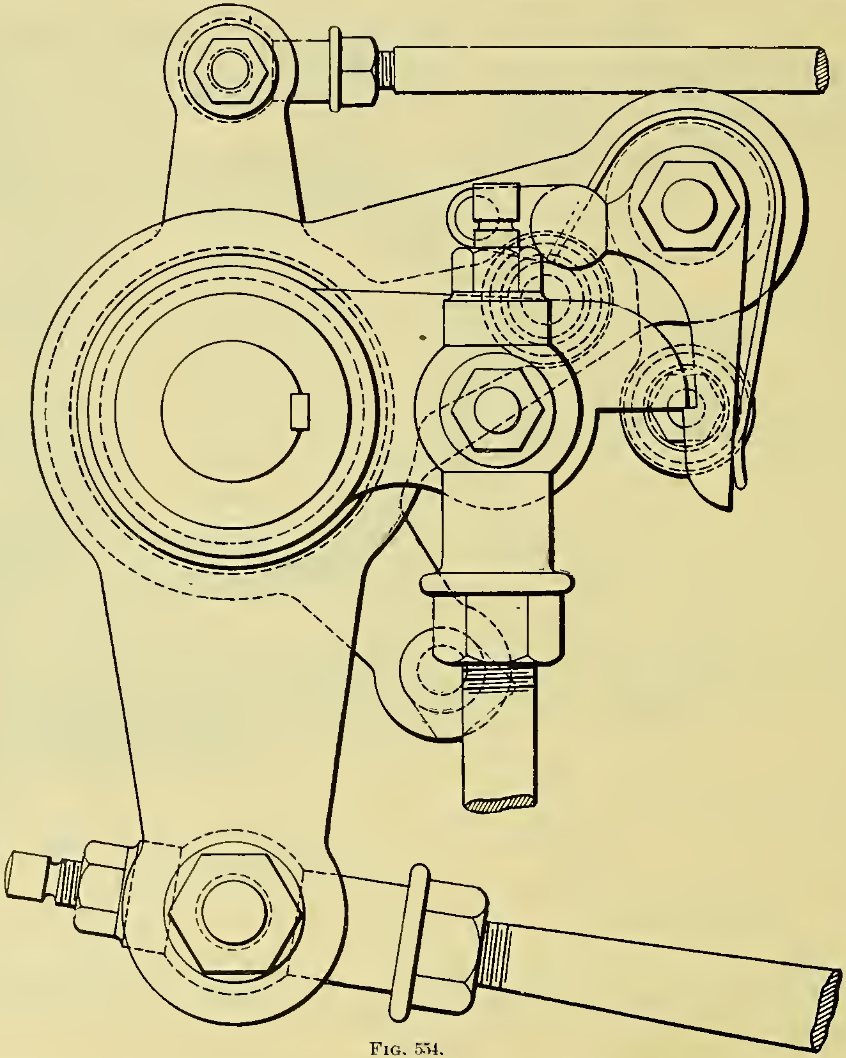


Fig. 554.

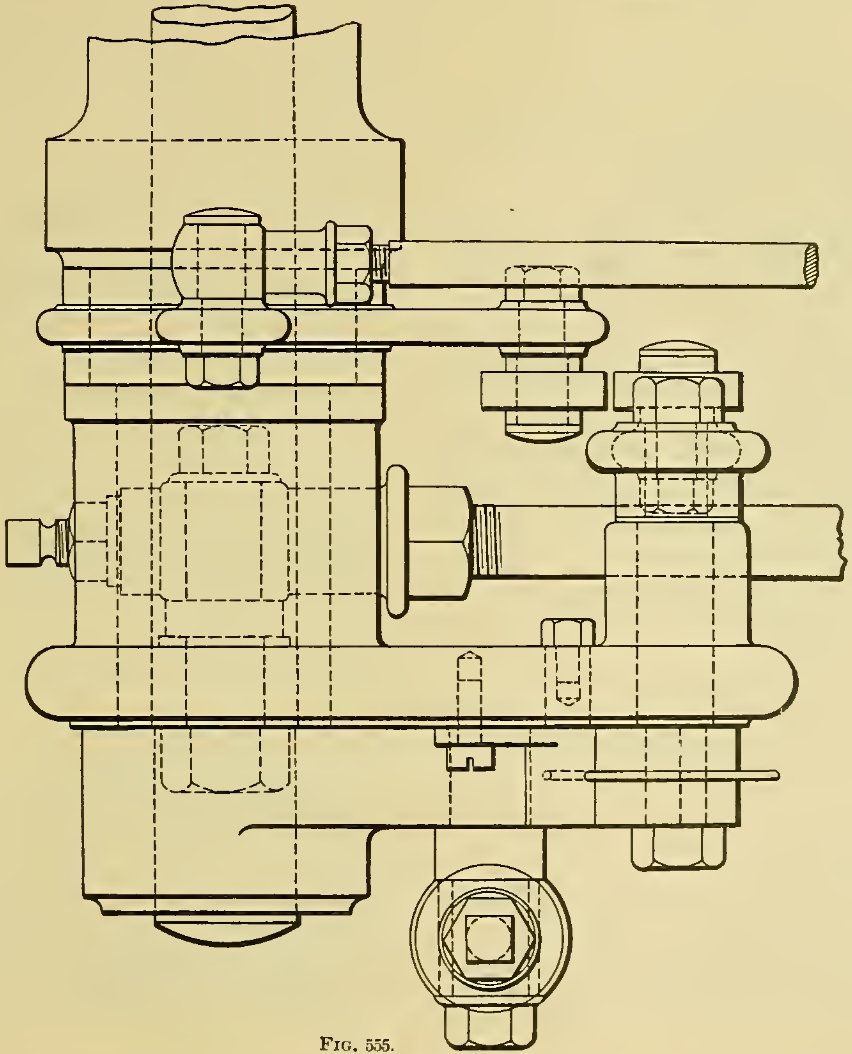


Fig. 555.

$$\text{the area of shoe} = \frac{6568}{125} = 52.5 \text{ sq. in.}$$

If the width of the shoe be taken equal to 4 in., then the length of it will be 13.1 in., as 4×13.1 equals 52.4 sq. in., found above (nearly).

The pin in the crosshead which holds the connecting rod, is best made with a diameter equal to that of the crank pin.

The smallest diameter of the connecting rod is found by dividing the diameter of the cylinder in inches by 55, and multiplying the quotient by the square root of the steam pressure per sq. in. of piston. The greatest diameter is one and one-half times the smallest.

The diameter of the crank pin is equal to

$$1.758 \sqrt[4]{\frac{HP}{L \times N}} \times l$$

where l is the length of the crank pin journal in inches.

This formula is true for a single crank and for one made of wrought iron.

The length of the pin may be made equal to $0.013 \times d^2$ where d is the diameter of the piston.

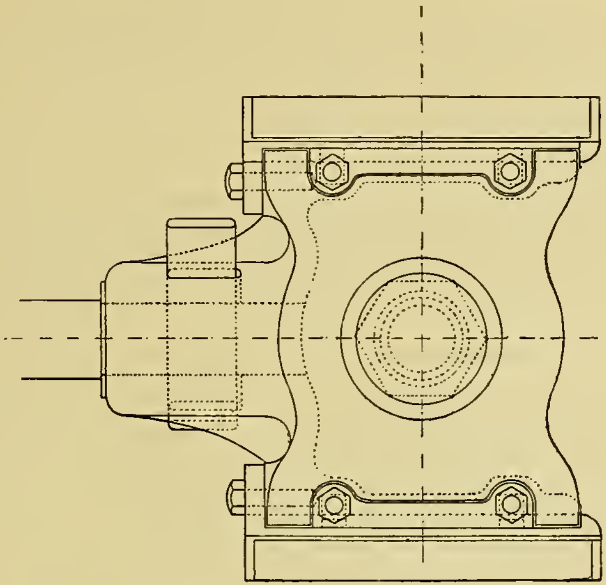
To find the diameter of a crank shaft for stationary engines, with cylinders up to 30 in. in diameter, divide the diameter of the cylinder by 2; then subtract ⅛ in., and the remainder will be the diameter of the crank shaft.

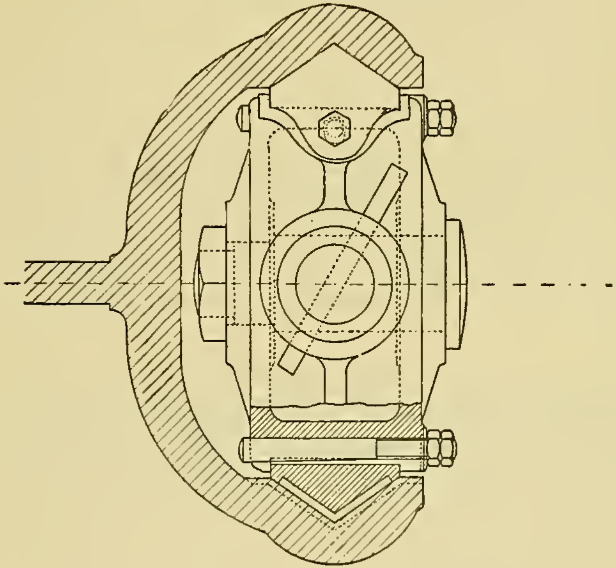
THE CORLISS ENGINE.

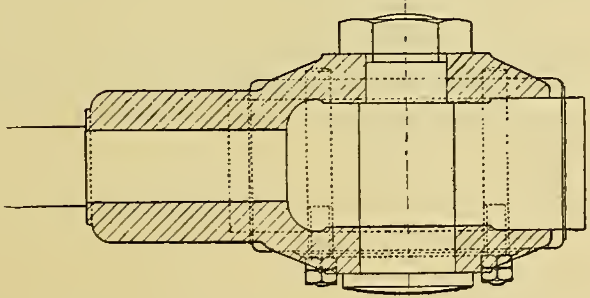
The illustrations represent views of the cylinder of the Fishkill Landing Corliss engines. Fig. 551 shows the valve gear of this engine.

A Corliss engine has four separate valves, two situated above the axis of the cylinder and intended for the admission and cut off of steam, while the other two are placed below the axis of the cylinder for the exhaust. The steam valves are rigidly connected with cranks seen on the outside of the cylinder. All valves are cylindrical in form and extend across the cylinder above and below, respectively. The cranks on the outside of the valves are operated by a number of links, and in this manner the motion of the valves is actuated.

The Corliss valve gear is used in a large number of steam engines. Fig. 551 shows a side elevation of the valve gear, while Fig. 552 exhibits a partial longitudinal section of the cylinder. A cross section being shown in Fig. 553. The cut-off mechanism is shown in detail in Figs. 554 and 555. In Figs. 556, 557 and 558 the crosshead is shown.







FIGS. 556, 557 AND 558.

The disc seen in the middle of the cylinder in Fig. 551, called the *wrist plate*, is made to rock upon the stud in its center by a rod leading from the eccentric on the crank shaft. The wrist plate has four valve connecting rods, which connect it with the bell cranks, which in turn operate the steam valves. These valve connecting rods can be lengthened or shortened, so that each valve may be set independent of the other three. As the wrist plate rocks backward and forward, the exhaust valves rock with it.

The two other *bell cranks*, which are provided with disengaging links, generally called hooks, are also given a rocking motion by the wrist plate by hooking in the blocks which are rigidly fastened to the cranks on the outer ends of the steam valve stems, thus causing the valves to rotate with them, and causing them to open the steam ports for the admittance of steam.

Having turned a certain distance, the disengaging links on the bell crank are unhooked by a cam operated by the governor, and the cranks of the valves are pulled back to their original position by means of the vertical rods from the vacuum air dash pots. The dash pot is a cylinder in which fits a piston nearly air-tight. As the valve is turned it lifts the piston in the dash pot and creates a partial vacuum below it. The atmospheric pressure acts as a weight forcing down the piston into the dash pot and at the same time closing the valves.

The air below the piston in the dash pot prevents a sudden shock when the piston drops down. As a consequence of this arrangement, the valves are entirely independent in their adjustment and the inlet ports may be suddenly opened full width by the quick movement of the steam valves, while the exhaust valves are nearly at rest.

The advantages of the Corliss valve gear are the large port area, the little friction through the valves, short lengths of ports, quick opening and closing of valves and easy adjustment. However, the great number of parts makes the expense of these engines greater, their operation noisy, besides which it is impossible to run them at a high speed. Corliss engines do not, as a rule, run higher than 150 revolutions per minute.

ELECTRICITY, THE DYNAMO AND MOTOR.

Electricity is a name derived from the Greek word *electron*—amber. It was discovered more than 2,000 years ago that amber when rubbed possessed the curious property of attracting light bodies. It was discovered afterwards that this property could be produced in jet by friction, and in A. D. 1600 or thereabouts, that glass, sealing-wax, etc., were also affected by rubbing, producing electricity.

Whatever electricity is, it is impossible to say, but for the present it is convenient to look upon it as a kind of invisible something which pervades all bodies.

While the nature of electricity is a mystery, and a constant challenge to the inquirer, many things about it have become known—thus, it is positively assured that electricity never manifests itself except when there is some mechanical disturbance in ordinary matter, and every exhibition of electricity in any of its multitudinous ways may always be traced back to a mass of matter.

The great forces of the world are invisible and impalpable; we cannot grasp or handle them; and though they are real enough, they have the appearance of being very unreal. Electricity and gravity are as subtle as they are mighty; they elude the eye and hand of the most skillful philosopher.

In view of this, it is well for the average man not to try to fathom, too deeply, the science of either. To take the machines and appliances as they are "on the market," and to acquire the skill to operate them, is the longest step toward *the reason for doing it, and why the desired results follow.*

The design, manufacture and the practical applications of *dynamo electric machinery* is a theme far beyond the scope of this work, and beyond the limits of many volumes equal to it in size; suffice it to say, that the subject is *as inexhaustible as it is useful to explore;* it is especially in this, as in other sections of the volume, that the aim of the author has been to suggest the field of work rather than to try to fully explain many things needed to be known.

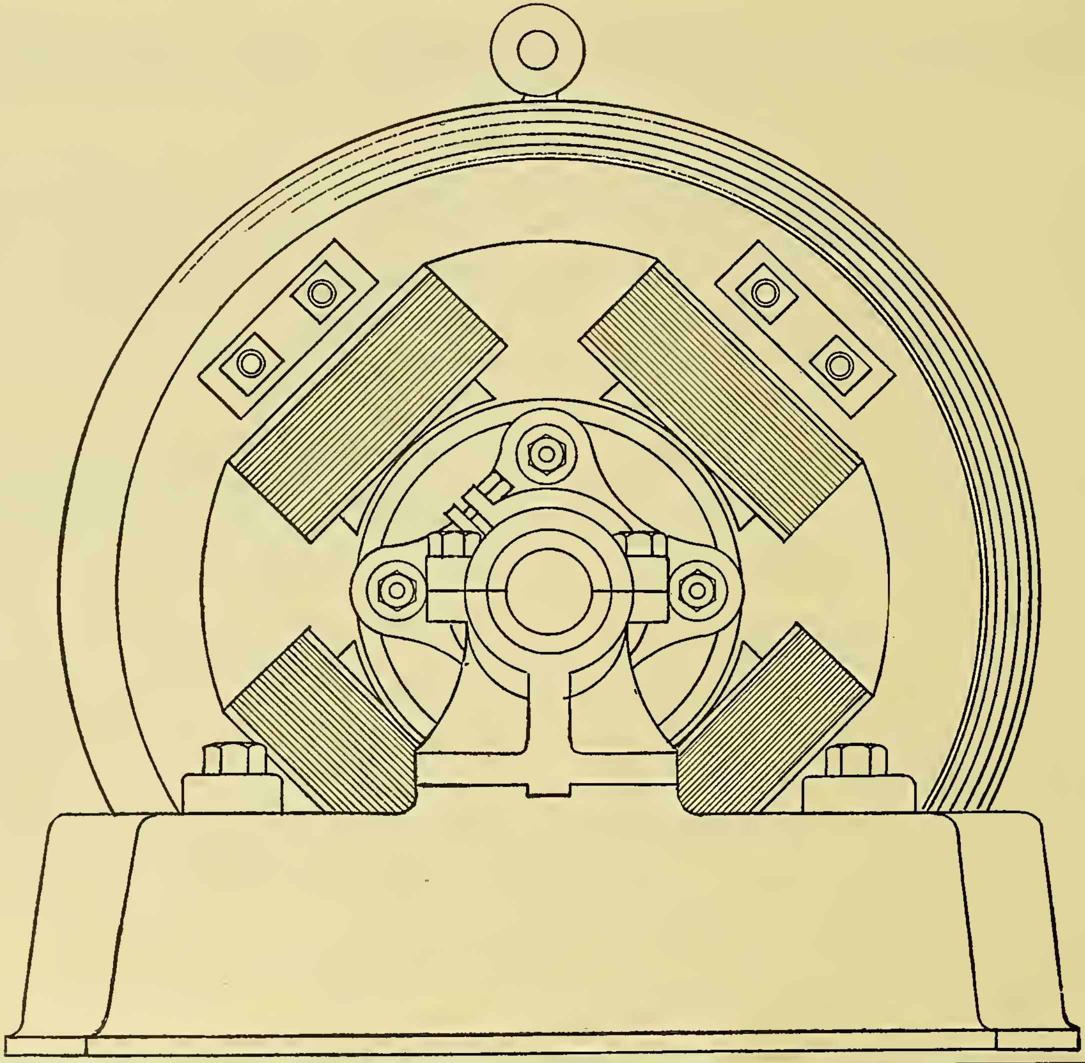
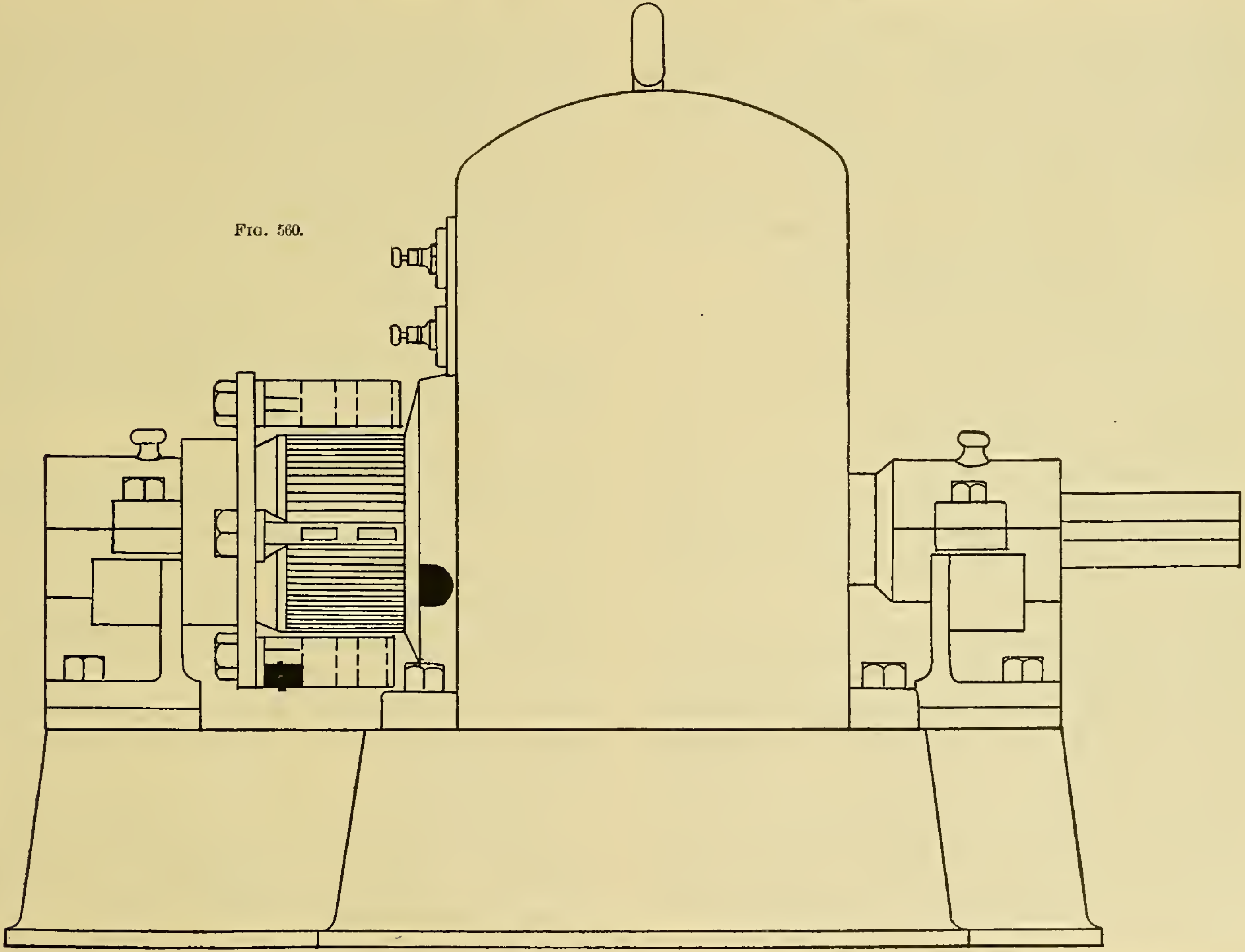


Fig. 559.

Fig. 560.



Electricity, it is conceded, is without weight, and, while electricity is, without doubt, one and the same thing, it is for convenience sometimes classified according to its motion, as—

1. Static electricity, or electricity *at rest.*

2. Current electricity, or electricity *in motion.*

3. Magnetism, or electricity *in rotation.*

4. Electricity in vibration.

Other useful divisions are into—

1. Positive and

2. Negative electricity.

And into—

1. Static, as the opposite of

2. Dynamic electricity.

There are still other definitions or divisions which are in every-day use, such as "frictional" electricity, "atmospheric" electricity, "resinous" electricity, "vitreous" electricity, etc.

Static electricity.—This is a term employed to define electricity produced by friction. It is properly employed in the sense of a static charge which shows itself by the attraction or repulsion between charged bodies. When static electricity is discharged, it causes more or less of a current, which shows itself by the passage of sparks or a brush discharge; by a peculiar prickling sensation; by a peculiar smell due to its chemical effects; by heating the air or other substances in its path and sometimes in other ways.

NOTE.—*Statics* is that branch of mechanics which treats of the forces which keep bodies at rest or in equilibrium. *Dynamics* treats of bodies in motion. Hence static electricity is electricity at rest. The earth's great store of electricity is at rest or in equilibrium.

Current electricity.—This may be defined as the quantity of electricity which passes through a conductor in a given time—or, electricity in the act of being discharged, or electricity in motion.

An electric current manifests itself by heating the wire or conductor, by causing a magnetic field around the conductor and by causing chemical charges in a liquid through which it may pass.

Radiated electricity is electricity in vibration. Where the current oscillates or vibrates back and forth with extreme rapidity, it takes the form of waves which are similar to waves of light.

Positive electricity.—This term expresses the condition of the point of an electrified body having the higher energy from which it flows to a lower level. The sign which denotes this phase of electric excitement is +; all electricity is either positive or, —, negative.

Negative electricity.—This is the reverse condition to the above and is expressed by the sign or symbol —. These two terms are used in the same sense as *hot* and *cold.*

Atmospheric electricity is the free electricity of the air which is almost always present in the atmosphere. Its exact cause is unknown. The phenomena of atmospheric electricity are of two kinds; there are the well-known manifestations of thunder-storms; and there are the phenomena of continual slight electrification in the air, best observed when the weather is fine; *the aurora* constitutes a third branch of the subject.

Dynamic electricity.—This term is used to define current electricity to distinguish it from static electricity. This is the electricity produced by the dynamo.

Frictional electricity is that produced by the friction of one substance against another.

Resinous electricity.—This is a term formerly used, in place of negative electricity. This phrase originated in the well-known fact that a certain (negative) kind of electricity was produced by rubbing rosin.

Vitreous electricity is a term, formerly used to describe that kind of electricity (positive) produced by rubbing glass.

Magneto-electricity is electricity in the form of currents flowing along wires; it is electricity derived from the motion of magnets—hence the name.

Voltaic electricity.—This is electricity produced by the action of the voltaic cell or battery.

Electricity itself is the same thing, or phase of energy, by whatever source it is produced, and the foregoing definitions are given only as a matter of convenience.

ELECTRO-MOTIVE FORCE.

The term is employed to denote that which moves or tends to move electricity from one place to another. For brevity it is written E. M. F.; it is the result of the difference of potential, and proportional to it. Just as in water pipes, a difference of level produces a pressure, and the pressure produces a flow as soon as the tap is turned on, so difference of potential produces electro-motive force, *and electro-motive force sets up a current as soon as a circuit is completed for the electricity to flow through.* Electro-motive force, therefore, may often be conveniently expressed as a difference of potential, and *vice versa*; but the reader must not forget the distinction.

In ordinary acceptance among engineers and practical working electricians, electro-motive force is thought of as pressure, and it is measured in units called volts. The usual standard for testing and comparison is a special form of voltaic cell called the Clark cell. This is made with great care and composed of pure chemicals.

The term *positive* expresses the condition of the point having the higher electric energy or pressure, and, *negative*, the lower relative condition of the other point, the current is forced through the circuit by the (E. M. F.) electric pressure at the generator, just as a current of steam is impelled through pipes by the generating pressure at the steam boiler.

Care must be taken not to confuse electro-motive force with electric force or electric energy; when matter is moved by a magnet, we speak rightly of magnetic force; when electricity moves matter, we may speak of electric force. But, E. M. F. is quite a different thing, not "force" at all, for it acts not on matter but on electricity, and tends to move it.

THE DYNAMO, OR GENERATOR.

The word dynamo, meaning power, is one transferred from the Greek to the English language, hence the primary meaning of the term signifying the electric generator is, *the electric power machine.*

The word generator is derived from a word meaning birth-giving, hence also the dynamo is the machine generating or giving birth to electricity.

Again, the dynamo is a machine driven by power, generally steam or water power, and *converting the mechanical energy expended in driving it, into electrical energy of the current form.*

Dynamos are classified as—

1. Unipolar dynamos.

2. Bi-polar (or 2-pole) dynamos.

3. Multipolar dynamos.

This division is caused by their different construction, but, whatever their shape or size or peculiarity of application, the principles upon which they work are always the same—a dynamo is always a machine for generating *electric currents.*

It should be understood that an electric dynamo or battery does not generate electricity, for if it were only the quantity of electricity that is desired, there would be no use for machines, as the earth may be regarded as a vast reservoir of electricity, of infinite quantity. But electricity in quantity without pressure is useless, as in the case of air or water, we can get no power without pressure.

As much air or water must flow into the pump or blower at one end, as flows out at the other. So it is with the dynamo; for proof that the current is not generated in the machine, we can measure the current flowing out through one wire, and on through the other—it will be found to be precisely the same.

As in mechanics a pressure is needed to produce a current of air, so in electrical phenomena an electro-motive force is necesary to produce a current of electricity. A current in either case can not exist without a pressure to produce it.

To summarize, the dynamo-electric generator or the dynamo-electric machine, proper, consists of five principal parts, viz.:

1. *The armature or revolving portion.*

2. *The field magnets*, which produce the magnetic field in which the armature turns.

3. *The pole-pieces.*

4. *The commutator or collector.*

5. *The collecting brushes* that rest on the commutator cylinder and take off the current of electricity generated by the machine.

In brief, the purpose of the dynamo is to change *mechanical motion*, applied to the armature, revolving it at high speed, into *electrical energy*.

THE ELECTRIC MOTOR.

An electric motor is a machine for converting electrical energy into mechanical energy; in other words *it produces mechanical power when supplied with an electric current;* a certain amount of energy must be expended in driving it; the *intake* of the machine is the term used in defining the energy expended in driving it; the amount of power it delivers to the machinery is denominated *its output*.

The difference between the output and the intake is the real *efficiency* of the machine; it is well known that the total efficiency of *an electric distribution system*, which may include several machines, usually ranges from 75 to 80 per cent. at full load, and should not under ordinary circumstances fall off more than—say 5 per cent. at one-third to half load; the efficiency of motors varies with their size, while a one-horse power motor will, perhaps, have an efficiency of 60 per cent. a 100-horse power may easily have an efficiency of 90 per cent.

A dynamo, as ordinarily constructed, consists of two parts; the stationary magnet frame and the revolving part, or the armature. In Figs. 559 and 560 is illustrated a multipolar generator, that is a dynamo having more than two poles, in this case four.

The armature is generally the revolving part and to it are secured in various manners numerous loops of wire. The space occupied at the end of the magnet poles by the armature, is called *the magnetic field*. The armature revolving in this magnetic field slightly charged by the influence of the magnetism naturally retained in the iron of the magnet frame, drives its numerous conductors through the magnetic lines, and as each of these conductors, called loops, passes through this magnetic field, it gathers a little amount of electrical energy, or as it is generally explained, a slight electric current is made to flow through it and on through the commutators and brushes to wires outside of the dynamo ready for service.

The larger the number of loops the greater the electrical energy gathered by the armature. The amount of the electrical energy gathered by the armature conductors is greatest when the magnetism in the magnet is highest.

When the armature is first set in motion the electric current in it is very mild as the magnetic influence is also very slight at that time, but as soon as a mild current is produced, it is made to pass through insulated wires wound around the magnet cores, which at once strengthens the magnetism and thus in turn calls forth a greater electrical energy within the armature, which greater energy is again utilized to strengthen the influence of the magnet. In this manner by increasing the magnetic influence, the electrical energy within the armature conductors is increased up to the desired limit.

When electrical energy is supplied to a dynamo the armature will turn with great velocity and force, and thus the machine will transform electrical energy into mechanical motion. In this case the machine is called a motor.

The armature in the dynamo shown Fig. 559 is of *the drum type*; it consists of the core, upon which wires are wound, these wires being connected to the commutator, upon this commutator, the brushes are riding, which gather up the current as it is delivered to the commutator by the armature, whence it is led outside of the machine to the circuit.

The armature core is made of sheet iron discs usually about 0.002 inch in thickness. The outer discs being unsupported at the outer edge, are usually made of sheets of $\frac{1}{16}''$ thickness. Three of these at each end of the core will be enough to hold the rest of the discs from spreading.

These discs are usually made of the best charcoal iron. Between the discs a thin sheet of paper is laid. The circumference of these discs is provided with apertures of various forms, for holding the armature coils in place of which several types are shown in Figs. 561–564.

NOTE.—There are a great variety of armatures in use; *the drum armature* has been found the most popular on account of its simplicity, and comparative efficiency.

One of the types is the *ring armature*, whose efficiency is so low, that it never found very extensive favor, although it is very simple and easy to repair.

For large machines, the *multipolar armature*, is used almost exclusively; still another type, *disc armature*.

FIG. 561.

FIG. 562.

Fig. 561 shows a disc with round holes to contain the conductors. Fig. 562 shows plain slots with parallel slides. Fig. 563 is a slight modification of the preceding form. In the slots shown in Fig. 564 the conductors are held securely by means of hard-wood strips, which are driven in above them. The disc is punched out of sheet iron, a hole for the shaft and key-way being also cut out. The disc is then placed under a punching press with a revolving table for the disc, which is automatically moved a certain distance between each stroke of the press. Thus all slots are punched.

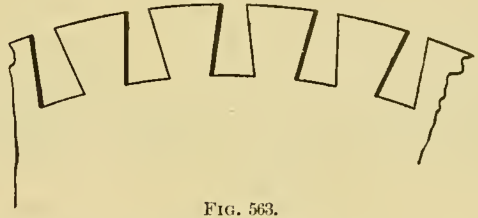


FIG. 563.

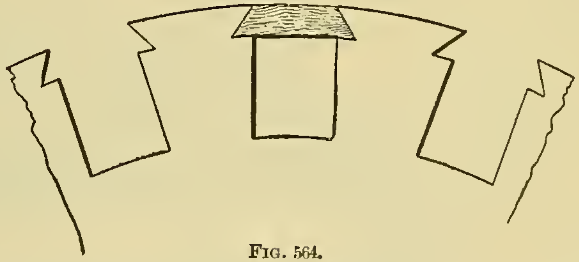


FIG. 564.

Figs. 565 and 566 show a section of the commutator as well as a partial end-view. It consists of the shell, that is the outside casting, placed directly upon the shaft. One end of the shell is provided with a circular projecting lip wedge-shaped in section, to support the segments, while the other end is provided with a thread. A ring, also wedge-shaped in section is placed on the shell near its end, for the purpose of supporting the other end of the segment, and a nut is then screwed upon the threaded end of the shell, pressing the ring toward the segments, and holding them securely. These segments are insulated from each other, as well as from the shell, by strips of mica or fibre, indicated by the heavy black lines in the illustration. The segments are made of hard copper. The prolongation of the segment at the back is called the ear or lug of the segment.

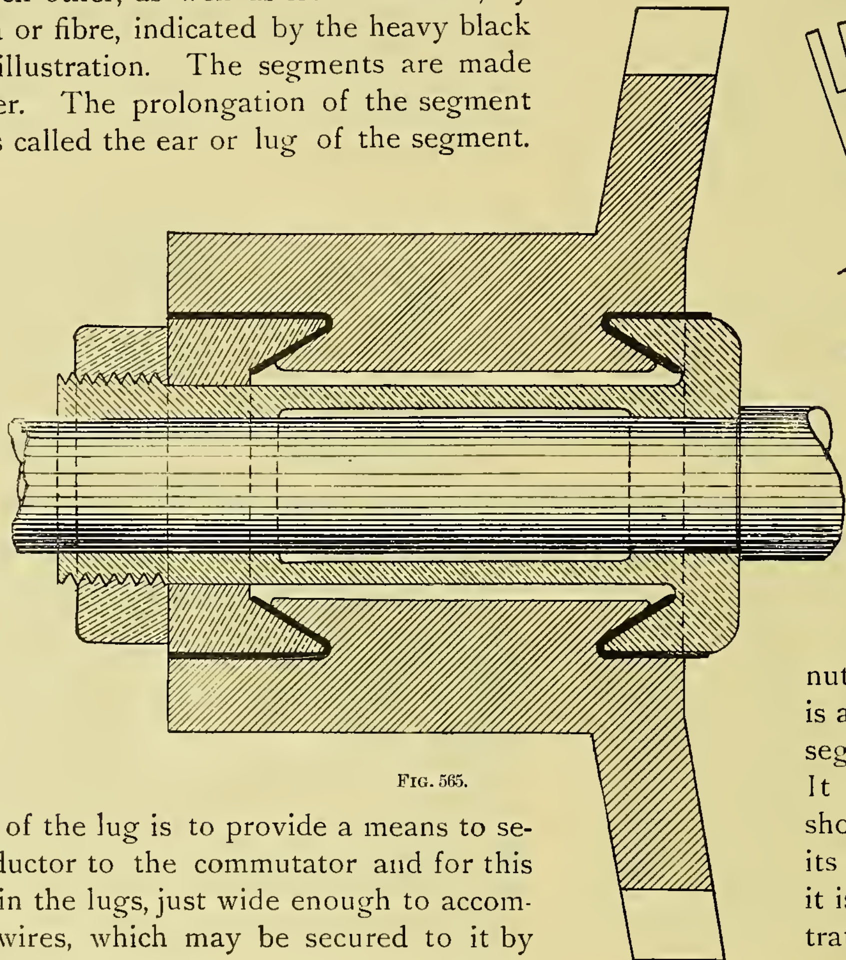


Fig. 565.

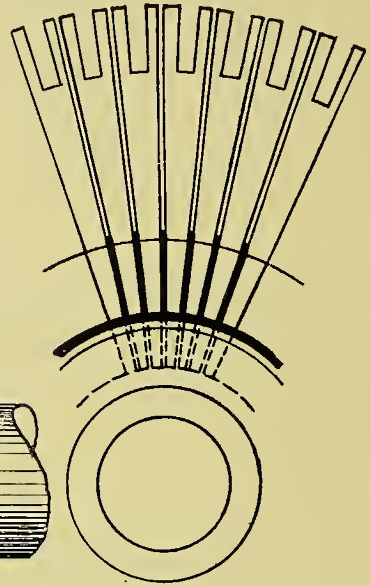


Fig. 566.

The purpose of the lug is to provide a means to secure the conductor to the commutator and for this slots are cut in the lugs, just wide enough to accommodate the wires, which may be secured to it by small screws or by soldering. The shell, ring and nut are made of bronze. Clearance is allowed between the shell and the segments to secure better insulation. It is not necessary that the shell should bear on the shaft throughout its entire length, and to save boring, it is cored out, as shown in the illustration, leaving about an inch at each end of the shell for the support.

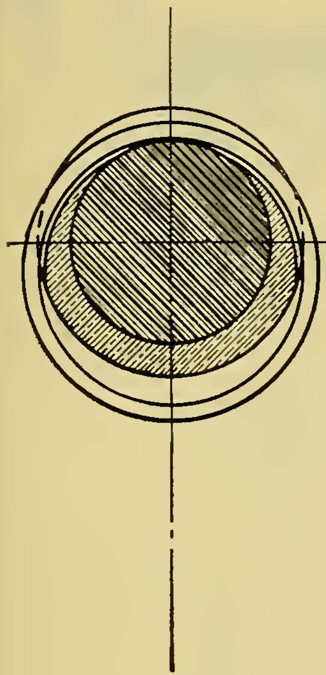


FIG. 567

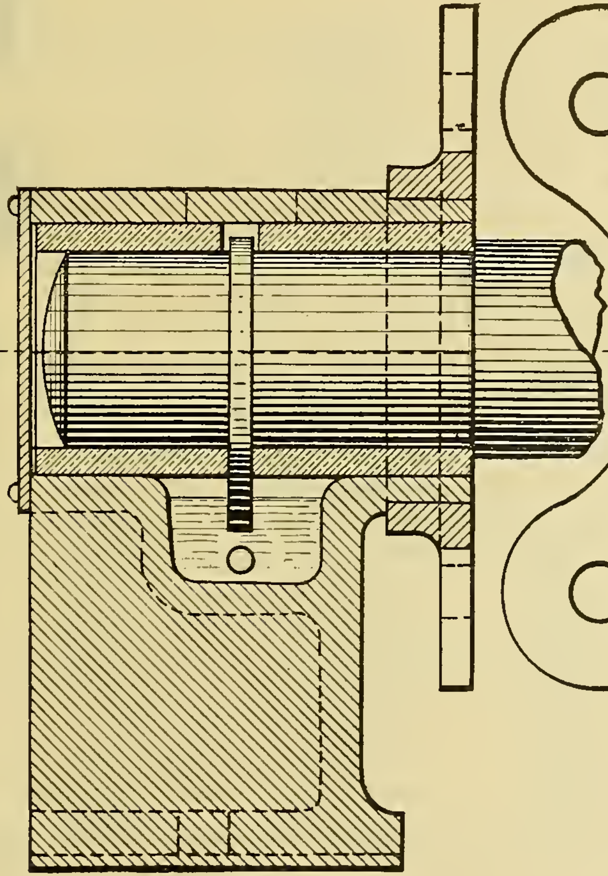


FIG. 568.

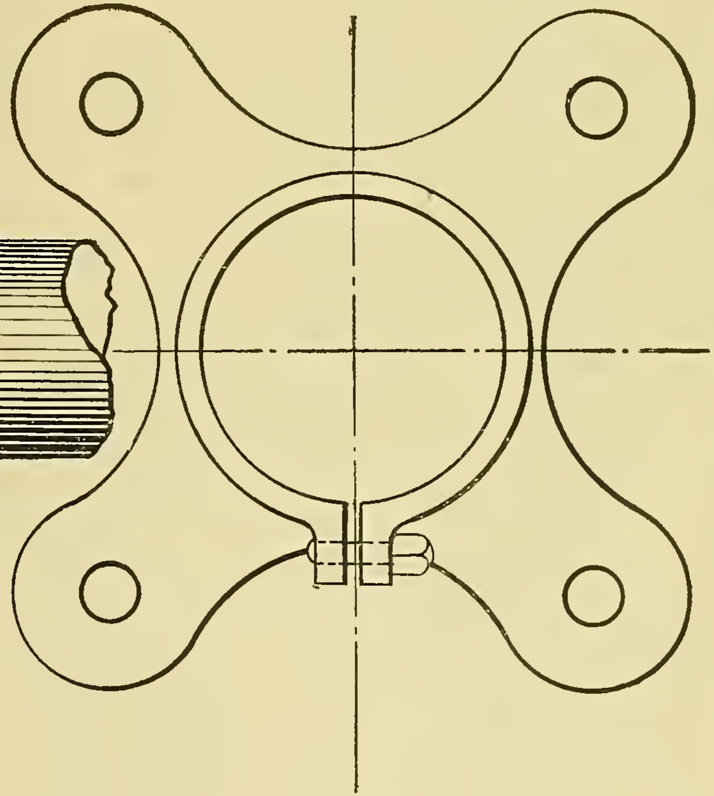


FIG. 569.

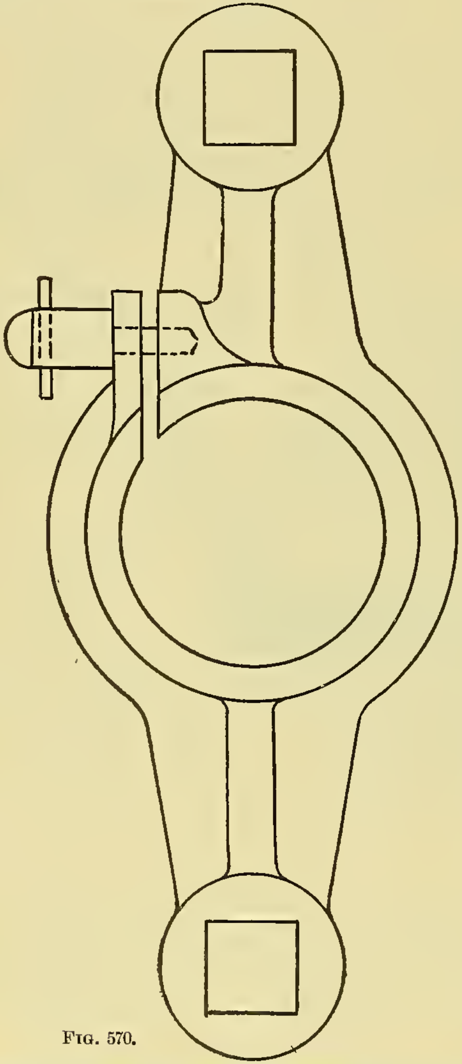


Fig. 570.

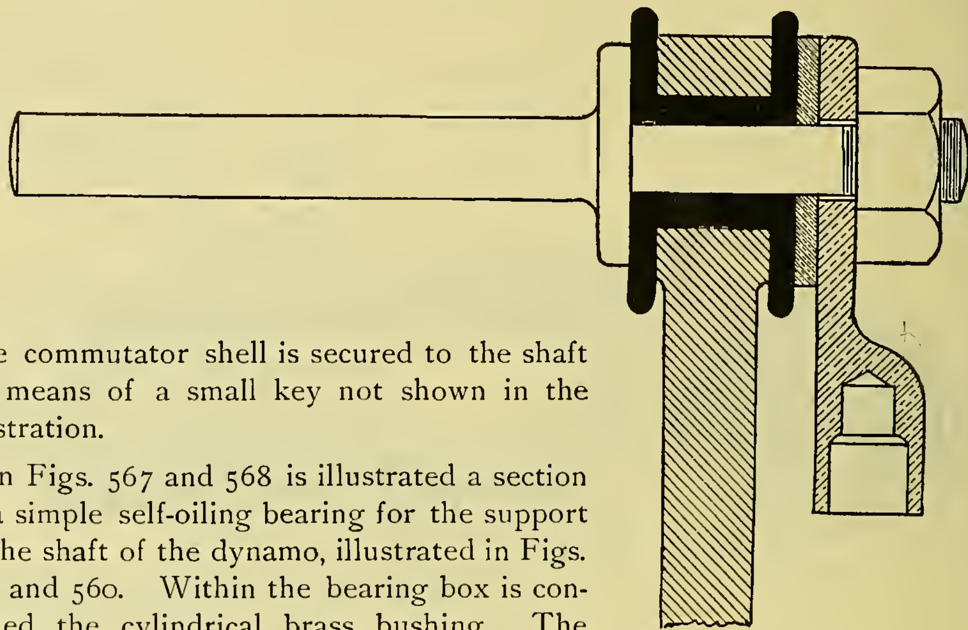


Fig. 571.

The commutator shell is secured to the shaft by means of a small key not shown in the illustration.

In Figs. 567 and 568 is illustrated a section of a simple self-oiling bearing for the support of the shaft of the dynamo, illustrated in Figs. 559 and 560. Within the bearing box is contained the cylindrical brass bushing. The upper part of the bushing is provided with a slot, and here is introduced the oil ring, which rests upon the shaft, dipping into the oil contained in the reservoir below. When the shaft is revolved, the ring takes up oil and carries it to the shaft. Larger bearings are provided with two oil rings. Provision must be made to drain off the oil and to furnish a fresh supply.

The upper part of the bearing box is often made with a large opening covered by a hinged lid for the purpose of inspection, as well as for supply of oil. A convenient addition is an oil gauge, which shows the amount of oil in the reservoir.

In the same illustration it can be seen that the rear end of the bearing box is turned to receive the brush frame, Fig. 569, which in this case is provided with four holes to receive four brushes. Another kind of brush frame, called a rocker arm, is shown in Fig. 570, made for two brushes. The holes for receiving the brush holder studs are often made square. A brush holder stud is shown in Fig. 571; it is made of brass and is circular in section. The section shown in black represents the insulating washers and insulating bushings, made of hard rubber, insulating the brush holder stud from the rocker arm. Outside on the stud is placed a brass washer and a cable lug, which is used to connect it with the main cable or leads carrying the current to the point of distribution.

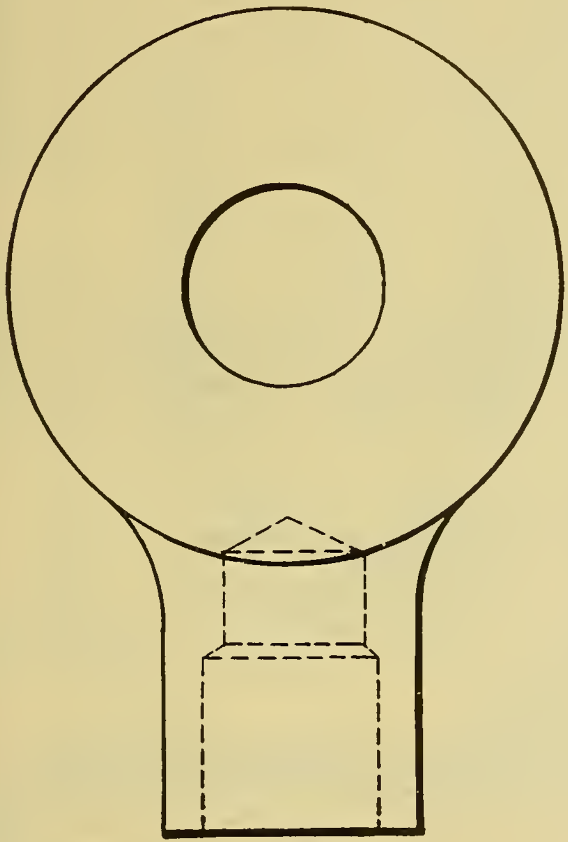


Fig. 572.

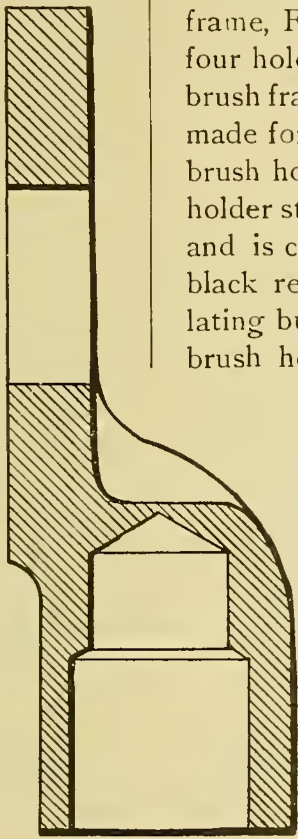


Fig. 573.

The cable lug is shown separately in Figs. 572 and 573. A form of brush holder which is rapidly becoming most popular, is shown in Fig. 574; it is called the Reaction Brush Holder. Here the brush is wedged in between the brush holder and the commutator without any support on the outer side, the pressure of the curved lever forcing the carbon brush against the inclined face of the holder as well as against the commutator. The pressure of the lever is caused by a helical spring, terminating in a straight projection, which can be set into any one of

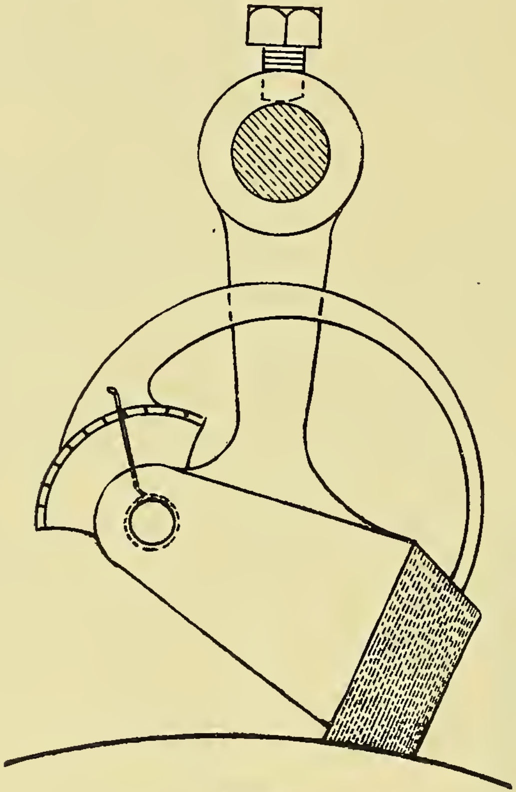


FIG. 574.

the notches on the lever, thus regulating the pressure of the lever to any desired degree.

The magnet frame may be cast in one or more parts, together with the pole pieces, or the pole pieces may be bolted to the frame. The magnet frame must be rigidly secured to the base. The bearings or pedestals may be cast in one piece with the base, or fastened to it by bolts. The magnets may be made of cast iron, wrought iron, or malleable iron, according to the requirements.

Two methods of exciting the field are shown in the diagrams in Figs. 575–576. The shunt method of excitation consists of forming a separate circuit of the magnetizing coils which are connected directly between the brushes, or in shunt, to the external circuit.

The diagram in Fig. 575 shows the manner in which shunt winding is accomplished.

Another method for excitation of the field is the series winding. Here the entire current flowing through the armature is made to flow through the magnetizing coils.

A combination of series and shunt winding, gives the compound winding, shown in the diagram, Fig. 576. This winding is very extensively used for generators, but is seldom used for motors, as either a series or a shunt winding serves for almost all conditions of operation.

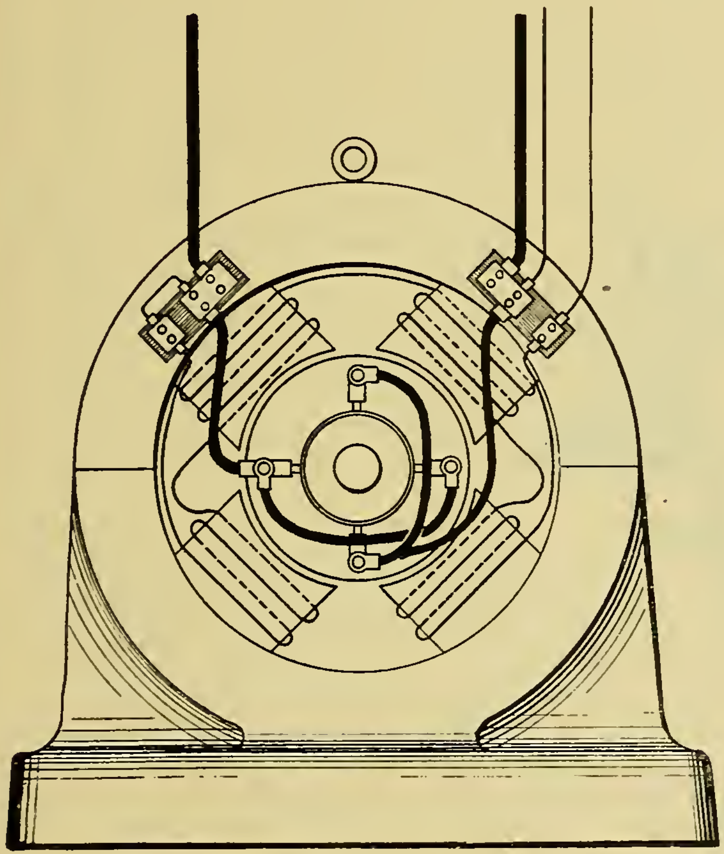


Fig. 575.

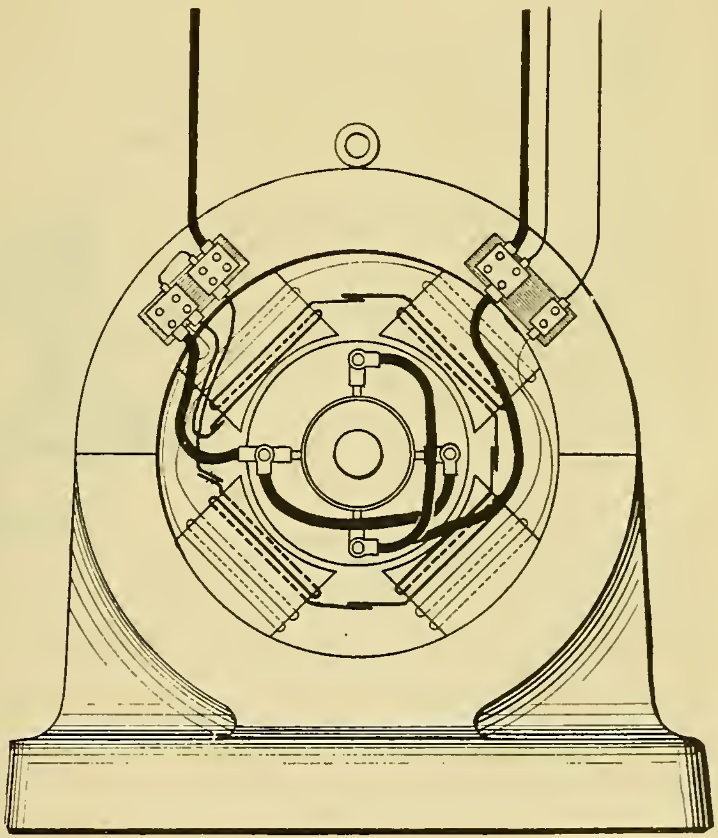


Fig. 576.

INSTRUMENTS AND METHODS OF USE.

Preceding the section of "Lettering" and beginning at page 41 much valuable matter relating to the "Drawing board, T square and triangles" may be found, with many illustrations; what follows properly belongs with the above section, but is removed to a less important part of the volume because the matter is almost too elementary; it is inserted here "lest we forget."

Good tools are necessary for a proper output of good work but it is not always the man who has the most or the better tools that does the best; a little observation also shows that every regular draughtsman has his own select tools, gathered as he has progressed in study and practice to suit his own "handy" method of work; the time comes when the draughtsman declines the employment of any but the regular instruments, relying upon his manual dexterity to execute all necessary drawings.

There is an old adage to the effect that "an ounce of showing is worth a pound of telling"; the kindly assistance of an experienced draughtsman at the beginning of one's efforts is invaluable and worth the fee that might be charged. Eugene C. Peck, M. E., has written an account of the method he employed in teaching a class of the employees of the Cleveland Twist Drill Co.; it is quoted almost in full in the note below:

NOTE.—The method employed was mapped out more with a view to teaching the employees to read drawings than to make draughtsmen of them, but at the same time so that those who cared to follow the profession in the future would be able to use all the information and practice to good advantage; no originality in plan of teaching was attempted; the class consisted of twenty pupils who had been through fractions and percentage in arithmetic; some had taken lessons previously in drawing, knew the use of different instruments and understood the ordinary geometrical problems occurring in drawing, while others were without any such previously acquired knowledge.

As very little drawing could be done in one evening in a class they were instructed to do all drawing at home. Each pupil was furnished with a blueprint of instructions such as would be needed outside of class, and also a plate (blueprint) to copy from. These plates were drawn, then blueprinted, but to a scale of about 10 inches to the foot, so that no copying by dividers could be done. The first four contain the ordinary geometrical problems, the next four projection, cylindrical and conical intersections and developments; then came the simple machine parts to teach the correct placing of views, shading, etc. From this on the plates gradually get more intricate and complicated, but in all cases are taken from our own shop drawings or a machine in the factory, and more especially is a drawing of a jig or fixture used which may have given any trouble to the machinist to read. These drawings are then made at home and left in the drawing office, where they are corrected and marked, a record of the progress of the student being kept for reference.

Later they were given a little algebra in the shape of simple formulas which, by the way, gave most of them some trouble until they got to handle the characters as though they had no value, or to treat them by the rules regardless of their value.

A short course in the practical laying out and working of gear problems came next, which gave very little trouble, as most of the students were more or less familiar with the subject.

This year's course in class closed with logarithms, and considering that I left the theory of exponents out of the question, taught them only the use of the tables and gave them rules to solve the different examples by, they handled the subject remarkably well.

COMPASSES.

Compasses are instruments for describing circles, measuring figures, etc.; Figs. 577–580 show a pair of compasses, *a pencil*, *a lengthening bar* and *a pen point*, either of which may be inserted into a socket in one leg of the instrument when a circle in pencil or in ink is to be drawn. The other leg is fitted with *a needle point* and acts as the center about which the circle is to be described.

The compasses shown in Fig. 577 have a single socket only; the leg with the needle-like point is called *a divider point;* the other leg has a stationary needle point which is placed in the center of the circle to be drawn: it will be noticed that one leg of the compasses is jointed; this is done so that *the compass points may be kept perpendicular to the paper when drawing circles.*

NOTE.—The student should learn to open and close the compasses with one hand; those provided with a cylindrical handle at the head are to be held gently between the thumb and the forefinger and those minus the handle should be held with the needle point leg resting between the thumb and fourth finger, and the other leg between the middle and forefinger. Only one hand should be used in locating the needle point at a point on the drawing about which the circle is to be drawn, unless the left hand merely serves to steady the needle point. Having placed the needle point at the desired point, and with it still resting on it, the pen or pencil may be moved in or out to any desired radius. When the lengthen ng bar is used both hands must be employed.

FIG. 577.

FIG. 578.

FIG. 579.

FIG. 580.

The joint at the head of the compasses should hold the legs firmly in any desired position and at the same time should permit their being opened and closed with one hand; the joint may be tightened or loosened by means of a screwdriver or spanner, which is furnished with the instru-

NOTE.—The needle point itself, in all good instruments, is a separate piece of round steel wire, placed in a socket provided at the end of the leg. The wire, as a rule, has a shoulder at its lower end, below which a fine, needle-like point projects.

FIG. 581.

ment; compasses should not be used for circles of too large a radius, not allowing the points to be placed at a right angle with the paper. *A lengthening bar*, Fig. 580, is used to extend the leg carrying the pen or pencil points, as the case may be, when circles of a large radius are to be described.

Circles should be drawn with a continuous motion, with an even, slight pressure on the pen; when inking in a circle it is well to stop exactly at the end of a single revolution, as the line may become uneven when going over it a second time; when closed, the needle point and the pen or pencil point are to be set in such a manner as to be even.

DIVIDERS.

Dividers are used for laying off distances upon a drawing, or for dividing straight lines or circles into parts; an instrument of this kind is shown in Fig. 581; the points should be thin and sharp, so that they will not puncture holes in the paper larger than is absolutely necessary; when using the dividers to space a line or circle into a number of equal parts, they should be held at the top between the thumb and finger, as when using compasses; to mark off the spaces, the instrument should be turned alternately to the right and left.

The divider shown in Fig. 581 is provided with *a hair spring attachment*, which enables the user to make quite *fine adjustments;* in this case one leg is made separate from the main body of the instrument with its upper end terminating in a spring, which tends to bring one leg toward the other.

The legs of dividers, as well as those of compasses, are made triangular in section, except near the point, where the corners are ground off sufficiently to make a round point.

If the point should be left triangular, the holes punctured into the paper, would be bored out to such an extent, while turning the instrument, that accurate measurements would be impossible.

It being essential that the points of dividers be kept in good condition, they should never be used for anything else, except the purpose they are made for. The joint at the head of the dividers should be kept not too tight, for unless there is a hair-spring attachment, as described above, it will be difficult to adjust the dividers accurately, owing to the spring in the legs. Lost motion in the head joint is also a very objectionable feature, and should be attended to as soon as detected.

BOW PENCIL AND BOW PEN.

A *bow pencil* and a *bow pen* are shown in Figs. 583 and 584; these instruments are made for describing small

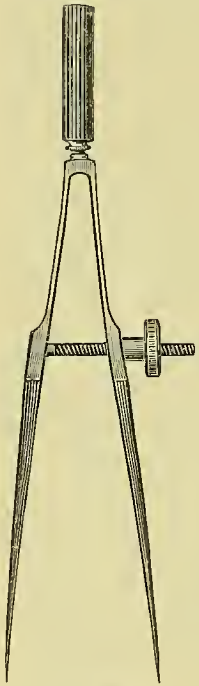


FIG. 582.

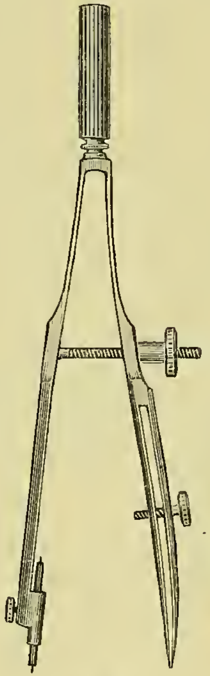


FIG. 583.

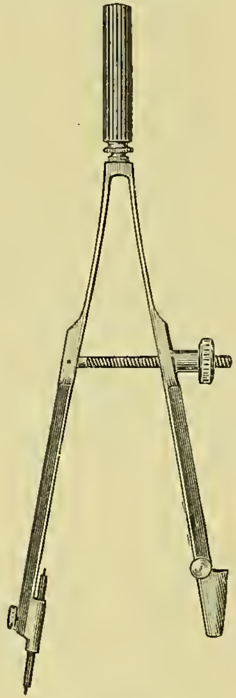


FIG. 584.

circles. The two points should be adjusted evenly, that is they should be of the same length, otherwise, very small circles cannot be described. To open or close either of the above mentioned instruments, support it in a vertical position by resting the needle point on the paper, and pressing slightly at the top with the forefinger of one hand, and turn the adjusting screw or nut with the thumb of the same hand. *Bow dividers* for measuring very small distances are also largely in use, see Fig. 582.


FIG. 585.


FIG. 586.

DRAWING PENS.

For drawing ink lines other than arcs and circles, the *drawing pen* or *ruling pen*, is used, Figs. 585 and 586; these consist of two thin steel blades, attached to a handle made of wood, ivory or light metal; the points are made of two steel blades which open and close, as required for thickness of lines, by a regulating thumb-screw.

When using the ruling pen it should be held as nearly perpendicular as possible, the hand bearing slightly on the tee square or the triangle against which the line is drawn. The pen must not be pressed against the edge of the tee square or triangle as the blades will then close together, thus making the line uneven. The edge should only serve as a guide; the pen should be held with the thumb--screw on the outside.

BEAM COMPASSES.

For describing very large circles *beam compasses* are used; these compasses are shown in Fig. 587, with a portion of the wooden rod or beam on which they are used.

At A, Fig. 587, is shown a section of the beam, which has the shape of a letter T. This form has considerable strength and rigidity. Beam compasses, as shown in Fig. 587, are provided with extra points for pencil or ink work. While the general adjustment is effected by means of the clamp against the wood, minute variations are made by the screw B, shifting one of the points.

NOTE.—A good drawing pen should be made of properly tempered steel, neither too soft nor hardened to brittleness The nibs should be accurately set, both of the same length, and both equally firm when in contact with the drawing paper. The points should be so shaped that they are fine enough to admit absolute control of the contact of the pen in starting and ending lines, but otherwise as broad and rounded as possible, in order to hold a convenient quantity of ink without dropping it. The lower (under) blade should be sufficiently firm to prevent the closing of the blades of the pen, when using the pen against a straight-edge. The spring of the pen which separates the two blades should be strong enough to hold the upper blade in position, but not so strong that it will interfere with easy adjustment of the thumb-screw; the thread of the thumb-screw should be deeply and evenly cut so as not to strip.

This instrument is quite delicate, and, when in good order, is very accurate. It should be used only for fine work on paper, and never for scribing in metal.

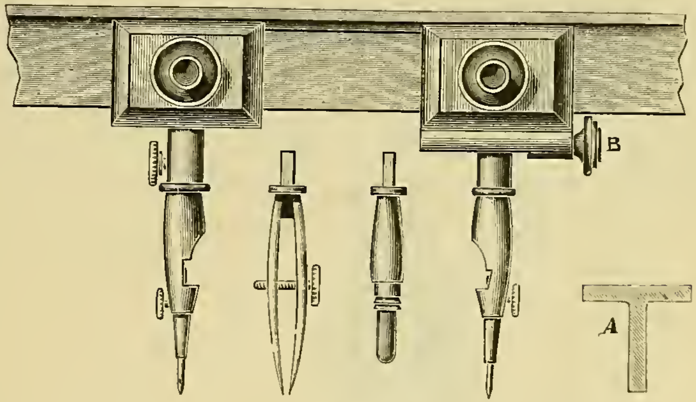


FIG. 587.

DRAWING INK.

Liquid *India ink* can be procured in bottles with glass tube feeders, as in Figs. 588 and 589, or with a quill attached to the cork, by means of which the pen may be filled by drawing it through the blades; a common writing pen may also be used for filling the pen in the same manner as described for the glass feeder or quill.

Dry ink of good quality however in sticks, Figs. 590–593, cannot be surpassed, although it requires skill in its preparation. In case the stick ink is used put enough clean, filtered or distilled water in a shallow dish or "tile" for making enough ink for the drawing in hand; place one end of the stick in the water, and grind by giving the stick a circular motion. *Do not bear hard upon the stick.* Test the ink occasionally to see whether it is black. Draw a fine line with a pen and hold the paper in a strong light. If it shows brown or gray grind a while longer and test again. Keep grinding until a fine

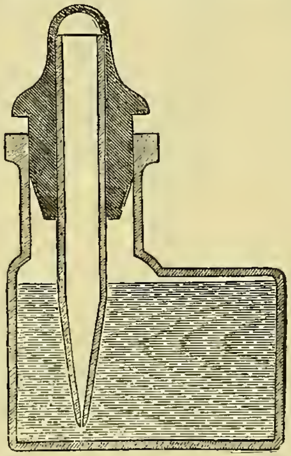


FIG. 588.

line shows black; the time required to obtain the desired result depends entirely on the amount of water used. The ink should be kept free of dust and prevented from evaporating by covering it with a flat plate of some kind.

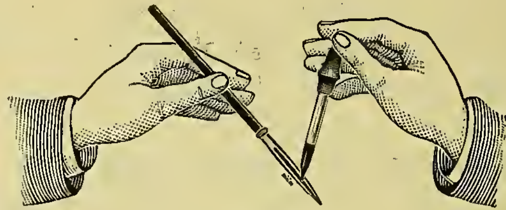


FIG. 589.

FIGS. 590-593.

NOTE.—If stick ink is used it is very good policy to buy a stick of the very best quality, costing, say about a dollar, as, perhaps, it will last longer than several dollars' worth of liquid ink. The only reason for using liquid ink is that all lines are then sure to be of the same blackness, and time is saved in grinding.

When trouble is caused by the ink drying between the blades and refusing to flow, especially when drawing fine lines, the only remedy is to wipe out the pen with a cloth. Do not lay the pen down for any great length of time when it contains ink; wipe it out first. The ink may sometimes be started by moistening the end of the finger and touching it to the point of the pen, or by drawing a slip of paper between the ends of the blades.

Before using the pen it is well to try it first on a piece of paper to make sure that it will produce lines of the required thickness; the border of the sheet of paper on the drawing board may be used for this purpose, according to long established custom.

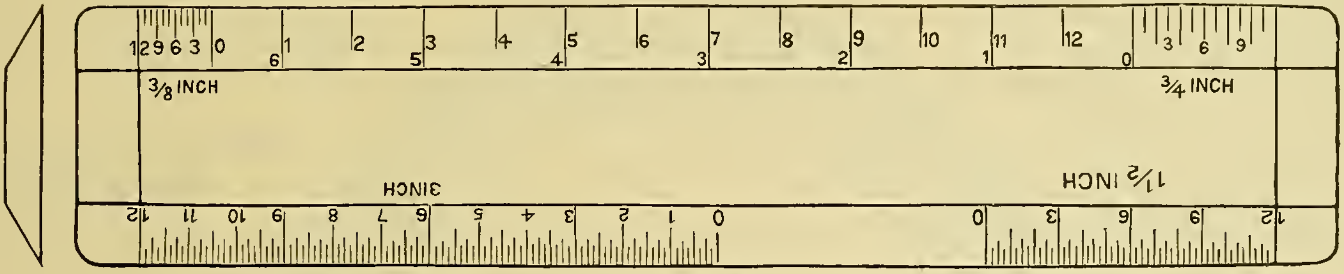


FIG. 594.

RULES AND SCALES.

The rule is used for measuring and comparing dimensions; they are divided in inches, halves, quarters, eighths, sixteenths, and thirty-seconds.

For some purposes the *rules* as explained above cannot be used, as *i. e.*, for making drawings smaller or larger than the actual size of the object to be drawn. *Scales* are then employed as shown in Figs. 594 and 595.

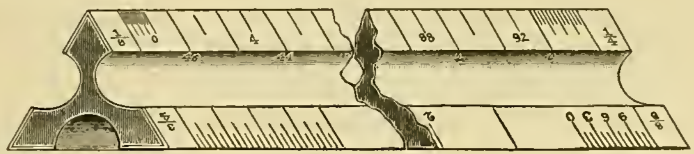


FIG. 595.

The most convenient forms are the usual flat or triangular boxwood scales, having beveled edges, each of which is graduated for a distance of twelve (12) inches. These beveled edges serve to bring the lines of division close to the paper when the scale is flat, so that the drawing may be accurately measured, or distances laid off correctly.

A very convenient form of scales is shown in Fig. 595. It represents a *triangular scale* (*broken*). It reads on its different edges as follows:

(a) 3 inches and 1½ inches to one foot, 1 inch and ½ inch to one foot, (b) ¾ inch and ⅜ inch to one foot, ¼ inch and ⅛ inch to one foot and (c) one edge reads sixteenths the whole 12 inches of its length.

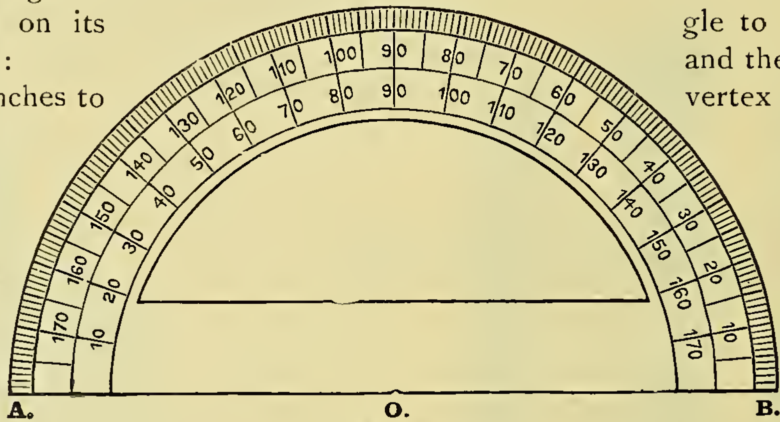


FIG. 596.

PROTRACTOR.

A protractor is shown in Fig. 596; it is an instrument for laying off or measuring angles on paper, or for dividing a circle into an equal number of parts; it is also used in connection with a scale to define the inclination of one line to another.

The outer edge of the protractor is a semicircle, with center at O and, for convenience, is divided into 180 equal parts or degrees from A to B and from B to A. Protractors are often made of metal, in which case the central part is cut away to allow the drawing under it to be seen.

When using the protractor it must be placed so that the line O B, Fig. 596, will coincide with the line forming one side of the angle to be laid off or measured, and the center O must be at the vertex of the angle.

IRREGULAR CURVES AND SWEEPS.

Curves are irregular lines; a circle is a regular line. Curves other than arcs of circles are drawn with the pencil or ruling pen by means of curved or irregular-shaped rulers, called *irregular curves or sweeps*, Figs. 597–608. These are made of various materials, wood, hard rubber or celluloid, in a great variety of shapes. A certain number of points

NOTE.—A whole circle contains 360 degrees, a right angle contains 90 degrees and therefore as many as a ¼ of a circle. A 45 degree angle contains as many degrees as ⅛ of a circle.

Figs. 597 to 608.

is first determined through which the line is to pass, and said line should be first sketched in lightly, free-hand. The irregular curve is then applied to the curved line so as to embrace as many points as possible; only the central points of those thus embraced should be inked in; this process is continued until the desired curve is completed.

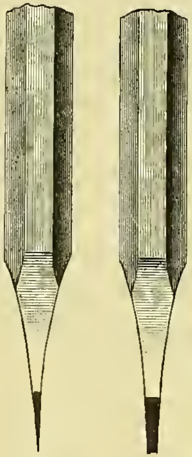


Fig. 609. Fig. 610.

It is very difficult to draw a smooth continuous curve. In order to avoid making the line curve out too much between the points or to cause it to change its direction abruptly where the different points join, the irregular curve should be fitted so as to pass through three points at least, and, when moving it to a new position, by setting it so that it will coincide with part of the line already drawn. When neatly penciled over, after having been sketched in free-hand, little difficulty will be experienced to ink it, the pencil line showing the direction in which the curve is to be drawn.

When inking with the irregular curve, *the blades* of the pen should be kept against it and the thumb-screw on the outside; the inside flat surface of the blades must have the same direction as the curve at the point where the pen touches the paper. It will be readily understood therefore that the direction of the pen must be continually changed.

PENCILS.

Drawings are generally made in *pencil* and then inked. A *hard pencil* is best for mechanical drawing. The pencil should be sharpened as shown in Figs. 609 and 610. Cut the wood away, about ¼ or ⅜ of an inch of the lead projecting; then sharpen it flat by rubbing it against a fine file or a piece of fine emery cloth or sandpaper that has been fastened to a flat stick. Grind it wedge-shaped as shown in the figure. If sharpened to a round point, the point will wear off quickly and make broad lines, thus making it very difficult to draw a line exactly through a point. The pencil for the compasses should be sharpened in the same manner but should have a narrower width.

The pencil line should be made as light as possible; pressing the pencil too hard will often cut the paper or leave a deep mark which cannot be erased. The presence of too much lead on the surface of the paper tends to prevent the ink passing to the paper and in rubbing out pencil lines the ink is reduced in blackness and the surface of the paper is roughened, which is a disadvantage. As little erasing or rubbing out as possible should be done.

Lines are drawn with the flat side of the lead pressed lightly against the straight-edge, as close to it as possible, the pencil being held almost vertically.

DRAWING PAPER.

The first thing to be considered in selecting *drawing paper* is the kind most suitable for the proposed plan. The qualities that constitute good paper are strength, uniformity of thickness and surface, neither repelling nor absorbing liquids, admitting of considerable erasing without destroying the surfaces, not becoming brittle nor discolored by reasonable exposure or age, and not buckling when stretched or when ink or color is applied.

The sizes and names of commercial drawing paper made *in sheets* is as follows :

Cap	13x17	ins.
Demy	15x20	"
Medium	17x22	"
Royal	19x24	"
Super Royal	19x27	"
Imperial	22x30	"
Atlas	26x34	"
Double Elephant	27x40	"
Antiquarian	30x53	"

For large drawings paper is made *in rolls*. "Detail paper" is especially made for marking out new designs ; it is made in rolls 36, 42, 44, 48 and 54 inches wide ; the size of detail drawings for shop use, of course, are dependent upon the type of the drawing, the size of the parts detailed and the scale to which they are drawn ; the following sizes are good average ones as they can be cut very economically from the rolls sold in print shops : 6 x 9, 9 x 12, 12 x 18, 18 x 24, 24 x 36, 36 x 48 and 48 x 72 inches.

PREPARING FOR WORK.

The paper is first secured to the drawing board by means of *thumb tacks*, one at each corner of the sheet. It should be stretched flat and smooth ; to obtain this result proceed as follows : press a thumb-tack through one of the corners about ½ inch or ¼ inch from the edge. Place the tee square in position

NOTE.—*Border lines* such as are used throughout the pages of this book are frequently of considerable service to the draughtsman but they must be used with a sense of "the fitness of things." Thus: border lines are out of place in working drawings, etc., but where a set of drawings are to be inspected and important contracts decided upon by non-technical business men or capitalists, a neat border line is often the one thing that attracts attention, to the advantage of the exhibitor of the plans and specifications used in the competition bids. The Patent Office rules also call for a border line. The size of the sheet of pure white paper on which a drawing is made must be exactly 10 x 15 inches. One inch from its edge a single marginal line is to be drawn leaving "the sight" precisely 8 x 13 inches.

as in drawing a horizontal line, and straighten the paper so that its upper edge will be parallel to the edge of the tee square blade. Pull the corner diagonally opposite that in which the thumb-tack was placed, so as to stretch the paper slightly and push in another thumb-tack. Proceed in the same manner for the remaining two corners.

The thumb-tacks or drawing-pins should have a head as thin as possible without cutting at its edges, slightly concave on the under side next to the paper, and should be only so much convex on its upper side as will give it sufficient thickness to enable the pin to be secured to it; it is better to use four or more small pins along the edge of a sheet of paper than use one much larger pin at each corner.

For particular work it is necessary to stretch the paper while it is damp. For stretching the paper in this way moisten the whole sheet on the under side, with the exception of a margin all around the sheet, of about half an inch and paste the dry border to the drawing board. To do this properly requires a certain amount of skill, and paper thus stretched gives undoubtedly a smoother surface than can be obtained when using thumb-tacks, but there are objections to this process as the paper stretched in this way is under a certain strain and may have some effect on the various dimensions of the drawing, when cut off the board.

Once the drawing completed, cut the paper from the board with a knife, by following the lines previously drawn all around the sheet for trimming. Make a continuous cut all around; if one of the longer sides is cut first and then the opposite side there is danger of tearing the paper when cutting the remaining sides.

PENCILING.

The pencil drawing should look as nearly like the ink drawing as possible. A good draughtsman leaves his work in such a state that any competent person can without difficulty ink in what he has drawn.

The pencil should always be *drawn, not pushed.* Lines are generally drawn from left to right and from the bottom to the top or upwards. Pencil lines should not be any longer than the proposed ink lines. By keeping a drawing in a neat, clean condition when penciling, the use of the rubber upon the finished inked drawing will be greatly diminished.

INKING.

A drawing should be *inked in* only after the penciling is entirely completed. Always begin at the top of the paper, first inking in all small circles and curves, then the larger circles and curves, next all horizontal lines, commencing again at the top of the drawing and working downward. Then ink in all vertical lines, starting on the left and moving toward the right; finally draw all oblique lines.

Irregular curves, small circles and arcs are inked in first, because it is easier to draw a straight line up to a curve than it is to take a curve up to a straight line.

DRAWING TO SCALE.

The meaning of this is, that the drawing when done bears a definite proportion to the full size of the particular part, or, in other words, is precisely the same as it would appear if viewed through a diminishing glass.

When it is required to make a drawing to a reduced scale, that is, of a smaller size than the actual size of the object, say for instance, ½ full size, every dimension of the object in the drawing must be one-half the actual size; in this case one inch on the object would be represented by ½ inch. Such a reduced drawing could be made with an ordinary rule, this, however, would require every size of the object to be divided by the proportion of the scale, which would entail a very great loss of time in calculations. This can be avoided by simply dividing the rule itself by 2, from the beginning. Such a rule, or *scale* as it is generally called, will be divided in ½ inches, each half inch representing one full inch divided into ½, ¼, ⅛, $\frac{1}{16}$, each of these representing the same proportions of the actual sizes of the object to be drawn. From this contracted scale the dimensions and measurements are laid off on the drawing.

A quarter size scale is made by taking three inches to represent one foot. Each of the three inches will be divided into 12 parts representing inches, each one of these again will be divided in ½, ⅛, $\frac{1}{16}$, etc.; each one of these representing to a quarter size scale the actual sizes of ½, ¼, ⅛, $\frac{1}{16}$ of an inch.

It must be mentioned that in several instances, in this work, distances in one figure are said to be equal to corresponding distances in the same object in another view, while by actual measurement they are somewhat different; this is owing to the use of different scales—each scale separate should be marked on the drawing.

Paper scales for large drawings are extremely useful and remarkably accurate. The advantage they possess over other kinds is that they expand and contract equally with the drawing paper during the various changes of the weather.

The nickel-plated sheet-metal steel scale which has two graduated edges conduces to most accurate work; this instrument having only two scales the annoyance experienced of frequently turning it, is greatly reduced.

A flat boxwood scale with beveled edges has less pitch on its side and for that reason can be more quickly and easily read than others.

SELECTION OF INSTRUMENTS.

The choice of drawing tools is one of the most difficult points to settle that can present itself. Success or failure may hang upon the getting the most suitable tools, hence it is well to follow the advice of some professional draughtsman, and in buying, procure such tools as are immediately needed and to add others as occasion demands.

The best quality of instruments last longer and in the end are the cheapest. German silver is the best metal used, much better than brass; the use of pocket or folding instruments is to be avoided; if it is necessary to carry the instruments nothing is better than to fold them up in a piece of chamois leather, or to have a little satchel or grip which will also accommodate the triangles, ink, colors, etc.

Louis Rouillon, B. S., Instructor of Drawing in Pratt Institute, New York, recommends the following set of tools for the beginner ;

Compasses, 5½ inches, with needle point; pen, pencil and lengthening bar.

Drawing pen, 4½ inches.

T square, 24-inch blade.

45-degree triangle, 9 inches.

30 and 60-degree triangle, 9 inches.

1 Scroll.

Dixon's V. H. pencil.

12-inch boxwood scale, flat, graduated 1-16 inch the entire length.

Bottle of liquid India ink, four thumb-tacks, pen and ink eraser.

20 sheets drawing paper, 11 × 15 inches, and a drawing-board about 16 × 23 inches will also be necessary.

Henry Raabe, M. E., is entitled to credit for the following list of instruments :

1 Pair of compasses, with pencil, pen, needle point, and lengthening bar; 1 Pair of dividers; 1 Drawing pen; 1 Bow pen; 1 Bow pencil; 1 Bow dividers; 1 45-degree triangle; 1 60-degree by 30-degree triangle; 1 Tee square; 1 Drawing board; 1 Protractor; 1 Scale from 1″ to the foot to ¼″ to the foot; 1 Scale from 3″ to the foot to ⅜″ to the foot; 1 Pencil rubber; 1 Ink eraser; 1 Pen holder with pens; 1 Pencil holder for short pencils; Compass pencils; Pencils from 6 H. to 3 H. (drawing pencils); Pencil pointer; Drawing ink; Sketch pads; Sketch pencils (soft); Thumb tacks, paper and tracing cloth.

PRACTICAL RULES AND USEFUL DATA.

For mental drill there is nothing better than the solution of mathematical problems. It is not necessary that these problems be intricate and in the higher branches, but only *not so easy* as to be readily understood without active and sustained brain work.

Accuracy, first of all, rapidity and a familiarity with the elements of numbers and their application to the problems immediately surrounding one,—these are the foundations of many successful lives ; to most minds the study of mathematics is dry and uninteresting ; to make the subject acceptable it must be presented in such a form as to immediately appeal to the student as of great practical value. This value is proven when applications are made to problems that confront the draughtsman and engineer in his daily routine. There is no more interesting subject for one who is disposed to study than that of useful numbers. It literally opens a new world to the student. It gives him his first idea of what it means to really *prove* anything, for the demonstrations of figures and geometry prove absolutely and completely the propositions with which they deal.

"In the wide expanse of mathematics it has been a task of the utmost difficulty for the author to lay out a road that would not too soon weary or discourage the student; if he had his wish he would gladly advance step by step with his pupil, and much better explain, by word and gesture and emphasis. the great principles which underlie the operations of mechanics ; to do this would be impossible, so he writes his admonition in two short words: In case of obstacles, 'GO ON.' If some rule or process seems too hard to learn, go around the difficulty, always advancing, and, in time, *return and conquer.*"

The foregoing paragraphs are simply to emphasize a few words explaining the value of the tables which are printed in the following pages; tables of the results of mathematical calculations are of immense economy in time, in guaranteeing accuracy and the saving of much drudgery

To thoroughly understand the easy and helpful use of the tables which follow should be the pleasant task of the student ; *the value of a teacher or instructor at this point cannot be over estimated;* men are not made to do their work alone, to help and to be helped is the universal law; when assistance is to be had whether it is for pay or favor the student should avail himself of it with many thanks.

ELEMENTS OF ALGEBRA.

Algebra is a mathematical science which teaches the art of making calculations by letters and signs instead of figures.

The name comes from two Arabic words, *algabron*, reduction of parts to a whole.

The letters and signs are called *Symbols.*

Quantities in algebra are expressed by *letters*, or by a combination of *letters* and *figures*; as a, b, c, $2x$, $3y$, $5z$, etc.

The first letters of the alphabet are used to express *known* quantities; the last letters, those which are *unknown*.

The *Letters* employed have no fixed numerical value of themselves. *Any* letter may represent any number, and the same letter may represent *different* numbers, but in each sum the same letter must always stand for the same amount.

The operations to be performed are expressed by the same signs as in Arithmetic; thus + means Addition, — expresses Subtraction, and × stands for Multiplication.

Thus $a+b$ denotes the sum of a and b and is read a plus b; $a-b$ means a less b; and $a \times b$ shows that a and b are to be multiplied together.

Multiplication is also denoted by a period between the factors as $a.b$. But the *multiplication of letters* is more commonly expressed by writing them together, the signs being omitted.

EXAMPLE: $7\,abc$ is the same as $7 \times a \times b \times c$.

The sign of Division is ÷, thus $a \div b$ is read a divided by b; but this is also expressed $\frac{a}{b}$; the sign of Equality is two short horizontal lines as $a=b$ and is read a equals b.

The *Parenthesis* ( ) or *Vinculum* ——, indicates that the included quantities are taken *collectively* or as one quantity.

EXAMPLE: $3\,(a+b)$ and $3\overline{a+b}$ each denote that the sum of a and b is multiplied by 3.

The character ∴ denotes *hence, therefore.*

A *Coefficient* is a number or letter prefixed to a quantity, to show *how many times* the quantity is to be taken. Hence a coefficient is a *multiplier* or *factor;* thus in $5a$, 5 is a numeral coefficient of a.

When no numeral coefficient is expressed, 1 is always understood. Thus xy means $1xy$.

DEFINITIONS.

An *Algebraic Operation* is combining quantities according to the principles of algebra.

A *Theorem* is a statement of a principle to be proved.

A *Problem* is something proposed to be done, as a question to be solved.

The *Expression of Equality* between two quantities is called an *Equation.*

An *Algebraic Expression* is any quantity expressed in algebraic language, as $3a$, $5a - 7a$, etc.

The *Terms* of an algebraic expression are those parts which are connected by the signs + and —.

Thus in $a+b$ there are two terms; in x, y and $z-a$ there are three.

A *Positive Quantity* is one that is to be *added* and has the sign + prefixed to it, as $4a+3b$.

A *Negative Quantity* is one that is to be *subtracted* and has the sign — prefixed to it, as $4a - 3b$.

A *Simple Quantity* is a single letter, or several letters written together without the sign + or —, as a, ab, $3\times y$.

A *Compound Quantity* is two or more simple quantities connected by the sign + or —, as $3a+4b$, $2x - y$.

The *Axioms* in algebra are self-evident truths as exemplified on pages 85 and 86.

ADVANTAGES OF ALGEBRA.

In algebra numbers are expressed by the letters of the alphabet; the advantage of the substitution is that we are enabled to pursue our investigations without being embarrassed by the necessity of performing arithmetical operations at every step.

Thus, if a given number be represented by the letter a, we know that $2a$ will represent twice that number, and $\frac{1}{2}a$ the half of that number, whatever the value of a may be. In like manner if a be taken from a there will be nothing left and this result will equally hold whether a be 5, or 7, or 1000, or any other number whatever.

By the aid of algebra, therefore, we are enabled to analyze and determine *the abstract properties of numbers*, and we are also enabled to resolve many questions that by simple arithmetic would either be difficult or impossible.

A draughtsman or engineer has but little practical use for a too extended acquaintance with algebra, as nearly all the algebraic rules have been transferred to ordinary arithmetical computation, but as the algebraic system is so inwoven into the school and college course of instruction it is well for every one to know something of the elements of the science.

Arithmeticians for very many years have made a study of the use of *formulæ* (this is *Latin* for the word forms) in stating problems and rules; these forms are nearly all expressed in algebraic terms, The advantage to be derived from the use of these is that it puts into a short space what otherwise might necessitate the use of a long verbal or written explanation.

Another advantage is that the memory retains the *form* of the expression much easier and longer than the longer method of expression, and it may be remarked that those who once become accustomed to the use of formulæ seldom abandon their employment.

EXAMPLES EXPLAINING THE SOLVNG OF FORMULÆ

1. If $x = a + b - c + d - f$; what must be the value of x when $a = 10$, $b = 7$, $c = 9$, $d = 4$, and $f = 6$?

First substitute the figures for the letters, thus:—
$x = 10 + 7 - 9 + 4 - 6$, then proceed as in the Arithmetical part.

$x = 21 - 15 = 6$ Answer.

2. If $x = 4g + 2m - 7n - p + 3q$; find the value of x when $g = 5$; $m = 3$; $n = 6$; $p = 1$; and $q = 8$.

Here $4g = 4$ times $5 = 20$; $2m =$ twice $3 = 6$; $7n = 7$ times $6 = 42$; and $3q = 3$ times $8 = 24$;

Hence, $x = 20 + 6 - 42 - 1 + 24$
$= 50 - 43$
$= 7$ Answer.

3. If $x = \frac{1}{2}a - \frac{1}{4}d + \frac{1}{5}c - \frac{3}{4}f$; find the value of x when $a = 10$; $d = 24$; $c = 25$; and $f = 12$.

As $a = 10$, then $\frac{1}{2}a = 5$; as $d = 24$, then $\frac{1}{4}d = 6$; as $c = 25$, then $\frac{1}{5}c = 5$; and as $f = 12$, then $\frac{3}{4}f = 9$.

Hence, $x = 5 - 6 + 5 - 9$.
$= 10 - 15$.
$= -5$ Answer.

4. If $x = c - (\frac{s}{2} - p)$; find the value of x when $c = 8$.
$s = 3\frac{1}{2}$ and $p = 1\frac{1}{2}$
$x = 8 - (\frac{3\frac{1}{2}}{2} - 1\frac{1}{2})$; here $3\frac{1}{2}$ is divided by $2 = 1\frac{3}{4}$.
$= 8 - (1\frac{3}{4} - 1\frac{1}{2})$
$= 8 - \frac{1}{4}$
$= 7\frac{3}{4}$ Answer.

5. $x = ab + cd - ef$; where $a = 2$, $b = 3$, $c = 4$, $d = 5$, $e = 6$, and $f = 7$.
$x = 2 \times 3 + 4 \times 5 - 6 \times 7$
$= 6 + 20 - 42$
$= 26 - 42$
$= -16$ Answer.

6. Then if $x = \frac{AB}{D - C}$; what is the value of x when $A = 6$; $B = 7$; $C = 10$; and $D = 16$?

$$x = \frac{6 \times 7}{16 - 10} = \frac{42}{6} = 7 \text{ Answer.}$$

LOGARITHMS.

This word is composed of two Greek nouns' meaning *reason* and *number;* a logarithm is an *artificial number* so related to the natural numbers that the multiplication and division of the latter may be performed by addition and subtraction and by their use the much more difficult operations of *raising to powers and the extraction of roots* are effected by easy cases of multiplication and division.

The early computers of logarithms carried them to ten places of decimals, but it was soon found that five and seven places were sufficient for most purposes; those given in this book are carried to six places. Naperian logarithms are called *natural* and also *Hyperbolic* logarithms; common logarithms are called the *decimal,* and also the Briggsian System.

In the Table, letter N over the first column stands for "number"; after 100 (see page 436) the numbers at the top of the columns express the tenth parts of N.

NOTE.—Logarithms were invented and a table published in 1614 by John Napier, of Scotland; but the kind now chiefly in use were proposed by his contemporary Henry Briggs, of London. The first extended table of common logarithms were calculated by Adrian Vlacq in 1628, and have been the basis of every one since published; when logarithms are spoken of without any qualifications common logarithms are to be understood. The labor of the operation incurred in the ordinary processes of arithmetic is often enormous; by the use of logarithms this labor is greatly lessened; logarithms are of inestimable value in the so-called higher mathematics, in navigation, in surveying, and in the investigation of many problems in physics.

LOGARITHMIC TABLE.

When the engineer or draughtsman is required to make long and difficult calculations, consisting of the multiplication, division, squaring, etc., of numbers, the logarithmic table will, as explained in the note, be of such assistance as may amply repay the study of the subject and the acquirement of rapid and accurate use of the table.

It must be understood that but an outline only of this interesting study is here presented and that the columns of figures given in the tables beginning on page 435 are but a very small part of those published in advanced works on mathematics; hence the examples given of the use of the table are necessarily confined to very small numbers.

To use the table, find the number in the first column marked N, and in the next column the corresponding logarithm will be found.

The figures given in the column are only the decimal part of the logarithm. The rules and examples for the application of logarithms are as follows:

RULE: *To multiply two numbers, add their logarithms, and the result will be the logarithm of the product.*

EXAMPLE: Multiply 25 by 6

$$\begin{array}{l} \log.\ 25 = 1.397940 \\ \log.\ 6 \quad\ \ .778151 \\ \hline 2.176091 = \log.\ 150 \end{array}$$

PROOF: 25
6
———
150

RULE: *To divide one number by another one, subtract the logarithm of the divisor from the logarithm of the dividend.*

EXAMPLE: Divide 175 by 7

$$\begin{array}{l} \log.\ 175 = 2.243038 \\ \log.\ 7 = \ \ .845098 \\ \hline 1.397940 = \log.\ 25 \end{array}$$

PROOF: $175 \div 7 = 25$

RULE. *To find any power of any number, multiply the index of the power with the logarithm of the number; the product is the logarithm of the power.*

EXAMPLE: Find the value of 3^4

$$\begin{array}{l} \log.\ 3 = \ .477121 \\ \quad\quad\quad\quad\quad 4 \\ \hline 1.908484 = \log.\ 81 \end{array}$$

PROOF: $\overset{1}{3} \times \overset{2}{3} = 9 \times \overset{3}{3} = 27 \times \overset{4}{3} = 81$

EXAMPLE: Find the value of 14^2

$$\begin{array}{l} \log.\ 14 = 1.146128 \\ \quad\quad\quad\quad\quad\quad 2 \\ \hline 2.292256 = \log.\ 196 \end{array}$$

RULE: *To find any root of a number, divide the logarithm of the number by the index of the root.*

EXAMPLE: Find the value of $\sqrt{64}$

$\log.\ 64 = 1.806180 \div 2 = .903090 = \log.\ 8.$

EXAMPLE: Find the value of $\sqrt[7]{128}$

$\log.\ 128 = 2.107210 \div 7 = .301030 = \log.\ 2.$

To find the *characteristic* or whole number to be placed before the *mantissa*, or decimal part of the logarithm, proceed as follows:

RULE: *If the number is between 1 and 10 the logarithm is only a fraction. The logarithm of 10 is 1, between 10 and 100, a 1 has to be placed in front of the fractional part found in the table; between 100 and 1,000, a 2 forms the whole number; between 1,000 and 10,000 the figure is 3, and so on.*

EXAMPLE: What is the logarithm of 123?—by looking in the table we find log. 123 = .089905 and placing a 2 in front of the decimal point, we have for the true log. of 123 = 2.089905.

TABLE OF LOGARITHMS.

There are two different tables of logarithms in use, one is called the Napierian system, named after its inventor, and the common system of which the base is 10; the accompanying tables are common logarithms.

The logarithm of a number usually consists of two parts, the integral, or whole part, and a fractional part; the integral part is called *the characteristic* or index, and the fractional part *the mantissa*. The last word is from the Latin and means *an addition*.

The abbreviation of the words "logarithm of" is log. or Log., thus: log. 136 = 2.133539, the characteristic of the logarithm 136 being 2, and the mantissa .133539. See Table, page 437.

In the tables the mantissas only are given.

N	Log.	N	Log.	N	Log.	N	Log.
1	000000	26	414973	51	707570	76	880814
2	301030	27	431364	52	716003	77	886491
3	477121	28	447158	53	724276	78	892095
4	602060	29	462398	54	732394	79	897627
5	698970	30	477121	55	740363	80	903090
6	778151	31	491362	56	748188	81	908485
7	845098	32	505150	57	755875	82	913814
8	903090	33	518514	58	763428	83	919078
9	954243	34	531479	59	770852	84	924279
10	000000	35	544068	60	778151	85	929419
11	041393	36	556303	61	785330	86	934498
12	079181	37	568202	62	792392	87	939519
13	113943	38	579784	63	799341	88	944483
14	146128	39	591065	64	806180	89	949390
15	176091	40	602060	65	812913	90	954243
16	204120	41	612784	66	819544	91	959041
17	230449	42	623249	67	826075	92	963788
18	255273	43	633468	68	832509	93	968483
19	278754	44	643453	69	838849	94	973128
20	301030	45	653213	70	845098	95	977724
21	322219	46	662758	71	851258	96	982271
22	342423	47	672098	72	857332	97	986772
23	361728	48	681241	73	863323	98	991226
24	380211	49	690196	74	869232	99	995635
25	397940	50	698970	75	875061	100	000000

TABLE OF LOGARITHMS—Continued.

N	0	1	2	3	4	5	6	7	8	9
100	000000	000434	000868	001301	001734	002166	002598	003029	003461	003891
101	004321	004751	005181	005609	006038	006466	006894	007321	007748	008174
102	008600	009026	009451	009876	010300	010724	011147	011570	011993	012415
103	012837	013259	013680	014100	014521	014940	015360	015779	016197	016616
104	017033	017451	017868	018284	018700	019116	019532	019947	020361	020775
105	021189	021603	022016	022428	022841	023252	023664	024075	024486	024896
106	025306	025715	026125	026533	026942	027350	027757	028164	028571	028978
107	029384	029789	030195	030600	031004	031408	031812	032216	032619	033021
108	033424	033826	034227	034628	035029	035430	035830	036230	036629	037028
109	037426	037825	038223	038620	039017	039414	039811	040207	040602	040998
110	041393	041787	042182	042576	042969	043362	043755	044148	044540	044932
111	045323	045714	046105	046495	046885	047275	047664	048053	048442	048830
112	049218	049606	049993	050380	050766	051153	051538	051924	052309	052694
113	053078	053463	053846	054230	054613	054996	055378	055760	056142	056524
114	056905	057286	057666	058046	058426	058805	059185	059563	059942	060320
115	060698	061075	061452	061829	062206	062582	062958	063333	063709	064083
116	064458	064832	065206	065580	065953	066326	066699	067071	067443	067815
117	068186	068557	068928	069298	069668	070038	070407	070776	071145	071514
118	071882	072250	072617	072985	073352	073718	074085	074451	074816	075182
119	075547	075912	076276	076640	077004	077368	077731	078094	078457	078819
120	079181	079543	079904	080266	080626	080987	081347	081707	082067	082426
N	0	1	2	3	4	5	6	7	8	9

TABLE OF LOGARITHMS—Continued.

N	0	1	2	3	4	5	6	7	8	9
121	082785	083144	083503	083861	084219	084576	084934	085291	085647	086004
122	086360	086716	087071	087426	087781	088136	088490	088845	089198	089552
123	089905	090258	090611	090963	091315	091667	092018	092370	092721	093071
124	093422	093772	094122	094471	094820	095169	095518	095866	096215	096562
125	096910	097257	097604	097951	098298	098644	098990	099335	099681	100026
126	100371	100715	101059	101403	101747	102091	102434	102777	103119	103462
127	103804	104146	104487	104828	105169	105510	105851	106191	106531	106871
128	107210	107549	107888	108227	108565	108903	109241	109579	109916	110253
129	110590	110926	111263	111599	111934	112270	112605	112940	113275	113609
130	113943	114277	114611	114944	115278	115611	115943	116276	116608	116940
131	117271	117603	117934	118265	118595	118926	119256	119586	119915	120245
132	120574	120903	121231	121560	121888	122216	122544	122871	123198	123525
133	123852	124178	124504	124830	125156	125481	125806	126131	126456	126781
134	127105	127429	127753	128076	128399	128722	129045	129368	129690	130012
135	130334	130655	130977	131298	131619	131939	132260	132580	132900	133219
136	133539	133858	134177	134496	134814	135133	135451	135769	136086	136403
137	136721	137037	137354	137671	137987	138303	138618	138934	139249	139564
138	139879	140194	140508	140822	141136	141450	141763	142076	142389	142702
139	143015	143327	143639	143951	144263	144574	144885	145196	145507	145818
140	146128	146438	146748	147058	147367	147676	147985	148294	148603	148911
N	0	1	2	3	4	5	6	7	8	9

TABLE OF LOGARITHMS—Continued.

N	0	1	2	3	4	5	6	7	8	9
141	149219	149527	149835	150142	150449	150756	151063	151370	151676	151982
142	152288	152594	152900	153205	153510	153815	154120	154424	154728	155032
143	155336	155640	155943	156246	156549	156852	157154	157457	157759	158061
144	158362	158664	158965	159266	159567	159868	160168	160469	160769	161068
145	161368	161667	161967	162266	162564	162863	163161	163460	163758	164055
146	164353	164650	164947	165244	165541	165838	166134	166430	166726	167022
147	167317	167613	167908	168203	168497	168792	169086	169380	169674	169968
148	170262	170555	170848	171141	171434	171726	172019	172311	172603	172895
149	173186	173478	173769	174060	174351	174641	174932	175222	175512	175802
150	176091	176381	176670	176959	177248	177536	177825	178113	178401	178689
151	178977	179264	179552	179839	180126	180413	180699	180986	181272	181558
152	181844	182129	182415	182700	182985	183270	183555	183839	184123	184407
153	184691	184975	185259	185542	185825	186108	186391	186674	186956	187239
154	187521	187803	188084	188366	188647	188928	189209	189490	189771	190051
155	190332	190612	190892	191171	191451	191730	192010	192289	192567	192846
156	193125	193403	193681	193959	194237	194514	194792	195069	195346	195623
157	195900	196176	196453	196729	197005	197281	197556	197832	198107	198382
158	198657	198932	199206	199481	199755	200029	200303	200577	200850	201124
159	201397	201670	201943	202216	202488	202761	203033	203305	203577	203848
160	204120	204391	204663	204934	205204	205475	205746	206016	206286	206556
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TABLE OF LOGARITHMS—Continued.

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161	206826	207096	207365	207634	207904	208173	208441	208710	208979	209247
162	209515	209783	210051	210319	210586	210853	211121	211388	211654	211921
163	212188	212454	212720	212986	213252	213518	213783	214049	214314	214579
164	214844	215109	215373	215638	215902	216166	216430	216694	216957	217221
165	217484	217747	218010	218273	218536	218798	219060	219323	219585	219846
166	220108	220370	220631	220892	221153	221414	221675	221936	222196	222456
167	222716	222976	223236	223496	223755	224015	224274	224533	224792	225051
168	225309	225568	225826	226084	226342	226600	226858	227115	227372	227630
169	227887	228144	228400	228657	228913	229170	229426	229682	229938	230193
170	230449	230704	230960	231215	231470	231724	231979	232234	232488	232742
171	232996	233250	233504	233757	234011	234264	234517	234770	235023	235276
172	235528	235781	236033	236285	236537	236789	237041	237292	237544	237795
173	238046	238297	238548	238799	239049	239299	239550	239800	240050	240300
174	240549	240799	241048	241297	241546	241795	242044	242293	242541	242790
175	243038	243286	243534	243782	244030	244277	244525	244772	245019	245266
176	245513	245759	246006	246252	246499	246745	246991	247237	247482	247728
177	247973	248219	248464	248709	248954	249198	249443	249687	249932	250176
178	250420	250664	250908	251151	251395	251638	251881	252125	252368	252610
179	252853	253096	253338	253580	253822	254064	254306	254548	254790	255031
180	255273	255514	255755	255996	256237	256477	256718	256958	257198	257439
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TABLE OF LOGARITHMS—Continued.

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181	257679	257918	258158	258398	258637	258877	259116	259355	259594	259833
182	260071	260310	260548	260787	261025	261263	261501	261739	261976	262214
183	262451	262688	262925	263162	263399	263636	263873	264109	264346	264582
184	264818	265054	265290	265525	265761	265996	266232	266467	266702	266937
185	267172	267406	267641	267875	268110	268344	268578	268812	269046	269279
186	269513	269746	269980	270213	270446	270679	270912	271144	271377	271609
187	271842	272074	272306	272538	272770	273001	273233	273464	273696	273927
188	274158	274389	274620	274850	275081	275311	275542	275772	276002	276232
189	276462	276692	276921	277151	277380	277609	277838	278067	278296	278525
190	278754	278982	279211	279439	279667	279895	280123	280351	280578	280806
191	281033	281261	281488	281715	281942	282169	282396	282622	282849	283075
192	283301	283527	283753	283979	284205	284431	284656	284882	285107	285332
193	285557	285782	286007	286232	286456	286681	286905	287130	287354	287578
194	287802	288026	288249	288473	288696	288920	289143	289366	289589	289812
195	290035	290257	290480	290702	290925	291147	291369	291591	291813	292034
196	292256	292478	292699	292920	293141	293363	293584	293804	294025	294246
197	294466	294687	294907	295127	295347	295567	295787	296007	296226	296446
198	296665	296884	297104	297323	297542	297761	297979	298198	298416	298635
199	298853	299071	299289	299507	299725	299943	300161	300378	300595	300813
200	301030	301247	301464	301681	301898	302114	302331	302547	302764	302980
N	0	1	2	3	4	5	6	7	8	9

TABLE OF LOGARITHMS—Continued.

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202	305351	305566	305781	305996	306211	306425	306639	306854	307068	307282
203	307496	307710	307924	308137	308351	308564	308778	308991	309204	309417
204	309630	309843	310056	310268	310481	310693	310906	311118	311330	311542
205	311754	311966	312177	312389	312600	312812	313023	313234	313445	313656
206	313867	314078	314289	314499	314710	314920	315130	315340	315551	315760
207	315970	316180	316390	316599	316809	317018	317227	317436	317646	317854
208	318063	318272	318481	318689	318898	319106	319314	319522	319730	319938
209	320146	320354	320562	320769	320977	321184	321391	321598	321805	322012
210	322219	322426	322633	322839	323046	323252	323458	323665	323871	324077
211	324282	324488	324694	324899	325105	325310	325516	325721	325926	326131
212	326336	326541	326745	326950	327155	327359	327563	327767	327972	328176
213	328380	328583	328787	328991	329194	329398	329601	329805	330008	330211
214	330414	330617	330819	331022	331225	331427	331630	331832	332034	332236
215	332438	332640	332842	333044	333246	333447	333649	333850	334051	334253
216	334454	334655	334856	335057	335257	335458	335658	335859	336059	336260
217	336460	336660	336860	337060	337260	337459	337659	337858	338058	338257
218	338456	338656	338855	339034	339253	339451	339650	339849	340047	340246
219	340444	340642	340841	341039	341237	341435	341632	341830	342028	342225
220	342423	342620	342817	343014	343212	343409	343606	343802	343999	344196
N	0	1	2	3	4	5	6	7	8	9

TABLE OF LOGARITHMS—Continued.

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221	344392	344589	344785	344981	345178	345374	345570	345766	345962	346157
222	346353	346549	346744	346939	347135	347330	347525	347720	347915	348110
223	348305	348500	348694	348889	349083	349278	349472	349666	349860	350054
224	350248	350442	350636	350829	351023	351216	351410	351603	351796	351989
225	352183	352375	352568	352761	352954	353147	353339	353532	353724	353916
226	354108	354301	354493	354685	354876	355068	355260	355452	355643	355834
227	356026	356217	356408	356599	356790	356981	357172	357363	357554	357744
228	357935	358125	358316	358506	358696	358886	359076	359266	359456	359646
229	359835	360025	360215	360404	360593	360783	360972	361161	361350	361539
230	361728	361917	362105	362294	362482	362671	362859	363048	363236	363424
231	363612	363800	363988	364176	364363	364551	364739	364926	365113	365301
232	365488	365675	365862	366049	366236	366423	366610	366796	366983	367169
233	367356	367542	367729	367915	368101	368287	368473	368659	368845	369030
234	369216	369401	369587	369772	369958	370143	370328	370513	370698	370883
235	371068	371253	371437	371622	371806	371991	372175	372360	372544	372728
236	372912	373096	373280	373464	373647	373831	374015	374198	374382	374565
237	374748	374932	375115	375298	375481	375664	375846	376029	376212	376394
238	376577	376759	376942	377124	377306	377488	377670	377852	378034	378216
239	378398	378580	378761	378943	379124	379306	379487	379668	379849	380030
240	380211	380392	380573	380754	380934	381115	381296	381476	381656	381837
N	0	1	2	3	4	5	6	7	8	9

TABLE OF LOGARITHMS—Continued.

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241	382017	382197	382377	382557	382737	382917	383097	383277	383456	383636
242	383815	383995	384174	384353	384533	384712	384891	385070	385249	385428
243	385606	385785	385964	386142	386321	386499	386677	386856	387034	387212
244	387390	387568	387746	387923	388101	388279	388456	388634	388811	388989
245	389166	389343	389520	389698	389875	390051	390228	390405	390582	390759
246	390935	391112	391288	391464	391641	391817	391993	392169	392345	392521
247	392697	392873	393048	393224	393400	393575	393751	393926	394101	394277
248	394452	394627	394802	394977	395152	395326	395501	395676	395850	396025
249	396199	396374	396548	396722	396896	397071	397245	397419	397592	397766
250	397940	398114	398287	398461	398634	398808	398981	399154	399328	399501
251	399674	399847	400020	400192	400365	400538	400711	400883	401056	401228
252	401401	401573	401745	401917	402089	402261	402433	402605	402777	402949
253	403121	403292	403464	403635	403807	403978	404149	404320	404492	404663
254	404834	405005	405176	405346	405517	405688	405858	406029	406199	406370
255	406540	406710	406881	407051	407221	407391	407561	407731	407901	408070
256	408240	408410	408579	408749	408918	409087	409257	409426	409595	409764
257	409933	410102	410271	410440	410609	410777	410946	411114	411283	411451
258	411620	411788	411956	412124	412293	412461	412629	412796	412964	413132
259	413300	413467	413635	413803	413970	414137	414305	414472	414639	414806
260	414973	415140	415307	415474	415641	415808	415974	416141	416308	416474
N	0	1	2	3	4	5	6	7	8	9

TABLE OF LOGARITHMS—Continued.

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261	416641	416807	416973	417139	417306	417472	417638	417804	417970	418135
262	418301	418467	418633	418798	418964	419129	419295	419460	419625	419791
263	419956	420121	420286	420451	420616	420781	420945	421110	421275	421439
264	421604	421768	421933	422097	422261	422426	422590	422754	422918	423082
265	423246	423410	423574	423737	423901	424065	424228	424392	424555	424718
266	424882	425045	425208	425371	425534	425697	425860	426023	426186	426349
267	426511	426674	426836	426999	427161	427324	427486	427648	427811	427973
268	428135	428297	428459	428621	428783	428944	429106	429268	429429	429591
269	429752	429914	430075	430236	430398	430559	430720	430881	431042	431203
270	431364	431525	431685	431846	432007	432167	432328	432488	432649	432809
271	432969	433130	433290	433450	433610	433770	433930	434090	434249	434409
272	434569	434729	434888	435048	435207	435367	435526	435685	435844	436004
273	436163	436322	436481	436640	436799	436957	437116	437275	437433	437592
274	437751	437909	438067	438226	438384	438542	438701	438859	439017	439175
275	439333	439491	439648	439806	439964	440122	440279	440437	440594	440752
276	440909	441066	441224	441381	441538	441695	441852	442009	442166	442323
277	442480	442637	442793	442950	443106	443263	443419	443576	443732	443889
278	444045	444201	444357	444513	444669	444825	444981	445137	445293	445449
279	445604	445760	445915	446071	446226	446382	446537	446692	446848	447003
280	447158	447313	447468	447623	447778	447933	448088	448242	448397	448552
N	0	1	2	3	4	5	6	7	8	9

TABLE OF LOGARITHMS—Continued.

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282	450249	450403	450557	450711	450865	451018	451172	451326	451479	451633
283	451786	451940	452093	452247	452400	452553	452706	452859	453012	453165
284	453318	453471	453624	453777	453930	454082	454235	454387	454540	454692
285	454845	454997	455150	455302	455454	455606	455758	455910	456062	456214
286	456366	456518	456670	456821	456973	457125	457276	457428	457579	457731
287	457882	458033	458184	458336	458487	458638	458789	458940	459091	459242
288	459392	459543	459694	459845	459995	460146	460296	460447	460597	460748
289	460898	461048	461198	461348	461499	461649	461799	461948	462098	462248
290	462398	462548	462697	462847	462997	463146	463296	463445	463594	463744
291	463893	464042	464191	464340	464490	464639	464788	464936	465085	465234
292	465383	465532	465680	465829	465977	466126	466274	466423	466571	466719
293	466868	467016	467164	467312	467460	467608	467756	467904	468052	468200
294	468347	468495	468643	468790	468938	469085	469233	469380	469527	469675
295	469822	469969	470116	470263	470410	470557	470704	470851	470998	471145
296	471292	471438	471585	471732	471878	472025	472171	472318	472464	472610
297	472756	472903	473049	473195	473341	473487	473633	473779	473925	474071
298	474216	474362	474508	474653	474799	474944	475090	475235	475381	475526
299	475671	475816	475962	476107	476252	476397	476542	476687	476832	476976
300	477121	477266	477411	477555	477700	477844	477989	478133	478278	478422
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TABLE OF LOGARITHMS—Continued.

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301	478566	478711	478855	478999	479143	479287	479431	479575	479719	479863
302	480007	480151	480294	480438	480582	480725	480869	481012	481156	481299
303	481443	481586	481729	481872	482016	482159	482302	482445	482588	482731
304	482874	483016	483159	483302	483445	483587	483730	483872	484015	484157
305	484300	484442	484585	484727	484869	485011	485153	485295	485437	485579
306	485721	485863	486005	486147	486289	486430	486572	486714	486855	486997
307	487138	487280	487421	487563	487704	487845	487986	488127	488269	488410
308	488551	488692	488833	488974	489114	489255	489396	489537	489677	489818
309	489958	490099	490239	490380	490520	490661	490801	490941	491081	491222
310	491362	491502	491642	491782	491922	492062	492201	492341	492481	492621
311	492760	492900	493040	493179	493319	493458	493597	493737	493876	494015
312	494155	494294	494433	494572	494711	494850	494989	495128	495267	495406
313	495544	495683	495822	495960	496099	496238	496376	496515	496653	496791
314	496930	497068	497206	497344	497483	497621	497759	497897	498035	498173
315	498311	498448	498586	498724	498862	498999	499137	499275	499412	499550
316	499687	499824	499962	500099	500236	500374	500511	500648	500785	500922
317	501059	501196	501333	501470	501607	501744	501880	502017	502154	502291
318	502427	502564	502700	502837	502973	503109	503246	503382	503518	503655
319	503791	503927	504063	504199	504335	504471	504607	504743	504878	505014
320	505150	505286	505421	505557	505693	505828	505964	506099	506234	506370
N	0	1	2	3	4	5	6	7	8	9

TABLE OF LOGARITHMS—Continued.

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321	506505	506640	506776	506911	507046	507181	507316	507451	507586	507721
322	507856	507991	508126	508260	508395	508530	508664	508799	508934	509068
323	509203	509337	509471	509606	509740	509874	510009	510143	510277	510411
324	510545	510679	510813	510947	511081	511215	511349	511482	511616	511750
325	511883	512017	512151	512284	512418	512551	512684	512818	512951	513084
326	513218	513351	513484	513617	513750	513883	514016	514149	514282	514415
327	514548	514681	514813	514946	515079	515211	515344	515476	515609	515741
328	515874	516006	516139	516271	516403	516535	516668	516800	516932	517064
329	517196	517328	517460	517592	517724	517855	517987	518119	518251	518382
330	518514	518646	518777	518909	519040	519171	519303	519434	519566	519697
331	519828	519959	520090	520221	520353	520484	520615	520745	520876	521007
332	521138	521269	521400	521530	521661	521792	521922	522053	522183	522314
333	522444	522575	522705	522835	522966	523096	523226	523356	523486	523616
334	523746	523876	524006	524136	524266	524396	524526	524656	524785	524915
335	525045	525174	525304	525434	525563	525693	525822	525951	526081	526210
336	526339	526469	526598	526727	526856	526985	527114	527243	527372	527501
337	527630	527759	527888	528016	528145	528274	528402	528531	528660	528788
338	528917	529045	529174	529302	529430	529559	529687	529815	529943	530072
339	530200	530328	530456	530584	530712	530840	530968	531096	531223	531351
340	531479	531607	531734	531862	531990	532117	532245	532372	532500	532627
N	0	1	2	3	4	5	6	7	8	9

TABLE OF LOGARITHMS—Continued.

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341	532754	532882	533009	533136	533264	533391	533518	533645	533772	533899
342	534026	534153	534280	534407	534534	534661	534787	534914	535041	535167
343	535294	535421	535547	535674	535800	535927	536053	536180	536306	536432
344	536558	536685	536811	536937	537063	537189	537315	537441	537567	537693
345	537819	537945	538071	538197	538322	538448	538574	538699	538825	538951
346	539076	539202	539327	539452	539578	539703	539829	539954	540079	540204
347	540329	540455	540580	540705	540830	540955	541080	541205	541330	541454
348	541579	541704	541829	541953	542078	542203	542327	542452	542576	542701
349	542825	542950	543074	543199	543323	543447	543571	543696	543820	543944
350	544068	544192	544316	544440	544564	544688	544812	544936	545060	545183
351	545307	545431	545555	545678	545802	545925	546049	546172	546296	546419
352	546543	546666	546789	546913	547036	547159	547282	547405	547529	547652
353	547775	547898	548021	548144	548267	548389	548512	548635	548758	548881
354	549003	549126	549249	549371	549494	549616	549739	549861	549984	550106
355	550228	550351	550473	550595	550717	550840	550962	551084	551206	551328
356	551450	551572	551694	551816	551938	552060	552181	552303	552425	552547
357	552668	552790	552911	553033	553155	553276	553398	553519	553640	553762
358	553883	554004	554126	554247	554368	554489	554610	554731	554852	554973
359	555094	555215	555336	555457	555578	555699	555820	555940	556061	556182
360	556303	556423	556544	556664	556785	556905	557026	557146	557267	557387
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TABLE OF LOGARITHMS—Continued.

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361	557507	557627	557748	557868	557988	558108	558228	558349	558469	558589
362	558709	558829	558948	559068	559188	559308	559428	559548	559667	559787
363	559907	560026	560146	560265	560385	560504	560624	560743	560863	560982
364	561101	561221	561340	561459	561578	561698	561817	561936	562055	562174
365	562293	562412	562531	562650	562769	562887	563006	563125	563244	563362
366	563481	563600	563718	563837	563955	564074	564192	564311	564429	564548
367	564666	564784	564903	565021	565139	565257	565376	565494	565612	565730
368	565848	565966	566084	566202	566320	566437	566555	566673	566791	566909
369	567026	567144	567262	567379	567497	567614	567732	567849	567967	568084
370	568202	568319	568436	568554	568671	568788	568905	569023	569140	569257
371	569374	569491	569608	569725	569842	569959	570076	570193	570309	570426
372	570543	570660	570776	570893	571010	571126	571243	571359	571476	571592
373	571709	571825	571942	572058	572174	572291	572407	572523	572639	572755
374	572872	572988	573104	573220	573336	573452	573568	573684	573800	573915
375	574031	574147	574263	574379	574494	574610	574726	574841	574957	575072
376	575188	575303	575419	575534	575650	575765	575880	575996	576111	576226
377	576341	576457	576572	576687	576802	576917	577032	577147	577262	577377
378	577492	577607	577722	577836	577951	578066	578181	578295	578410	578525
379	578639	578754	578868	578983	579097	579212	579326	579441	579555	579669
380	579784	579898	580012	580126	580241	580355	580469	580583	580697	580811
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TABLE OF LOGARITHMS—Continued.

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382	582063	582177	582291	582404	582518	582631	582745	582858	582972	583085
383	583199	583312	583426	583539	583652	583765	583879	583992	584105	584218
384	584331	584444	584557	584670	584783	584896	585009	585122	585235	585348
385	585461	585574	585686	585799	585912	586024	586137	586250	586362	586475
386	586587	586700	586812	586925	587037	587149	587262	587374	587486	587599
387	587711	587823	587935	588047	588160	588272	588384	588496	588608	588720
388	588832	588944	589056	589167	589279	589391	589503	589615	589726	589838
389	589950	590061	590173	590284	590396	590507	590619	590730	590842	590953
390	591065	591176	591287	591399	591510	591621	591732	591843	591955	592066
391	592177	592288	592399	592510	592621	592732	592843	592954	593064	593175
392	593286	593397	593508	593618	593729	593840	593950	594061	594171	594282
393	594393	594503	594614	594724	594834	594945	595055	595165	595276	595386
394	595496	595606	595717	595827	595937	596047	596157	596267	596377	596487
395	596597	596707	596817	596927	597037	597146	597256	597366	597476	597586
396	597695	597805	597914	598024	598134	598243	598353	598462	598572	598681
397	598791	598900	599009	599119	599228	599337	599446	599556	599665	599774
398	599883	599992	600101	600210	600319	600428	600537	600646	600755	600864
399	600973	601082	601191	601299	601408	601517	601625	601734	601843	601951
400	602060	602169	602277	602386	602494	602603	602711	602819	602928	603036
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TABLE OF LOGARITHMS—Continued.

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401	603144	603253	603361	603469	603577	603686	603794	603902	604010	604118
402	604226	604334	604442	604550	604658	604766	604874	604982	605089	605197
403	605305	605413	605521	605628	605736	605844	605951	606059	606166	606274
404	606381	606489	606596	606704	606811	606919	607026	607133	607241	607348
405	607455	607562	607669	607777	607884	607991	608098	608205	608312	608419
406	608526	608633	608740	608847	608954	609061	609167	609274	609381	609488
407	609594	609701	609808	609914	610021	610128	610234	610341	610447	610554
408	610660	610767	610873	610979	611086	611192	611298	611405	611511	611617
409	611723	611829	611936	612042	612148	612254	612360	612466	612572	612678
410	612784	612890	612996	613102	613207	613313	613419	613525	613630	613736
411	613842	613947	614053	614159	614264	614370	614475	614581	614686	614792
412	614897	615003	615108	615213	615319	615424	615529	615634	615740	615845
413	615950	616055	616160	616265	616370	616476	616581	616686	616790	616895
414	617000	617105	617210	617315	617420	617525	617629	617734	617839	617943
415	618048	618153	618257	618362	618466	618571	618676	618780	618884	618989
416	619093	619198	619302	619406	619511	619615	619719	619824	619928	620032
417	620136	620240	620344	620448	620552	620656	620760	620864	620968	621072
418	621176	621280	621384	621488	621592	621695	621799	621903	622007	622110
419	622214	622318	622421	622525	622628	622732	622835	622939	623042	623146
420	623249	623353	623456	623559	623663	623766	623869	623973	624076	624179
N	0	1	2	3	4	5	6	7	8	9

TABLE OF LOGARITHMS—Continued.

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422	625312	625415	625518	625621	625724	625827	625929	626032	626135	626238
423	626340	626443	626546	626648	626751	626853	626956	627058	627161	627263
424	627366	627468	627571	627673	627775	627878	627980	628082	628185	628287
425	628389	628491	628593	628695	628797	628900	629002	629104	629206	629308
426	629410	629512	629613	629715	629817	629919	630021	630123	630224	630326
427	630428	630530	630631	630733	630835	630936	631038	631139	631241	631342
428	631444	631545	631647	631748	631849	631951	632052	632153	632255	632356
429	632457	632559	632660	632761	632862	632963	633064	633165	633266	633367
430	633468	633569	633670	633771	633872	633973	634074	634175	634276	634376
431	634477	634578	634679	634779	634880	634981	635081	635182	635283	635383
432	635484	635584	635685	635785	635886	635986	636087	636187	636287	636388
433	636488	636588	636688	636789	636889	636989	637089	637189	637290	637390
434	637490	637590	637690	637790	637890	637990	638090	638190	638290	638389
435	638489	638589	638689	638789	638888	638988	639088	639188	639287	639387
436	639486	639586	639686	639785	639885	639984	640084	640183	640283	640382
437	640481	640581	640680	640779	640879	640978	641077	641177	641276	641375
438	641474	641573	641672	641771	641871	641970	642069	642168	642267	642366
439	642465	642563	642662	642761	642860	642959	643058	643156	643255	643354
440	643453	643551	643650	643749	643847	643946	644044	644143	644242	644340
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TABLE OF LOGARITHMS—Continued

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441	644439	644537	644636	644734	644832	644931	645029	645127	645226	645324
442	645422	645521	645619	645717	645815	645913	646011	646110	646208	646306
443	646404	646502	646600	646698	646796	646894	646992	647089	647187	647285
444	647383	647481	647579	647676	647774	647872	647969	648067	648165	648262
445	648360	648458	648555	648653	648750	648848	648945	649043	649140	649237
446	649335	649432	649530	649627	649724	649821	649919	650016	650113	650210
447	650308	650405	650502	650599	650696	650793	650890	650987	651084	651181
448	651278	651375	651472	651569	651666	651762	651859	651956	652053	652150
449	652246	652343	652440	652536	652633	652730	652826	652923	653019	653116
450	653213	653309	653405	653502	653598	653695	653791	653888	653984	654080
451	654177	654273	654369	654465	654562	654658	654754	654850	654946	655042
452	655138	655235	655331	655427	655523	655619	655715	655810	655906	656002
453	656098	656194	656290	656386	656482	656577	656673	656769	656864	656960
454	657056	657152	657247	657343	657438	657534	657629	657725	657820	657916
455	658011	658107	658202	658298	658393	658488	658584	658679	658774	658870
456	658965	659060	659155	659250	659346	659441	659536	659631	659726	659821
457	659916	660011	660106	660201	660296	660391	660486	660581	660676	660771
458	660865	660960	661055	661150	661245	661339	661434	661529	661623	661718
459	661813	661907	662002	662096	662191	662286	662380	662475	662569	662663
460	662758	662852	662947	663041	663135	663230	663324	663418	663512	663607
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TABLE OF LOGARITHMS—Continued.

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462	664642	664736	664830	664924	665018	665112	665206	665299	665393	665487
463	665581	665675	665769	665862	665956	666050	666143	666237	666331	666424
464	666518	666612	666705	666799	666892	666986	667079	667173	667266	667360
465	667453	667546	667640	667733	667826	667920	668013	668106	668199	668293
466	668386	668479	668572	668665	668759	668852	668945	669038	669131	669224
467	669317	669410	669503	669596	669689	669782	669875	669967	670060	670153
468	670246	670339	670431	670524	670617	670710	670802	670895	670988	671080
469	671173	671265	671358	671451	671543	671636	671728	671821	671913	672005
470	672098	672190	672283	672375	672467	672560	672652	672744	672836	672929
471	673021	673113	673205	673297	673390	673482	673574	673666	673758	673850
472	673942	674034	674126	674218	674310	674402	674494	674586	674677	674769
473	674861	674953	675045	675137	675228	675320	675412	675503	675595	675687
474	675778	675870	675962	676053	676145	676236	676328	676419	676511	676602
475	676694	676785	676876	676968	677059	677151	677242	677333	677424	677516
476	677607	677698	677789	677881	677972	678063	678154	678245	678336	678427
477	678518	678609	678700	678791	678882	678973	679064	679155	679246	679337
478	679428	679519	679610	679700	679791	679882	679973	680063	680154	680245
479	680336	680426	680517	680607	680698	680789	680879	680970	681060	681151
480	681241	681332	681422	681513	681603	681693	681784	681874	681964	682055
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TABLE OF LOGARITHMS—Continued.

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482	683047	683137	683227	683317	683407	683497	683587	683677	683767	683857
483	683947	684037	684127	684217	684307	684396	684486	684576	684666	684756
484	684845	684935	685025	685114	685204	685294	685383	685473	685563	685652
485	685742	685831	685921	686010	686100	686189	686279	686368	686458	686547
486	686636	686726	686815	686904	686994	687083	687172	687261	687351	687440
487	687529	687618	687707	687796	687886	687975	688064	688153	688242	688331
488	688420	688509	688598	688687	688776	688865	688953	689042	689131	689220
489	689309	689398	689486	689575	689664	689753	689841	689930	690019	690107
490	690196	690285	690373	690462	690550	690639	690728	690816	690905	690993
491	691081	691170	691258	691347	691435	691524	691612	691700	691789	691877
492	691965	692053	692142	692230	692318	692406	692494	692583	692671	692759
493	692847	692935	693023	693111	693199	693287	693375	693463	693551	693639
494	693727	693815	693903	693991	694078	694166	694254	694342	694430	694517
495	694605	694693	694781	694868	694956	695044	695131	695219	695307	695394
496	695482	695569	695657	695744	695832	695919	696007	696094	696182	696269
497	696356	696444	696531	696618	696706	696793	696880	696968	697055	697142
498	697229	697317	697404	697491	697578	697665	697752	697839	697926	698014
499	698101	698188	698275	698362	698449	698535	698622	698709	698796	698883
500	698970	699057	699144	699231	699317	699404	699491	699578	699664	699751
N	0	1	2	3	4	5	6	7	8	9

TABLE OF LOGARITHMS—Continued.

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502	700704	700790	700877	700963	701050	701136	701222	701309	701395	701482
503	701568	701654	701741	701827	701913	701999	702086	702172	702258	702344
504	702431	702517	702603	702689	702775	702861	702947	703033	703119	703205
505	703291	703377	703463	703549	703635	703721	703807	703893	703979	704065
506	704151	704236	704322	704408	704494	704579	704665	704751	704837	704922
507	705008	705094	705179	705265	705350	705436	705522	705607	705693	705778
508	705864	705949	706035	706120	706206	706291	706376	706462	706547	706632
509	706718	706803	706888	706974	707059	707144	707229	707315	707400	707485
510	707570	707655	707740	707826	707911	707996	708081	708166	708251	708336
511	708421	708506	708591	708676	708761	708846	708931	709015	709100	709185
512	709270	709355	709440	709524	709609	709694	709779	709863	709948	710033
513	710117	710202	710287	710371	710456	710540	710625	710710	710794	710879
514	710963	711048	711132	711217	711301	711385	711470	711554	711639	711723
515	711807	711892	711976	712060	712144	712229	712313	712397	712481	712566
516	712650	712734	712818	712902	712986	713070	713154	713238	713323	713407
517	713491	713575	713659	713742	713826	713910	713994	714078	714162	714246
518	714330	714414	714497	714581	714665	714749	714833	714916	715000	715084
519	715167	715251	715335	715418	715502	715586	715669	715753	715836	715920
520	716003	716087	716170	716254	716337	716421	716504	716588	716671	716754
N	0	1	2	3	4	5	6	7	8	9

TABLE OF LOGARITHMS—Continued.

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521	716838	716921	717004	717088	717171	717254	717338	717421	717504	717587
522	717671	717754	717837	717920	718003	718086	718169	718253	718336	718419
523	718502	718585	718668	718751	718834	718917	719000	719083	719165	719248
524	719331	719414	719497	719580	719663	719745	719828	719911	719994	720077
525	720159	720242	720325	720407	720490	720573	720655	720738	720821	720903
526	720986	721068	721151	721233	721316	721398	721481	721563	721646	721728
527	721811	721893	721975	722058	722140	722222	722305	722387	722469	722552
528	722634	722716	722798	722881	722963	723045	723127	723209	723291	723374
529	723456	723538	723620	723702	723784	723866	723948	724030	724112	724194
530	724276	724358	724440	724522	724604	724685	724767	724849	724931	725013
531	725095	725176	725258	725340	725422	725503	725585	725667	725748	725830
532	725912	725993	726075	726156	726238	726320	726401	726483	726564	726646
533	726727	726809	726890	726972	727053	727134	727216	727297	727379	727460
534	727541	727623	727704	727785	727866	727948	728029	728110	728191	728273
535	728354	728435	728516	728597	728678	728759	728841	728922	729003	729084
536	729165	729246	729327	729408	729489	729570	729651	729732	729813	729893
537	729974	730055	730136	730217	730298	730378	730459	730540	730621	730702
538	730782	730863	730944	731024	731105	731186	731266	731347	731428	731508
539	731589	731669	731750	731830	731911	731991	732072	732152	732233	732313
540	732394	732474	732555	732635	732715	732796	732876	732956	733037	733117
N	0	1	2	3	4	5	6	7	8	9

TABLE OF LOGARITHMS—Continued.

N	0	1	2	3	4	5	6	7	8	9
541	733197	733278	733358	733438	733518	733598	733679	733759	733839	733919
542	733999	734079	734160	734240	734320	734400	734480	734560	734640	734720
543	734800	734880	734960	735040	735120	735200	735279	735359	735439	735519
544	735599	735679	735759	735838	735918	735998	736078	736157	736237	736317
545	736397	736476	736556	736635	736715	736795	736874	736954	737034	737113
546	737193	737272	737352	737431	737511	737590	737670	737749	737829	737908
547	737987	738067	738146	738225	738305	738384	738463	738543	738622	738701
548	738781	738860	738939	739018	739097	739177	739256	739335	739414	739493
549	739572	739651	739731	739810	739889	739968	740047	740126	740205	740284
550	740363	740442	740521	740600	740678	740757	740836	740915	740994	741073
551	741152	741230	741309	741388	741467	741546	741624	741703	741782	741860
552	741939	742018	742096	742175	742254	742332	742411	742489	742568	742647
553	742725	742804	742882	742961	743039	743118	743196	743275	743353	743431
554	743510	743588	743667	743745	743823	743902	743980	744058	744136	744215
555	744293	744371	744449	744528	744606	744684	744762	744840	744919	744997
556	745075	745153	745231	745309	745387	745465	745543	745621	745699	745777
557	745855	745933	746011	746089	746167	746245	746323	746401	746479	746556
558	746634	746712	746790	746868	746945	747023	747101	747179	747256	747334
559	747412	747489	747567	747645	747722	747800	747878	747955	748033	748110
560	748188	748266	748343	748421	748498	748576	748653	748731	748808	748885
N	0	1	2	3	4	5	6	7	8	9

TABLE OF LOGARITHMS—Continued.

N	0	1	2	3	4	5	6	7	8	9
561	748963	749040	749118	749195	749272	749350	749427	749504	749582	749659
562	749736	749814	749891	749968	750045	750123	750200	750277	750354	750431
563	750508	750586	750663	750740	750817	750894	750971	751048	751125	751202
564	751279	751356	751433	751510	751587	751664	751741	751818	751895	751972
565	752048	752125	752202	752279	752356	752433	752509	752586	752663	752740
566	752816	752893	752970	753047	753123	753200	753277	753353	753430	753506
567	753583	753660	753736	753813	753889	753966	754042	754119	754195	754272
568	754348	754425	754501	754578	754654	754730	754807	754883	754960	755036
569	755112	755189	755265	755341	755417	755494	755570	755646	755722	755799
570	755875	755951	756027	756103	756180	756256	756332	756408	756484	756560
571	756636	756712	756788	756864	756940	757016	757092	757168	757244	757320
572	757396	757472	757548	757624	757700	757775	757851	757927	758003	758079
573	758155	758230	758306	758382	758458	758533	758609	758685	758761	758836
574	758912	758988	759063	759139	759214	759290	759366	759441	759517	759592
575	759668	759743	759819	759894	759970	760045	760121	760196	760272	760347
576	760422	760498	760573	760649	760724	760799	760875	760950	761025	761101
577	761176	761251	761326	761402	761477	761552	761627	761702	761778	761853
578	761928	762003	762078	762153	762228	762303	762378	762453	762529	762604
579	762679	762754	762829	762904	762978	763053	763128	763203	763278	763353
580	763428	763503	763578	763653	763727	763802	763877	763952	764027	764101
N	0	1	2	3	4	5	6	7	8	9

TABLE OF LOGARITHMS—Continued.

N	0	1	2	3	4	5	6	7	8	9
581	764176	764251	764326	764400	764475	764550	764624	764699	764774	764848
582	764923	764998	765072	765147	765221	765296	765370	765445	765520	765594
583	765669	765743	765818	765892	765966	766041	766115	766190	766264	766338
584	766413	766487	766562	766636	766710	766785	766859	766933	767007	767082
585	767156	767230	767304	767379	767453	767527	767601	767675	767749	767823
586	767898	767972	768046	768120	768194	768268	768342	768416	768490	768564
587	768638	768712	768786	768860	768934	769008	769082	769156	769230	769303
588	769377	769451	769525	769599	769673	769746	769820	769894	769968	770042
589	770115	770189	770263	770336	770410	770484	770557	770631	770705	770778
590	770852	770926	770999	771073	771146	771220	771293	771367	771440	771514
591	771587	771661	771734	771808	771881	771955	772028	772102	772175	772248
592	772322	772395	772468	772542	772615	772688	772762	772835	772908	772981
593	773055	773128	773201	773274	773348	773421	773494	773567	773640	773713
594	773786	773860	773933	774006	774079	774152	774225	774298	774371	774444
595	774517	774590	774663	774736	774809	774882	774955	775028	775100	775173
596	775246	775319	775392	775465	775538	775610	775683	775756	775829	775902
597	775974	776047	776120	776193	776265	776338	776411	776483	776556	776629
598	776701	776774	776846	776919	776992	777064	777137	777209	777282	777354
599	777427	777499	777572	777644	777717	777789	777862	777934	778006	778079
600	778151	778224	778296	778368	778441	778513	778585	778658	778730	778802
N	0	1	2	3	4	5	6	7	8	9

USEFUL TABLES FOR DRAUGHTSMEN, MACHINISTS AND ENGINEERS.

TABLE OF DECIMAL EQUIVALENTS.

8ths, 16ths, 32ds and 64ths of an Inch.

8ths.	**32nds.**	**64ths.**	
$\frac{1}{8}$ =.125	$\frac{1}{32}$=.03125	$\frac{1}{64}$=.015625	$\frac{33}{64}$=.515625
$\frac{1}{4}$ —.250	$\frac{3}{32}$=.09375	$\frac{3}{64}$=.046875	$\frac{35}{64}$=.546875
$\frac{3}{8}$ =.375	$\frac{5}{32}$=.15625	$\frac{5}{64}$=.078125	$\frac{37}{64}$=.578125
$\frac{1}{2}$ =.500	$\frac{7}{32}$=.21875	$\frac{7}{64}$=.109375	$\frac{39}{64}$=.609375
$\frac{5}{8}$ = 625	$\frac{9}{32}$=.28125	$\frac{9}{64}$=.140625	$\frac{41}{64}$=.640625
$\frac{3}{4}$ =.750	$\frac{11}{32}$=.34375	$\frac{11}{64}$=.171875	$\frac{43}{64}$=.671875
$\frac{7}{8}$ =.875	$\frac{13}{32}$=.40625	$\frac{13}{64}$=.203125	$\frac{45}{64}$=.703125
16ths.	$\frac{15}{32}$=.46875	$\frac{15}{64}$×.234375	$\frac{47}{64}$=.734375
$\frac{1}{16}$=.0625	$\frac{17}{32}$=.53125	$\frac{17}{64}$=.265625	$\frac{49}{64}$=.765625
$\frac{3}{16}$=.1875	$\frac{19}{32}$=.59375	$\frac{19}{64}$=.296875	$\frac{51}{64}$=.796875
$\frac{5}{16}$=.3125	$\frac{21}{32}$=.65625	$\frac{21}{64}$=.328125	$\frac{53}{64}$=.828125
$\frac{7}{16}$=.4375	$\frac{23}{32}$=.71875	$\frac{23}{64}$=.359375	$\frac{55}{64}$=.859375
$\frac{9}{16}$=.5625	$\frac{25}{32}$=.78125	$\frac{25}{64}$=.390625	$\frac{57}{64}$=.890625
$\frac{11}{16}$=.6875	$\frac{27}{32}$=.84375	$\frac{27}{64}$=.421875	$\frac{59}{64}$=.921875
$\frac{13}{16}$=.8125	$\frac{29}{32}$=.90625	$\frac{29}{64}$=.453125	$\frac{61}{64}$=.953125
$\frac{15}{16}$=.9375	$\frac{31}{32}$=.96875	$\frac{31}{64}$=.484375	$\frac{63}{64}$=.984375

STANDARDS FOR WIRE GAUGES IN USE IN THE UNITED STATES.

Dimensions of Sizes in Decimal Parts of an Inch.

Number of Wire Gauge.	American or Brown & Sharpe.	Birmingham, or Stubs' Wire.	Washburn & Moen Mfg. Co., Worcester, Ms.	Imperial Wire Gauge.	Stubs' Steel Wire.	U. S. Stand. for Plate.	Number of Wire Gauge.
000000	....	....	....	.464	....	.46875	000000
00000	....	....	....	.432	....	.4375	00000
0000	.46	.454	.3938	.400	....	.40625	0000
000	.40964	.425	.3625	.372	....	.375	000
00	.3648	.38	.3310	.348	....	.34375	00
0	.32486	.34	.3065	.324	....	.3125	0
1	.2893	.3	.2830	.300	.227	.28125	1
2	.25763	.284	.2625	.276	.219	.265625	2
3	.22942	.259	.2437	.252	.212	.25	3
4	.20431	.238	.2253	.232	.207	.234375	4
5	.18194	.22	.2070	.212	.204	.21875	5
6	.16202	.203	.1920	.192	.201	.203125	6
7	.14428	.18	.1770	.176	.199	.1875	7
8	.12849	.165	.1620	.160	.197	.171875	8
9	.11443	.148	.1483	.144	.194	.15625	9
10	.10189	.134	.1350	.128	.191	.140625	10
11	.090742	.12	.1205	.116	.188	.125	11
12	.080808	.109	.1055	.104	.185	.109375	12
13	.071961	.095	.0915	.092	.182	.09375	13
14	.064084	.083	.0800	.080	.180	.078125	14
15	.057068	.072	.0720	.072	.178	.0703125	15
16	.05082	.065	.0625	.064	.175	.0625	16
17	.045257	.058	.0540	.056	.172	.05625	17
18	.040303	.049	.0475	.048	.168	.05	18
19	.03589	.042	.0410	.040	.164	.04375	19
20	.031961	.035	.0348	.036	.161	.0375	20
21	.028462	.032	.03175	.032	.157	.034375	21
22	.025347	.028	.0286	.028	.155	.03125	22
23	.022571	.025	.0258	.024	.153	.028125	23
24	.0201	.022	.0230	.022	.151	.025	24
25	.0179	.02	.0204	.020	.148	.021875	25
26	.01594	.018	.0181	.018	.146	.01875	26
27	.014195	.016	.0173	.0164	.143	.0171875	27
28	.012641	.014	.0162	.0149	.139	.015625	28
29	.011257	.013	.0150	.0136	.134	.0140625	29
30	.010025	.012	.0140	.0124	.127	.0125	30
31	.008928	.01	.0132	.0116	.120	.0109375	31
32	.00795	.009	.0128	.0108	.115	.01015625	32
33	.00708	.008	.0118	.0100	.112	.009375	33
34	.006304	.007	.0104	.0092	.110	.00859375	34
35	.005614	.005	.0095	.0084	.108	.0078125	35
36	.005	.004	.0090	.0076	.106	.00703125	36
37	.004453	....	....	.0068	.103	.006640625	37
38	.003965	....	....	.0060	.101	.00625	38
39	.003531	...	....	.0052	.099	......	39
40	.003144	....	....	.0048	.097	......	40

RULES

Relative to the Circle.

To find the area of a circle—

Multiply circumference by one-quarter of the diameter.
Or multiply the square of diameter by 0.7854.
Or " " circumference " .07958.
Or " " ½ diameter " 3.1416.

To find circumference—

Multiply diameter by 3.1416.
Or divide " " 0.3183.

To find diameter—

Multiply circumference by 0.3183.
Or divide " " 3.1416.

To find Radius—

Multiply circumference by 0.15915.
Or divide " " 6.28318.

In the following tables *the diameter* of a given inch is to be found in the first column, *the area* is to be found in the second column, and the *circumference* in the third column.

Example: A circle with a diameter of 2.7 inches has an area of 5.7256 *square inches* and a circumference of 8.4823 *linear inches*.

TABLES.

Area and Circumferences of Circles advancing by tenths.

Diam.	Area.	Circum.	Diam.	Area.	Circum.
0.0			3.0	7.0686	9.4248
.1	.007854	.31416	.1	7.5477	9.7389
.2	.031416	.62832	.2	8.0425	10.0531
.3	.070686	.94248	.3	8 5530	10.3673
.4	.12566	1.2566	.4	9.0792	10.6814
.5	.19735	1.5708	.5	9.6211	10.9956
.6	.28274	1.8850	.6	10.1788	11.3097
.7	.38485	2.1991	.7	10.7521	11.6239
.8	.50266	2.5133	.8	11.3411	11.9381
.9	.63617	2.8274	.9	11.9456	12.2522
1.0	.7854	3.1416	4.0	12.5664	12.5664
.1	.9503	3.4558	.1	13.2025	12.8805
.2	1.1310	3.7699	.2	13.8544	13.1947
.3	1.3273	4.0841	.3	14.5220	13.5088
.4	1.5394	4.3982	.4	15.2053	13.8230
.5	1.7671	4.7124	.5	15.9043	14.1372
.6	2.0106	5.0265	.6	16.6190	14.4513
.7	2.2698	5.3407	.7	17.3494	14.7655
.8	2.5447	5.6549	.8	18.0956	15.0796
.9	2.8353	5.9690	.9	18.8574	15.3938
2.0	3.1416	6.2832	5.0	19.6350	15.7080
.1	3.4636	6.5973	.1	20.4282	16.0221
.2	3.8013	6.9115	.2	21.2372	16.3363
.3	4.1548	7.2257	.3	22.0618	16.6504
.4	4.5239	7.5398	.4	22.9022	16.9646
.5	4.9087	7.8540	.5	23.7583	17.2788
.6	5.3093	8.1681	.6	24.6301	17.5929
.7	5.7256	8.4823	.7	25.5176	17.9071
.8	6.1575	8.7965	.8	26.4208	18.2212
.9	6.6052	9.1106	.9	27.3397	18.5354

TABLES OF AREAS AND CIRCUMFERENCES OF CIRCLES—Continued.

Diam.	Area.	Circum.	Diam.	Area.	Circum.	Diam.	Area.	Circum.	Diam.	Area.	Circum.
6.0	28.2743	18.8496	10.0	78.5398	31.4159	14.0	153.9380	43.9823	8.0	254.4690	56.5486
.1	29.2247	19.1637	.1	80.1185	31.7301	.1	156.1450	44.2965	.1	257.3043	56.8628
.2	30.1907	19.4779	.2	81.7128	32.0442	.2	158.3677	44.6106	.2	260.1553	57.1770
.3	31.1725	19.7920	.3	83.3229	32.3584	.3	160.6061	44.9248	.3	263.0220	57.4911
.4	32.1699	20.1062	.4	84.9487	32.6726	.4	162.8602	45.2389	.4	265.9044	57.8053
.5	33.1831	20.4204	.5	86.5901	32.9867	.5	165.1300	45.5531	.5	268.8025	58.1195
.6	34.2119	20.7345	.6	88.2473	33.3009	.6	167.4155	45.8673	.6	271.7164	58.4336
.7	35.2565	21.0487	.7	89.9202	33.6150	.7	169.7167	46.1814	.7	274.6459	58.7478
.8	36.3168	21.3628	.8	91.6088	33.9292	.8	172.0336	46.4956	.8	277.5911	59.0619
.9	37.3928	21.6770	.9	93.3132	34.2434	.9	174.3662	46.8097	.9	280.5521	59.3761
7.0	38.4845	21.9911	11.0	95.0332	34.5575	15.0	176.7146	47.1239	19.0	283.5287	59.6903
.1	39.5919	22.3053	.1	96.7689	34.8717	.1	179.0786	47.4380	.1	286.5211	60.0044
.2	40.7150	22.6195	.2	98.5203	35.1858	.2	181.4584	47.7522	.2	289.5292	60.3186
.3	41.8539	22.9336	.3	100.2875	35.5000	.3	183.8539	48.0664	.3	292.5530	60.6327
.4	43.0084	23.2478	.4	102.0703	35.8142	.4	186.2650	48.3805	.4	295.5925	60.9469
.5	44.1786	23.5619	.5	103.8689	36.1283	.5	188.6919	48.6947	.5	298.6477	61.2611
.6	45.3646	23.8761	.6	105.6832	36.4425	.6	191.1345	49.0088	.6	301.7186	61.5752
.7	46.5663	24.1903	.7	107.5132	36.7566	.7	193.5928	49.3230	.7	304.8052	61.8894
.8	47.7836	24.5044	.8	109 3588	37.0708	.8	196.0668	49.6372	.8	307.9075	62.2035
.9	49.0167	24.8186	.9	111.2202	37.3850	.9	198.5565	49.9513	.9	311.0255	62.5177
8.0	50.2655	25.1327	12.0	113.0973	37.6991	16.0	201.0619	50.2655	20.0	314.1593	62.8319
.1	51.5300	25.4469	.1	114.9901	38.0133	.1	203.5831	50.5796	.1	317.3087	63.1460
.2	52.8102	25.7611	.2	116.8987	38.3274	.2	206.1199	50.8938	.2	320.4739	63.4602
.3	54.1061	26.0752	.3	118.8229	38.6416	.3	208.6724	51.2080	.3	323.6547	63.7743
.4	55.4177	26.3894	.4	120.7628	38.9557	.4	211.2407	51.5221	.4	326.8513	64.0885
.5	56.7450	26.7035	.5	122.7185	39.2699	.5	213.8246	51.8363	.5	330.0636	64.4026
.6	58.0880	27.0177	.6	124.6898	39.5841	.6	216.4243	52.1504	.6	333.2916	64.7168
.7	59.4468	27.3319	.7	126.6769	39.8982	.7	219.0397	52.4646	.7	336.5353	65.0310
.8	60.8212	27.6460	.8	128.6796	40.2124	.8	221.6708	52.7788	.8	339.7947	65.3451
.9	62.2114	27.9602	.9	130.6981	40.5265	.9	224.3176	53.0929	.9	343.0698	65.6593
9.0	63.6173	28.2743	13.0	132.7323	40.8407	17.0	226.9801	53.4071	21.0	346.3606	65.9734
.1	65.0388	28.5885	.1	134.7822	41.1549	.1	229.6583	53.7212	.1	349.6671	66.2876
.2	66.4761	28.9027	.2	136.8478	41.4690	.2	232 3522	54.0354	.2	352.9894	66.6018
.3	67.9291	29.2168	.3	138.9291	41.7832	.3	235.0618	51.3496	.3	356.3273	66.9159
.4	69.3978	29.5310	.4	141.0261	42.0973	.4	237.7871	54.6637	.4	359.6809	67.2301
.5	70.8822	29.8451	.5	143.1388	42.4115	.5	240.5282	54.9779	.5	363.0503	67.5442
.6	72.3823	30.1593	.6	145.2672	42.7257	.6	243.2849	55.2920	.6	366.4354	67.8584
.7	73.8981	30,4734	.7	147.4114	43.0398	.7	246.0574	55.6062	.7	369.8361	68.1726
.8	75.4296	30.7876	.8	149.5712	43.3540	.8	248.8456	55.9203	.8	373.2526	68.4867
.9	76.9769	31.1018	.9	151.7468	43.6681	.9	251.6494	56.2345	.9	376.6848	68.8009

TABLES OF AREAS AND CIRCUMFERENCES OF CIRCLES—Continued.

Diam.	Area.	Circum.	Diam.	Area.	Circum.	Diam.	Area.	Circum.	Diam.	Area.	Circum.
22.0	380.1327	69.1150	26.0	530.9292	81.6814	30.0	706.8583	94.2478	34.0	907.9203	106.8142
.1	383.5963	69.4292	.1	535.0211	81.9956	.1	711.5786	94.5619	.1	913.2688	107.1283
.2	387.0756	69.7434	.2	539.1287	82.3097	.2	716.3145	94.8761	.2	918.6331	107.4425
.3	390.5707	70.0575	.3	543.2521	82.6239	.3	721.0662	95.1903	.3	924.0131	107.7566
.4	394.0814	70.3717	.4	547.3911	82.9380	.4	725.8336	95.5044	.4	929.4088	108.0708
.5	397.6078	70.6858	.5	551.5459	83.2522	.5	730.6167	95.8186	.5	934.8202	108.3849
.6	401.1500	71.0000	.6	555.7163	83.5664	.6	735.4154	96.1327	.6	940 2473	108.6991
.7	404.7078	71.3142	.7	559.9025	83.8805	.7	740.2299	96.4469	.7	945.6901	109.0133
.8	408.2814	71.6283	.8	564 1044	84.1947	.8	745.0601	96.7611	.8	951.1486	109.3274
.9	411.8707	71.9425	.9	568.3220	84.5088	.9	749.9060	97.0752	.9	956.6228	109.6416
23.0	415.4756	72.2566	27.0	572.5553	84.8230	31.0	754.7676	97.3894	35.0	962.1128	109.9557
.1	419.0993	72.5708	.1	576.8043	85.1372	.1	759.6450	97.7035	.1	967.6184	110.2699
.2	422.7327	72.8849	.2	581.0690	85.4513	.2	764.5380	98.0177	.2	973.1397	110.5841
.3	426.3848	73.1991	.3	585.3494	85.7655	.3	769.4467	98.3319	.3	978.6768	110.8982
.4	430.0526	73.5133	.4	589.6455	86.0796	.4	774.3712	98.6460	.4	984.2296	111.2124
.5	433.7361	73.8274	.5	593.9574	86.3938	.5	779.3113	98.9602	.5	989.7980	111.5265
.6	437.4354	74.1416	.6	598.2849	86.7080	.6	784.2672	99.2743	.6	995.3822	111.8407
.7	441.1503	74.4557	.7	602.6282	87.0221	.7	789.2388	99 5885	.7	1000.9821	112.1549
.8	444.8809	74.7699	.8	606.9871	87.3363	.8	794.2260	99.9026	.8	1006.5977	112.4690
.9	448.6273	75.0841	.9	611.3618	87.6504	.9	799.2290	100.2168	.9	1012.2290	112.7832
24.0	452.3893	75.3982	28.0	615.7522	87.9646	32.0	804.2477	100.5310	36.0	1017.8760	113.0973
.1	456.1671	75.7124	.1	620.1582	88.2788	.1	809.2821	100.8451	.1	1023.5387	113.4115
.2	459.9606	76.0265	.2	624.5800	88.5929	.2	814 3322	101.1593	.2	1029.2172	113.7257
.3	463.7698	76.3407	.3	629.0175	88.9071	.3	819.3980	101.4734	.3	1034.9113	114.0398
.4	467.5947	76.6549	.4	633.4707	89.2212	.4	824.4796	101.7876	.4	1040.6212	114.3540
.5	471.4352	76.9690	.5	637.9397	89.5354	.5	829.5768	102.1018	.5	1046.3467	114.6681
.6	475.2916	77.2832	.6	642.4243	89.8495	.6	834.6898	102.4159	.6	1052.0880	114.9823
.7	479.1636	77.5973	.7	646.9246	90.1637	.7	839.8185	102.7301	.7	1057.8449	115.2965
.8	483.0513	77.9115	.8	651.4407	90.4779	.8	844.9628	103.0442	.8	1063.6176	115.6106
.9	486.9547	78.2257	.9	655.9724	90.7920	.9	850.1229	103.3584	.9	1069.4060	115.9248
25.0	490.8739	78.5398	29.0	660.5199	91.1063	33.0	855.2986	103.6726	37.0	1075.2101	116.2389
.1	494.8087	78.8540	.1	665.0830	91.4203	.1	860.4902	103.9867	.1	1081.0299	116.5531
.2	498.7592	79.1681	.2	669.6619	91.7345	.2	865.6973	104.3009	.2	1086.8654	116.8672
.3	502.7255	79.4823	.3	674.2565	92.0487	.3	870.9202	104.6150	.3	1092.7166	117.1814
.4	506.7075	79.7965	.4	678.8668	92.3628	.4	876.1588	104.9292	.4	1098.5835	117.4956
.5	510.7052	80.1106	.5	683.4928	92.6770	.5	881.4131	105.2434	.5	1104.4662	117.8097
.6	514.7185	80.4248	.6	688.1345	92.9911	.6	886.6831	105.5575	.6	1110.3645	118.1239
.7	518.7476	80.7389	.7	692.7919	93.3053	.7	891.9688	105.8717	.7	1116.2786	118.4380
.8	522.7924	81.0531	.8	697.4650	93.6195	.8	897.2703	106.1858	.8	1122.2083	118.7522
.9	526.8529	81.3672	.9	702.1538	93.9336	.9	902.5874	106.5000	.9	1128.1538	119.0664

TABLES OF AREAS AND CIRCUMFERENCES OF CIRCLES—Continued.

Diam.	Area.	Circum.	Diam.	Area.	Circum.	Diam.	Area.	Circum.	Diam.	Area.	Circum.
38.0	1134.1149	119.3805	42.0	1385.4424	131.9469	46.0	1661.9025	144.5133	50.0	1963.4954	157.0796
.1	1140.0918	119.6947	.1	1392.0476	132.2611	.1	1669.1360	144.8274	.1	1971.3572	157.3938
.2	1146.0844	120.0088	.2	1398.6685	132.5752	.2	1676.3853	145.1416	.2	1979.2348	157.7080
.3	1152.0927	120.3230	.3	1405.3051	132.8894	.3	1683.6502	145.4557	.3	1987.1280	158.0221
.4	1158.1167	120.6372	.4	1411.9574	133.2035	.4	1690.9308	145.7699	.4	1995.0370	158.3363
.5	1164.1564	120.9513	.5	1418.6254	133.5177	.5	1698.2272	146.0841	.5	2002.9617	158.6504
.6	1170.2118	121.2655	.6	1425.3092	133.8318	.6	1705.5392	146.3982	.6	2010.9020	158.9646
.7	1176.2830	121.5796	.7	1432.0086	134.1460	.7	1712.8670	146.7124	.7	2018.8581	159.2787
.8	1182.3698	121.8938	.8	1438.7238	134.4602	.8	1720.2105	147.0265	.8	2026.8299	159.5929
.9	1188.4724	122.2080	.9	1445.4546	134.7743	.9	1727.5697	147.3407	.9	2034.8174	159.9071
39.0	1194.5906	122.5221	43.0	1452.2012	135.0885	47.0	1734.9445	147.6550	51.0	2042.8206	160.2212
.1	1200.7246	122.8363	.1	1458.9635	135.4026	.1	1742.3351	147.9690	.1	2050.8395	160.5354
.2	1206.8742	123.1504	.2	1465.7415	135.7168	.2	1749.7414	148.2832	.2	2058.8742	160.8495
.3	1213.0396	123.4646	.3	1472.5352	136.0310	.3	1757.1635	148 5973	.3	2066.9245	161 1637
.4	1219.2207	123.7788	.4	1479.3446	136.3451	.4	1764.6012	148.9115	.4	2074.9905	161.4779
.5	1225.4175	124.0929	.5	1486.1697	136.6593	.5	1772.0546	149.2257	.5	2083.0723	161.7920
.6	1231.6300	124.4071	.6	1493.0105	136.9734	.6	1779.5237	149.5398	.6	2091.1697	162.1062
.7	1237.8582	124.7212	.7	1499.8670	137.2876	.7	1787.0086	149.8540	.7	2099.2829	162.4203
.8	1244.1021	125.0354	.8	1506.7393	137.6018	.8	1794.5091	150.1681	.8	2107.4118	162.7345
.9	1250.3617	125.3495	.9	1513.6272	137.9159	.9	1802.0254	150.4823	.9	2115.5563	163.0487
40.0	1256.6371	125.6637	44.0	1520.5308	138.2301	48.0	1809.5574	150.7964	52.0	2123.7166	163.3628
.1	1262.9281	125.9779	.1	1527.4502	138.5442	.1	1817.1050	151.1106	.1	2131.8926	163.6770
.2	1269.2348	126.2920	.2	1534.3853	138.8584	.2	1824.6684	151.4248	.2	2140.0843	163.9911
.3	1275.5573	126.6062	.3	1541.3360	139.1726	.3	1832.2475	151.7389	.3	2148.2917	164.3053
.4	1281.8955	126.9203	.4	1548.3025	139.4867	.4	1839.8423	152.0531	.4	2156.5149	164.6195
.5	1288.2493	127.2345	.5	1555.2847	139.8009	.5	1847.4528	152.3672	.5	2164.7537	164.9336
.6	1294.3189	127.5487	.6	1562.2826	140.1153	.6	1855.0790	152.6814	.6	2173.0082	165 2479
.7	1301.0042	127.8628	.7	1569.2962	140.4292	.7	1862.7210	152.9956	.7	2181.2785	165.5619
.8	1307.4052	128.1770	.8	1576.3255	140.7434	.8	1870.3786	153.3097	.8	2189.5644	165.8761
.9	1313.8219	128.4911	.9	1583.3706	141.0575	.9	1878.0519	153.6239	.9	2197.8661	166.1903
41.0	1320.2543	128.8053	45.0	1590.4313	141.3717	49.0	1885.7409	153.9380	53.0	2206.1834	166.5044
.1	1326.7024	129.1195	.1	1597.5077	141.6858	.1	1893.4457	154.2522	.1	2214.5165	166.8186
.2	1333.1663	129.4336	.2	1604.5999	142.0000	.2	1901.1662	154.5664	.2	2222.8653	167.1327
.3	1339.6458	129.7478	.3	1611.7077	142.3142	.3	1908.9024	154.8805	.3	2231.2298	167.4469
.4	1346.1410	130.0619	.4	1618.8313	142.6283	.4	1916.6543	155.1947	.4	2239.6100	167.7610
.5	1352.6520	130.3761	.5	1625.9705	142.9425	.5	1924.4218	155.5088	.5	2248.0059	168.0752
.6	1359.1786	130.6903	.6	1633.1255	143.2566	.6	1932.2051	155.8230	.6	2256.4175	168.3894
.7	1365.7210	131.0044	.7	1640.2962	143.5708	.7	1940.0042	156.1372	.7	2264.8448	168.7035
.8	1372.2791	131.3186	.8	1647.4826	143.8849	.8	1947.8189	156.4513	.8	2273.2879	169.0177
.9	1378.8529	131.6227	.9	1654.6847	144.1991	.9	1955.6493	156.7655	.9	2281.7466	169.3318

TABLES OF AREAS AND CIRCUMFERENCES OF CIRCLES—Continued.

Diam.	Area.	Circum	Diam.	Area.	Circum.	Diam.	Area.	Circum.	Diam.	Area.	Circum.
54.0	2290.2210	169.6460	58.0	2642.0794	182.2124	62.0	3019.0705	194.7787	66.0	3421.1944	207.3451
.1	2298.7112	169.9602	.1	2651.1979	182.5265	.1	3028.8173	195.0929	.1	3431.5695	207.6593
.2	2307.2171	170.2743	.2	2660.3321	182.8407	.2	3038.5798	195.4071	.2	3441.9603	207.9734
.3	2315.7386	170.5885	.3	2669.4820	183.1549	.3	3048.3580	195.7212	.3	3452.3669	208.2876
.4	2324.2759	170.9026	.4	2678.6476	183.4690	.4	3058.1520	196.0354	.4	3462.7891	208.6017
.5	2332.8289	171.2168	.5	2687.8289	183.7832	.5	3067.9616	196.3495	.5	3473.2270	208.9159
.6	2341.3976	171.5310	.6	2697.0259	184.0973	.6	3077.7869	196.6637	.6	3483.6807	209.2301
.7	2349.9820	171.8451	.7	2706.2386	184.4115	.7	3087.6279	196.9779	.7	3494.1500	209.5442
.8	2258.5821	172.1593	.8	2715.4670	184.7256	.8	3097.4847	197.2920	.8	3504.6351	209.8584
.9	2367.1979	172.4735	.9	2724.7112	185.0398	.9	3107.3571	197.6062	.9	3515.1359	210.1725
55.0	2375.8294	172.7876	59.0	2733.9710	185.3540	63.0	3117.2453	197.9203	67.0	3525.6524	210.4867
.1	2384.4767	173.1017	.1	2743.2466	185.6681	.1	3127.1492	198.2345	.1	3536.1845	210.8009
.2	2393.1396	173.4159	.2	2752.5378	185.9823	.2	3137.0688	198.5487	.2	3546.7324	211.1150
.3	2401.8183	173.7301	.3	2761.8448	186.2964	.3	3147.0040	198.8628	.3	3557.2960	211.4292
.4	2410.5126	174.0442	.4	2771.1675	186.6106	.4	3156.9550	199.1770	.4	3567.8754	211.7433
.5	2419.2227	174.3584	.5	2780.5058	186.9248	.5	3166.9217	199.4911	.5	3578.4704	212.0575
.6	2427.9485	174.6726	.6	2789.8599	187.2389	.6	3176.9043	199.8053	.6	3589.0811	212.3717
.7	2436.6899	174.9867	.7	2799.2297	187.5531	.7	3186.9028	200.1195	.7	3599.7075	212 6858
.8	2445.4471	175.3009	.8	2808.6152	187.8672	.8	3196.9161	200.4336	.8	3610.3497	213.0000
.9	2454.2200	175.6150	.9	2818.0165	188.1814	.9	3206.9456	200.7478	.9	3621.0075	213.3141
56.0	2463.0086	175.9292	60.0	2827.4334	188.4956	64.0	3216.9909	201.0620	68.0	3631.6811	213.6283
.1	2471.8130	176.2433	.1	2836 8660	188.8097	.1	3227.0518	201.3761	.1	3642.3704	213.9425
.2	2480.6330	176.5575	.2	2846.3144	189.1239	.2	3237.1285	201.6902	.2	3653.0754	214.2566
.3	2489.4687	176.8717	.3	2855.7784	189.4380	.3	3247.2222	202.0044	.3	3663.7960	214.5708
.4	2498.3201	177.1858	.4	2865.2582	189.7522	.4	3257.3289	202.3186	.4	3674.5324	214.8849
.5	2507.1873	177.5000	.5	2874.7536	190.0664	.5	3267.4527	202.6327	.5	3685.2845	215.1991
.6	2516.0701	177.8141	.6	2884.2648	190.3805	.6	3277.5922	202.9469	.6	3696.0523	215.5133
.7	2524.9687	178.1283	.7	2893.7917	190.6947	.7	3287.7474	203.2610	.7	3706.8359	215.8274
.8	2533.8830	178.4425	.8	2903.3343	191.0088	.8	3297.9183	203.5752	.8	3717.6351	216.1416
.9	2542.8129	178.7566	.9	2912.8926	191.3230	.9	3308.1049	203.8894	.9	3728.4500	216.4556
57.0	2551.7586	179.0708	61.0	2922.4666	191.6372	65.0	3318.3072	204.2035	69.0	3739.2807	216.7699
.1	2560.7200	179.3849	.1	2932.0563	191.9513	.1	3328.5253	204.5176	.1	3750.1270	217.0841
.2	2569.6971	179.6991	.2	2941.6617	192.2655	.2	3338.7590	204.8318	.2	3760.9891	217.3982
.3	2578.6899	180.0133	.3	2951.2828	192.5796	.3	3349.0085	205.1460	.3	3771.8668	217.7124
.4	2587.6985	180.3274	.4	2960.9197	192.8938	.4	3359.2736	205.4602	.4	3782.7603	218.0265
.5	2596.7227	180.6416	.5	2970.5722	193.2079	.5	3369.5545	205.7743	.5	3793.6695	218.3407
.6	2605.7626	180.9557	.6	2980.2405	193.5221	.6	3379.8510	206.0885	.6	3804.5944	218.6548
.7	2614.8183	181.2699	.7	2989.9244	193.8363	.7	3390.1633	206.4026	.7	3815.5350	218.9690
.8	2623.8896	181.5841	.8	2999.6241	194.1504	.8	3400.4913	206.7168	.8	3826.4913	219.2832
.9	2632.9767	181.8982	.9	3009.3395	194.4646	.9	3410.8350	207.0310	.9	3837.4633	219.5973

TABLES OF AREAS AND CIRCUMFERENCES OF CIRCLES—Continued.

Diam.	Area.	Circum.	Diam.	Area.	Circum.	Diam.	Area.	Circum.	Diam.	Area.	Circum.
70.0	3848.4510	219.9115	74.0	4300.8403	232.4779	78.0	4778.3624	245.0442	82.0	5281.0173	257.6106
.1	3859.4544	220.2256	.1	4312.4721	232.7920	.1	4790.6225	245.3584	.1	5293.9056	257.9247
.2	3870.4736	220.5398	.2	4324.1195	233.1062	.2	4802.8983	245.6725	.2	5306.8097	258.2389
.3	3881.5084	220.8540	.3	4335.7827	233.4203	.3	4815.1897	245 9867	.3	5319.7295	258.5531
.4	3892.5590	221.1681	.4	4347.4616	233.7345	.4	4827.4969	246.3009	.4	5332.6650	258.8672
.5	3903.6252	221.4823	.5	4359.1562	234.0487	.5	4839.8189	246.6150	.5	5345.6162	259.1814
.6	3914.7072	221.7964	.6	4370.8664	234.3628	.6	4852.1584	246.9292	.6	5358.5832	259.4956
.7	3925.8049	222.1106	.7	4382.5924	234.6770	.7	4864.5128	247.2433	.7	5371.5658	259.8097
.8	3936.9182	222.4248	.8	4394.3341	234.9911	.8	4876.8828	247.5575	.8	5384.5641	260.1239
.9	3948.0473	222.7389	.9	4406.0916	235.3053	.9	4889.2685	247.8717	.9	5397.5782	260.4380
71.0	3959.1921	223.0531	75.0	4417.8647	235.6194	79.0	4901.6699	248.1858	83.0	5410.6079	260.7522
.1	3970.3526	223.3672	.1	4429.6535	235.9336	.1	4914.0871	248.5000	.1	5423.6534	261.0663
.2	3981.5239	223.6814	.2	4441.4580	236.2478	.2	4926.5199	248.8141	.2	5436.7146	261.3805
.3	3992.7208	223.9956	.3	4453.2783	236.5619	.3	4938.9685	249.1283	.3	5449.7915	261.6947
.4	4003.9284	224.3097	.4	4465.1142	236.8761	.4	4951.4328	249.4425	.4	5462.8840	262.0088
.5	4015.1518	224.6239	.5	4476 9659	237.1902	.5	4963.9127	249.7566	.5	5475.9923	262.3230
.6	4026.3908	224.9380	.6	4488.8332	237.5044	.6	4976.4084	250.0708	.6	5489.1163	262.6371
.7	4037.6456	225.2522	.7	4500.7163	237.8186	.7	4988.9198	250.3850	.7	5502.2561	262.9513
.8	4048.9160	225.5664	.8	4512.6151	238.1327	.8	5001.4469	250.6991	.8	5515.4115	263.2655
.9	4060.2022	225.8805	.9	4524.5296	238.4469	.9	5013.9897	251.0133	.9	5528.5826	263.5796
72.0	4071.5041	226.1947	76.0	4536.4598	238.7610	80.0	5026.5482	251.3274	84.0	5541.7694	263.8938
.1	4082.8217	226.5088	.1	4548.4057	239.0752	.1	5039.1225	251.6416	.1	5554.9720	264.2079
.2	4094.1550	226.8230	.2	4560.3673	239.3894	.2	5051.7124	251.9557	.2	5568.1902	264.5221
.3	4105.5040	227.1371	.3	4572.3446	239.7035	.3	5064.3180	252.2699	.3	5581.4242	264.8363
.4	4116.8687	227.4513	.4	4584.3377	240.0177	.4	5076.9394	252.5840	.4	5594.6739	265.1514
.5	4128.2491	227.7655	.5	4596.3464	240.3318	.5	5089.5764	252.8982	.5	5607.9392	265.4646
.6	4139.6452	228.0796	.6	4608.3708	240.6460	.6	5102.2292	253.2124	.6	5621.2203	265.7787
.7	4151.0571	228.3938	.7	4620.4110	240.9602	.7	5114 8977	253.5265	.7	5634.5171	266.0929
.8	4162.4846	228.7079	.8	4632.4669	241.2743	.8	5127.5819	253.8407	.8	5647.8296	266.4071
.9	4173.9279	229.0221	.9	4344.5384	241.5885	.9	5140.2818	254.1548	.9	5661.1578	266.7212
73.0	4185.3868	229.3363	77.0	4656.6257	241.9026	81.0	5152.9973	254.4690	85.0	5674.5017	267.0354
.1	4196.8615	229.6504	.1	4668.7287	242.2168	.1	5165.7287	254.7832	.1	5687.8614	267.3495
.2	4208.3519	229.9646	.2	4680.8474	242.5310	.2	5178.4757	255.0973	.2	5701.2367	267.6637
.3	4219.8579	230.2787	.3	4692.9818	242.8451	.3	5191.2384	255.4115	.3	5714.6277	267.9779
.4	4231.3797	230.5929	.4	4705.1319	243.1592	.4	5204.0168	255.7256	.4	5728.0345	268.2920
.5	4242.9172	230.9071	.5	4717.2977	243.4734	.5	5216.8110	256.0398	.5	5741.4569	268.6062
.6	4254.4704	231.2212	.6	4729.4792	243.7876	.6	5229.6208	256.3540	.6	5754.8951	268.9203
.7	4266.0394	231.5354	.7	4741.6765	244.1017	.7	5242.4463	256.6681	.7	5768.3490	269.2345
.8	4277.6240	231.8395	.8	4753.8894	244.4159	.8	5255.2876	256.9823	.8	5781.8185	269.5486
.9	4289.2243	232.1637	.9	4766.1181	244.7301	.9	5268.1446	257.2966	.9	5795.3038	269.8628

TABLES OF AREAS AND CIRCUMFERENCES OF CIRCLES—Continued.

Diam.	Area.	Circum.	Diam.	Area.	Circum.
86.0	5808.8048	270.2770	90.0	6361.7251	282.7433
.1	5822.3215	270.4911	.1	6375.8701	283.0575
.2	5835.8539	270.8053	.2	6390.0309	283.3717
.3	5849.4020	271.1194	.3	6404.2073	283.6858
.4	5862.9659	271.4336	.4	6418.3995	284.0000
.5	5876.5454	271.7478	.5	6432.6073	284.3141
.6	5890.1407	272.0619	.6	6446.8309	284.6283
.7	5903.7516	272.3761	.7	6461.0701	284.9425
.8	5917.3783	272.6902	.8	6475.3251	285.2566
.9	5931.0206	273.0044	.9	6489.5958	285.5708
87.0	5944.6787	273.3186	91.0	6503.8822	285.8849
.1	5958.3525	273.6327	.1	6518.1843	286.1991
.2	5972.0420	273.9469	.2	6532.5021	286.5133
.3	5985.7472	274.2610	.3	6546.8356	286.8274
.4	5999.4681	274.5752	.4	6561.1848	287.1416
.5	6013.2047	274.8894	.5	6575.5498	287.4557
.6	6026.9570	275.2035	.6	6589.9304	287.7699
.7	6040 7250	275.5177	.7	6604 3268	288.0840
.8	6054.5088	275.8318	.8	6618.7388	288.3982
.9	6068.3082	276.1460	.9	6633.1666	288.7124
88.0	6082.1234	276.4602	92.0	6647.6101	289.0265
.1	6095.9542	276.7743	.1	6662.0692	289.3407
.2	6109.8008	277.0885	.2	6676.5441	289.6548
.3	6123.6631	277.4026	.3	6691.0347	289.9690
.4	6137.5411	277.7168	.4	6705.5410	290.2832
.5	6151.4348	278.0309	.5	6720.0630	290.5973
.6	6165.3442	278.3451	.6	6734.6008	290.9115
.7	6179.2693	278.6563	.7	6749.1542	291.2256
.8	6193.2101	278.9740	.8	6763.7233	291.5398
.9	6207.1666	279.2876	.9	6778.3082	291.8540
89.0	6221.1389	279 6017	93.0	6792.9087	292.1681
.1	6235.1268	279.9159	.1	6807.5250	292.4823
.2	6249 1304	280.2301	.2	6822.1569	292.7964
.3	6263.1498	280 5442	.3	6836.8046	293.1106
.4	6277.1849	280.8584	.4	6851.4680	293.4248
.5	6291.2356	281.1725	.5	6866.1471	293.7389
.6	6305.3021	281.4867	.6	6880.8419	294.0531
.7	6319.3843	281.8009	.7	6895.5524	294.3672
.8	6333.4822	282.1150	.8	6910.2786	294.6814
.9	6347.5958	282.4292	.9	6925.0205	294.9956

Diam.	Area.	Circum.	Diam.	Area.	Circum.
94.0	6939.7782	295.3097	97.0	7389.8113	304.7345
.1	6954.5515	295.6239	.1	7405.0559	305.0486
.2	6969.3106	295.9380	.2	7420.3162	305.3628
.3	6984.1453	296.2522	.3	7435.5922	305.6770
.4	6998.9658	296.5663	.4	7450.8839	305.9911
.5	7013.8019	296.8805	.5	7466.1913	306.3053
.6	7028.6538	297.1947	.6	7481.5144	306.6194
.7	7043.5214	297.5088	.7	7496.8532	306.9336
.8	7058.4047	297.8230	.8	7521.2078	307.2478
.9	7073.3033	298.1371	.9	7527.5780	307.5619
95.0	7088.2184	298.4513	98.0	7542.9640	307.8761
.1	7103.1488	298.7655	.1	7558.3656	308.1902
.2	7118.1950	299.0796	.2	7573.7830	308.5044
.3	7133.0568	299.3938	.3	7589.2161	308.8186
.4	7148.0343	299.7079	.4	7604.6648	309.1327
.5	7163.0276	300.0221	.5	7620.1293	309.4469
.6	7178.0366	300.3363	.6	7635.6095	309.7610
.7	7193.0612	300.6504	.7	7651.1054	310.0752
.8	7208.1016	300.9646	.8	7666.6170	310.3894
.9	7223.1577	301.2787	.9	7682.1444	310.7035
96.0	7238.2295	301.5929	99.0	7697.6893	311.0177
.1	7253.3170	301.9071	.1	7713.2461	311.3318
.2	7268.4202	302.2212	.2	7728.8206	311.6460
.3	7283.5391	302.5354	.3	7744.4107	311.9602
.4	7298.6737	302.8405	.4	7760.0166	312.2743
.5	7313.8240	303.1637	.5	7775.6382	312.5885
.6	7328.9901	303.4779	.6	7791.2754	312.9026
.7	7344.1718	303.7920	.7	7806.9284	313.2168
.8	7359.3693	304.1062	.8	7822.5971	313.5300
.9	7374.5824	304.4203	.9	7838.2815	313.8451
			100.0	7853.9816	314.1593

CIRCULAR MEASURE.

60 seconds (″) make 1 minute (′).
60 minutes " 1 degree (°).
360 degrees " 1 circum. (C.).

The circumference of every circle whatever, is supposed to be divided into 360 equal parts, called *degrees*.

A degree is $\frac{1}{360}$ of the circumference of any circle, small or large.

A quadrant is a fourth of a circumference, or an arc of 90 degrees.

A degree is divided into 60 parts called minutes, expressed by the sign (′), and each minute is divided into 60 seconds, expressed by (″); so that the circumference of any circle contains 21,600 minutes, or 1,296,000 seconds.

LONG MEASURE—MEASURES OF LENGTH.

12 inches	= 1 foot.	40 rods	= 1 furlong.
3 feet	= 1 yard.	8 furlongs	= 1 common mile.
5½ yards	= 1 rod.	3 miles	= 1 league.

The mile (5,280 feet) of the above table is the legal mile of the United States and England, and is called the statute mile.

ROMAN TABLE.

I.	denotes	One.	XVII.	denotes	Seventeen.
II.	"	Two.	XVIII.	"	Eighteen.
III.	"	Three.	XIX.	"	Nineteen.
IV.	"	Four.	XX.	"	Twenty.
V.	"	Five.	XXX.	"	Thirty.
VI.	"	Six.	XL.	"	Forty.
VII.	"	Seven.	L.	"	Fifty.
VIII.	"	Eight.	LX.	"	Sixty.
IX.	"	Nine.	LXX.	"	Seventy.
X.	"	Ten.	LXXX.	"	Eighty.
XI.	"	Eleven.	XC.	"	Ninety.
XII.	"	Twelve.	C.	"	One hundred.
XIII.	"	Thirteen.	D.	"	Five hundred.
XIV.	"	Fourteen.	M.	"	One thousand.
XV.	"	Fifteen.	$\overline{\text{X}}$.	"	Ten thousand.
XVI.	"	Sixteen.	$\overline{\text{M}}$.	"	One million.

GREEK ALPHABET.

Α	α	alpha	Ι	ι	iōta	Ρ	ρ	rho
Β	β	bēta	Κ	κ	kappa	Σ	σ	sigma
Γ	γ	gamma	Λ	λ	lambda	Τ	τ	tau
Δ	δ	delta	Μ	μ	mu	Υ	υ	upsīlon
Ε	ε	epsīlon	Ν	ν	nu	Φ	φ	phi
Ζ	ζ	zeta	Ξ	ξ	xi	Χ	χ	chi
Η	η	ēta	Ο	ο	omīcron	Ψ	ψ	psi
Θ	θ	thēta	Π	π	pi	Ω	ω	ōmega

NOTE.—The letters of the Greek alphabet are used sometimes as arbitrary signs, and the letter π (pi) is used almost universally to represent the ratio of the circumference to the diameter of the circle.

TABLES

Of Squares and Cubes, and Square and Cube Roots of numbers from 1 to 200. (See opposite column.)

RULES.

To find side of an inscribed square—

Multiply diameter by 0.7071.
Or multiply circumference " 0.2251.
Or divide " " 4.4428.

To find side of an equal square—

Multiply diameter by 0.8862.
Or divide " " 1.1264.
Or multiply circumference " 0.2821.
Or divide " " 3.545.

Square—

A side multiplied by 1.4142 equals diameter of its circumscribing circle.

A side multiplied by 4.443 equals circumference of its circumscribing circle.

A side multiplied by 1.128 equals diameter of an equal circle.

A side multiplied by 3.544 equals circumference of an equal circle.

A side multiplied by 1.273 equals circle inches of an equal circle.

SQUARES, CUBES AND ROOTS.

Number.	Square.	Cube.	Square Root.	Cube Root.
1	1	1	1.0	1.0
2	4	8	1.414213	1.25992
3	9	27	1.732050	1.44225
4	16	64	2.0	1.58740
5	25	125	2.236068	1.70997
6	36	216	2.449489	1.81712
7	49	343	2.645751	1.91293
8	64	512	2 828427	2.0
9	81	729	3.0	2.08008
10	100	1000	3.162277	2.15443
11	121	1331	3.316624	2.22398
12	144	1728	3.464101	2.28942
13	169	2197	3.605551	2.35133
14	196	2744	3.741657	2.41014
15	225	3375	3.872983	2.46621
16	256	4096	4.0	2.51984
17	289	4913	4.123105	2.57128
18	324	5832	4.242640	2.62074
19	361	6859	4.358898	2.66840
20	400	8000	4.472136	2.71441
21	441	9261	4.582575	2.75892
22	484	10648	4.690415	2.80203
23	529	12167	4.795831	2.84386
24	576	13824	4.898979	2.88449
25	625	15625	5.0	2.92401
26	676	17576	5.099019	2.96249
27	729	19683	5.196152	3.0
28	784	21952	5.291502	3.03658
29	841	24389	5.385164	3.07231
30	900	27000	5.477225	3.10723
31	961	29791	5.567764	3.14138
32	1024	32768	5.656854	3.17480
33	1089	35937	5.744562	3.20753
34	1156	39304	5.830951	3.23961
35	1225	42875	5.916079	3.27106
36	1296	46656	6.0	3.30192
37	1369	50653	6.082762	3.33222
38	1444	54872	6.164414	3.36197
39	1521	59319	6.244998	3.39121
40	1600	64000	6.324555	3.41995

TABLES OF SQUARES, CUBES AND ROOTS—Continued.

Number.	Square.	Cube.	Square Root.	Cube Root.
41	1681	68921	6.403124	3.44821
42	1764	74088	6.480740	3.47602
43	1849	79507	6.557438	3.50339
44	1936	85184	6.633249	3 53034
45	2025	91125	6.708203	3.55689
46	2116	97336	6.782330	3.58304
47	2209	103823	6.855654	3.60882
48	2304	110592	6.928303	3.63424
49	2401	117649	7.0	3.65930
50	2500	125000	7.071067	3.68403
51	2601	132651	7.141428	3.70843
52	2704	140608	7.211102	3.73251
53	2809	148877	7.280109	3.75628
54	2916	157464	7.348469	3.77976
55	3025	166375	7.416198	3.80295
56	3136	175616	7.483314	3.82586
57	3249	185193	7.549834	3.84850
58	3364	195112	7.615773	3.87087
59	3481	205379	7.681145	3.89299
60	3600	216000	7.745966	3.91486
61	3721	226981	7.810249	3.93649
62	3844	238328	7.874007	3.95789
63	3969	250047	7.937253	3.97905
64	4096	262144	8.0	4.0
65	4225	274625	8.062257	4.02072
66	4356	287496	8.124038	4.04124
67	4489	300763	8.185352	4.06154
68	4624	314432	8.246211	4.08165
69	4761	328509	8.306623	4.10156
70	4900	343000	8.366600	4.12128
71	5041	357911	8.426149	4.14081
72	5184	373248	8.485281	4.16016
73	5329	389017	8.544003	4.17933
74	5476	405224	8.602325	4.19833
75	5625	421875	8.660254	4.21716
76	5776	438976	8.717797	4.23582
77	5929	456533	8.774964	4.25432
78	6084	474552	8.831760	4.27265
79	6241	493039	8.888194	4.29084
80	6400	512000	8.944271	4.30887

Number.	Square.	Cube.	Square Root.	Cube Root.
81	6561	531441	9.0	4.32674
82	6724	551368	9.055385	4.34448
83	6889	571787	9.110438	4.36207
84	7056	592704	9.165151	4.37951
85	7225	614125	9.219544	4.39683
86	7396	636056	9.273618	4.41400
87	7569	658503	9.327379	4.43104
88	7744	681472	9.380831	4.44796
89	7921	704969	9.433981	4.46474
90	8100	729000	9.486833	4.48140
91	8281	753571	9.539392	4.49794
92	8464	778688	9.591663	4.51435
93	8649	804357	9.643650	4.53065
94	8836	830584	9.695359	4.54683
95	9025	857375	9.746794	4.56290
96	9216	884736	9.797959	4.57785
97	9409	912673	9.848857	4.59470
98	9604	941192	9.899494	4.61043
99	9801	970299	9.949874	4.62606
100	10000	1000000	10.0	4.64158
101	10201	1030301	10.049875	4.65701
102	10404	1061208	10.099504	4.67233
103	10609	1092727	10.148891	4.68754
104	10816	1124864	10.198039	4.70266
105	11025	1157625	10.246950	4.71769
106	11236	1191016	10.295630	4.73262
107	11449	1225043	10.344080	4.74745
108	11664	1259712	10.392304	4.76220
109	11881	1295029	10.440306	4.77685
110	12100	1331000	10.488088	4.79142
111	12321	1367631	10.535653	4.80589
112	12544	1404928	10.583005	4.82028
113	12769	1442897	10.630145	4.83458
114	12996	1481544	10.677078	4.84880
115	13225	1520875	10.723805	4.86294
116	13456	1560896	10.770329	4.87699
117	13689	1601613	10.816653	4.89097
118	13924	1643032	10.862780	4.94086
119	14161	1685159	10.908712	4.91868
120	14400	1728000	10.954451	4.93242

TABLES OF SQUARES, CUBES AND ROOTS—Continued.

Number.	Square.	Cube.	Square Root.	Cube Root.
121	14641	1771561	11.0	4.94608
122	14884	1815848	11.045361	4 95967
123	15129	1860867	11.090536	4.97319
124	15376	1906624	11.135528	4.98663
125	15625	1953125	11.180339	5.0
126	15876	2000376	11.224972	5.01329
127	16129	2048383	11.269427	5.02652
128	16384	2097152	11.313708	5.03968
129	16641	2146689	11.357816	5.05277
130	16900	2197000	11.401754	5.06579
131	17161	2248091	11.445523	5.07875
132	17424	2299968	11.489125	5.09164
133	17689	2352637	11.532562	5.10446
134	17956	2406104	11.575836	5.11723
135	18225	2460375	11.618950	5.12992
136	18496	2515456	11.661903	5.14256
137	18769	2571353	11.704699	5.15513
138	19044	2628072	11.747344	5.16764
139	19321	2685619	11.789826	5.18010
140	19600	2744000	11.832159	5.19249
141	19881	2803221	11.874342	5.20482
142	20164	2863288	11.916375	5.21710
143	20449	2924207	11.958260	5.22932
144	20736	2985984	12.0	5.24148
145	21025	3048625	12.041594	5.25358
146	21316	3112136	12.083046	5.26563
147	21609	3176523	12.123455	5.27763
148	21904	3241792	12.165525	5.28957
149	22201	3307949	12.266555	5.30145
150	22500	3375000	12.247448	5.31329
151	22801	3442951	12.288205	5.32507
152	23104	3511808	12.328828	5.33680
153	23409	3581577	12.369316	5.34848
154	23716	3652264	12.409673	5.36010
155	24025	3723875	12.449899	5.37168
156	24336	3796416	12.489996	5.38323
157	24649	3869893	12.529964	5.39469
158	24964	3944312	12.569805	5.40612
159	25281	4019679	12.609520	5.41750
160	25600	4096000	12.649110	5.42883

Number.	Square.	Cube.	Square Root.	Cube Root.
161	25921	4173281	12.688577	5.44012
162	26244	4251528	12.727922	5.45136
163	26569	4330747	12.767145	5.43255
164	26896	4410944	12.806248	5.47370
165	27225	4492125	12.845232	5.48480
166	27556	4574296	12.884098	5.49586
167	27889	4657463	12.922848	5.50687
168	28224	4741632	12.961481	5.51784
169	28561	4826809	13.0	5.52877
170	28900	4913000	13.038404	5.53965
171	29241	5000211	13.076696	5.55049
172	29584	5088448	13.114877	5.56129
173	29929	5177717	13.152946	5.57205
174	30276	5268024	13.190906	5.58277
175	30625	5359375	12.228756	5.59344
176	30976	5451776	13.266499	5.60407
177	31329	5545233	13.304134	5.61467
178	31684	5639752	13.341664	5.62522
179	32041	5735339	13.379088	5.63574
180	32400	5832000	13.416407	5.64621
181	32761	5929741	13.453624	5.65665
182	33124	6028568	13.490737	5.66705
183	33489	6128487	13.527749	5.67741
184	33856	6229504	13.564660	5.68773
185	34225	6331625	13 601470	5.69801
186	34596	6434856	13.638181	5.70826
187	34969	6539203	13.674794	5.71847
188	35344	6644672	13.711309	5.72865
189	35721	6751269	13.747727	5.73879
190	36100	6859000	13.784048	5.74889
191	36481	6967871	13 820275	5.75896
192	36864	7077888	13.856406	5.76899
193	37249	7189057	13.892444	5.77899
194	37636	7301384	13.928388	5.78896
195	38025	7414875	13.964240	5.79889
196	38416	7529536	14.0	5.80878
197	38809	7645373	14.035668	5.81864
198	39204	7762392	14.071247	5.82847
199	39601	7880599	14.106736	5.83827
200	40000	8000000	14.142135	5.84803

UNITED STATES STANDARD SIZES OF WROUGHT IRON WELDED PIPE.

Inside diameter nom.	Actual outside Diameter.	Thickness.	Actual inside Diameter.	External circumference.	Internal circumference.	Length of pipe per square foot of outside surface	Length of pipe per square foot of inside surface.	External area.	Actual internal area.	Length of pipe containing one cubic foot.	Weight per foot of length.	No. of threads per inch of screw.	Length of perfect screw
⅛	.405	.068	0.269	1.272	0.848	9.440	14.15	.129	.0572	2500.	.243	27	0.19
¼	.54	.088	0.364	1.696	1.144	7.075	10.50	.229	.1041	1385.	.422	18	0.29
⅜	.675	.091	0.493	2.121	1.552	5.657	7.67	.358	.1916	751.5	.561	18	0.30
½	.840	.109	0.622	2.652	1.957	4.502	6.13	.554	.3048	472.4	.845	14	0.39
¾	1.050	.113	0.824	3.299	2.589	3.637	4.635	.866	.5333	270.0	1.126	14	0.40
1	1.315	.134	1.047	4.134	3.292	2.903	3.679	1.357	.8627	166.9	1.670	11½	0.51
1¼	1.660	.140	1.38	5.215	4.335	2.301	2.768	2.164	1.496	96.25	2.258	11½	0.54
1½	1.90	.145	1.61	5.969	5.061	2.010	2.371	2.835	2.038	70.65	2.694	11½	0.55
2	2.375	.154	2.067	7.461	6.494	1.611	1.848	4.430	3.355	42.36	3.667	11½	0.58
2½	2.875	.204	2.467	9.032	7.754	1.328	1.547	6.491	4.783	30.11	5.773	8	0.89
3	3.50	.217	3.066	10.996	9.636	1.091	1.245	9.621	7.388	19.40	7.547	8	0.95
3½	4.0	.226	3.548	12.566	11.146	.955	1.077	12.566	9.837	14.56	9.055	8	1.00
4	4.50	.237	4.026	14.137	12.648	.849	0.949	15.904	12.730	11.31	10.728	8	1.05
4½	5.0	.247	4.506	15.708	14.153	765	0.848	19.635	15.939	9.03	12.492	8	1.10
5	5.563	.259	5.045	17.475	15.849	629	0.757	24.299	19.990	7.20	14.564	8	1.16
6	6.625	.280	5.065	20.813	19.054	.577	0.630	34.471	28.889	4.98	18.767	8	1.26
7	7.625	.301	7.023	23.954	22.063	.505	0.544	45.663	38.737	3.72	23.410	8	1.36
8	8.625	.322	7.981	27.096	25.076	.444	0.478	58.426	50.039	2.88	28.348	8	1.46
9	9.688	.344	9.00	30.433	28.277	.394	0.425	73.715	63.633	2.26	34.677	8	1.57
10	10.750	.366	10.018	33.772	31.475	.355	0.381	90.762	78.838	1.80	40.641	8	1.68

Thread taper three-fourths inch to one foot.

All pipe below 1½ inches is butt-welded, and proved to 300 pounds per square inch ; 1½ inch and above is lap-welded and proved to 500 pounds per square inch.

INDEX.

"Knowledge is power, and the price of knowledge is continued study"

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