A MANUAL of MECHANICAL DRAWING

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BY

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INTRODUCTION.

The lessons embodied in this work are the outgrowth of some experience in teaching Mechanical Drawing, also of many years of practice as a draughtsman.

It is the belief of the writer of this work that a pupil who has *mastered* the several lessons in their regular order will be able to read any drawing, and further, that he will be capable of making the usual run of drawings that come up in the repair shop, and, in fact, in many of the larger works. It is not the object of the writer to train designers. That would be out of the question, as designing calls for a wide range of knowledge based upon experience, whereas drawing is purely mechanical, and based upon certain unvarying laws.

Some draughtsmen will turn out better work than others. This comes partly from practice, and is in many cases due to a natural aptitude in the manipulation of the instruments.

The pupil in following the work laid out in these pages must not content himself with merely copying the several plates, but should, on the contrary, do each one over and over, until he *knows it absolutely,* and can see the object of the lesson and understand why each line is drawn. He should study the Problems until he has them at his finger tips. In working them over and over again he is not only learning the problems, but is at the same time acquiring facility in the handling of the tools.

The first lesson on the Planes of Projection is of first importance, and must be *understood,* as it is the key to all that follows. This cannot be too strongly emphasized.

If any one takes up this book with the idea of merely copying the plates, he had better not begin; there is no royal road to acquiring the knowledge necessary to become a draughtsman. It can be done only by thoroughly understanding the principles underlying the art of drawing. The only merit claimed for this work is in the selection of the lessons, their systematic arrangement, and in making the explanations simple and direct —stripping them of all needless words.

The same laws apply to all branches of technical drawing; therefore the pupil who has learned the laws upon which technical drawing is based can take up any special line, such as mechanical, architectural, etc.

The aim of this book is to teach these laws and how to apply them, and as the writer has proved the method embodied herein, he feels encouraged to offer the work to those who are wanting this knowledge.

CHAPTER I.

Geometrical Definitions.

1 Space has three Dimensions, called *Length*, *Breadth* and *Thickness*.

2 A *Point* has position, but not magnitude.

3 A *Line* has *length*, but neither *breadth* nor *thickness*.

4 A *Surface* has *two* dimensions, *length* and *breadth*.

5 A *Solid* has *three* dimensions, *length*, *breadth* and *thickness*.

6 A *Straight* line is one which does not change its direction at any point.

7 A *Curved* line is one which does change its direction at every point.

8 A *Broken* line is made up of straight lines, each one lying in a different direction.

9 A *Plane Surface*, or a *Plane*, is a surface in which, if any two points be taken, the straight line joining these points will lie wholly within the surface.

10 A *Curved Surface* is a surface no part of which is plane.

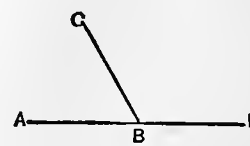
11 A *Plane Figure* is a portion of a plane bounded by lines either straight or curved.

12 A *Straight Line* is the shortest distance between two points.

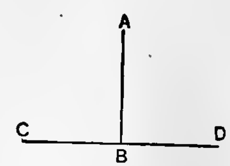
13 An *Angle* is the amount of divergence of two lines; the point in which the lines meet is called the *vertex*.

14 The magnitude of an angle depends wholly upon the *extent of opening* of its sides, and is expressed in degrees (°), minutes (′) and seconds (″).

15 *Adjacent* angles are angles that have a common vertex and a common side. Thus the angles A B C and C B D are adjacent angles.

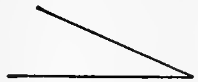


16 A *Right Angle* is an angle included between two straight lines which meet each other so that the two adjacent angles formed by producing one of the lines through the vertex are equal. Thus if the straight line A B meet the straight line C D, making the adjacent angles A B C and A B D equal to each other, they will each be a right angle.



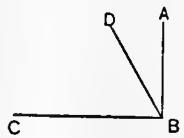
17 *Perpendicular* lines are lines which make a right angle with each other.

18 An *Acute Angle* is less than a right angle.

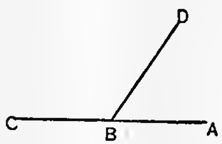


19 An *Obtuse Angle* is greater than a right angle.

20 The *Complement* of an angle is the difference between a right angle and the given angle. Thus A B D is the complement of D B C.



21 The *Supplement* of an angle is the difference between two right angles and the given angle. Thus A B D is the supplement of D B C.

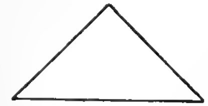


22 As before stated (14), the magnitude of an angle is expressed in degrees, minutes and seconds. The sum of all the angles that can be formed about a given point is equal to 360°, and as but four right angles can be formed about a given point, it follows that each right angle is equal to 90°.

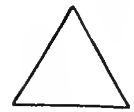
23 A *Triangle* is a portion of a plane bounded by three straight lines.

24 A *Scalene* triangle is one which has no two sides equal.

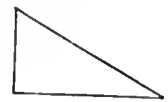
25 An *Isosceles* triangle is one which has two sides equal.



26 An *Equilateral* triangle is one which has all three sides equal.

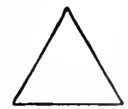


27 A *Right* triangle has one of its angles a right angle. The side opposite the right angle is called the hypothenuse.



28 An *Obtuse* triangle has one of its angles an obtuse angle.

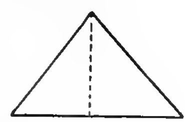
29 An *Acute* triangle is one which has all of its angles acute.



30 An *Equiangular* triangle is one which has all of its angles equal; it is also equilateral.

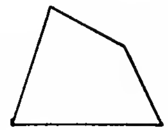
31 The *Base* of a triangle is the side upon which it is supposed to stand, and the angle opposite the base is called the *Vertical* angle, and its vertex is called the Vertex of the triangle.

32 The Altitude of a triangle is the perpendicular distance from the base to the vertex.

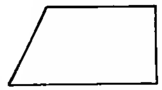


33 A *Quadrilateral* is a plane figure bounded by four straight lines.

34 A *Trapezium* is a quadrilateral which has no two sides parallel.



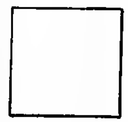
35 A *Trapezoid* is a quadrilateral which has two sides parallel.



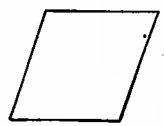
36 A *Parallelogram* is a quadrilateral which has its opposite sides parallel.

37 A *Rectangle* is a parallelogram in which all the angles are right angles.

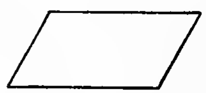
38 A *Square* is a parallelogram in which all the angles are right angles and all the sides equal.



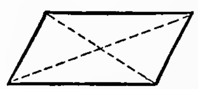
39 A *Rhombus* is a parallelogram which has its sides equal but its angles oblique.



40 A *Rhomboid* is a parallelogram which has its opposite sides equal and its angles oblique.

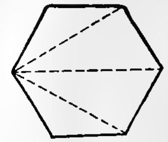


41 A *Diagonal* of a quadrilateral is a straight line joining any two opposite angles.



42 A *Polygon* is a plane figure bounded by straight lines.

43 A *Diagonal* of a polygon is a straight line joining the vertices of two angles not adjacent.

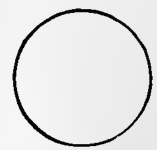


44 An *Equilateral* polygon is one in which all the sides are equal.

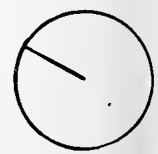
45 An *Equiangular* polygon is one in which all the angles are equal.

46 Polygons are named from the number of their sides. A polygon of three sides is a *Triangle,* one of four sides a *Quadrilateral,* one of five sides a *Pentagon,* one of six sides a *Hexagon,* one of seven sides a *Heptagon,* one of eight sides an *Octagon,* one of nine sides a *Nonagon,* one of ten sides a *Decagon,* one of eleven sides an *Undecagon,* and one of twelve sides a *Dodecagon.*

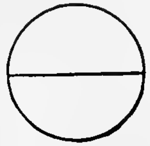
47 A *Circle* is a plain figure bounded by a curved line called the *Circumference,* all points of which are equally distant from a point within called the *Centre.*



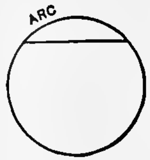
48 A *Radius* of a circle is a straight line drawn from the centre to the circumference.



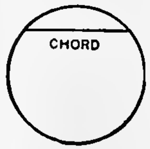
49 A *Diameter* of a circle is any straight line passing through the centre and having its extremities in the circumference.



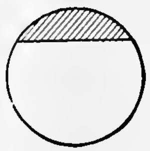
50 An *Arc* of a circle is any portion of the circumference.



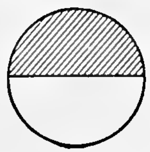
51 A *Chord* of a circle is any straight line having its extremities in the circumference.



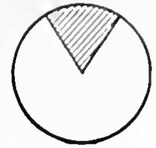
52 A *Segment* of a circle is a portion of the surface enclosed by an arc and its chord.



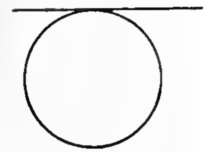
53 A *Semicircle* is a segment equal to half the circle.



54 A *Sector* of a circle is a portion of a circle enclosed by two radii and the arc which they intersect.



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



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

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

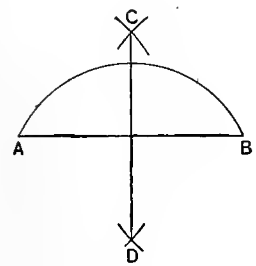
58 A *Polygon* is *inscribed* in a circle when all of its sides are chords of the circle.

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

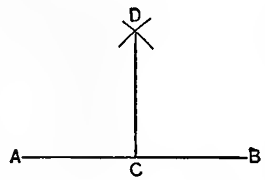
CHAPTER II.

Problems.

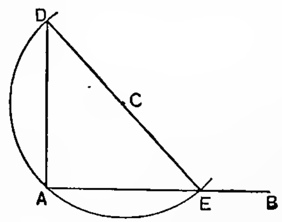
1 To *bisect* a straight line, draw a radial line to an arc or to bisect an arc. Let A B be the given line or arc. With A and B as centres and a radius greater than half the length of the line or arc, sweep the arcs intersecting at C and D, draw the line C D.



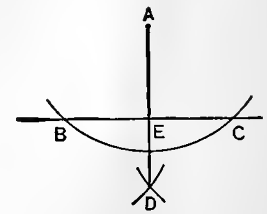
2 To draw a perpendicular to a straight line from a given point in that line. Let C be the given point in the line A B. With C as a centre, draw the arcs at A and B, making A C and C B equal; then with A and B for centres, and radius greater than A C, draw the intersecting arcs at D. Join C and D.



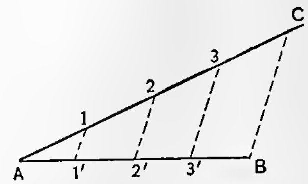
3 From the end of a straight line to draw a perpendicular to that line. From some point without the line as C, draw the arc D A E, passing through A at the extremity of the line and cutting the line at E. From E draw E D through C, draw D A, which will be the required perpendicular.



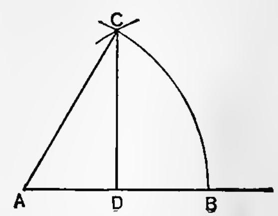
4 To draw a perpendicular to a straight line from any point without that line. Let A be the given point; with A as centre draw an arc cutting the given line at B and C; with B and C for centres and radius greater than B E draw the intersecting arcs at D. Draw A E with A and D as points.



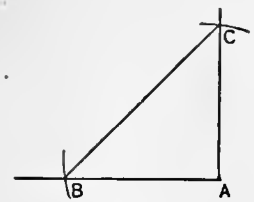
5 To divide a straight line into any number of equal parts. Let A B be the given line. Draw A C at any convenient angle (acute) with A B and mark A C off into the required number of equal points, as 1—2—3. Draw C B and parallel with it 3—3′, 2—2′ and 1—1′.



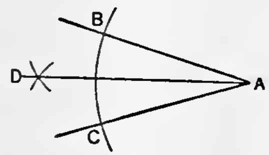
6 To lay off angles of 30° and 60°. Draw A B and with radius A B draw arc B C. With B for centre and same radius draw arc at C, draw C D perpendicular to A B. Then will angle C A D be 60° and D C A 30°.



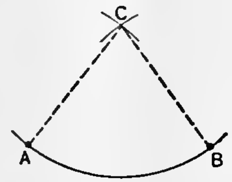
7 To lay off an angle of 45°. Draw A C perpendicular to A B, with A for centre and radius A B draw arcs B and C, draw B C. Then will angles A C B and C B A be angles of 45°.



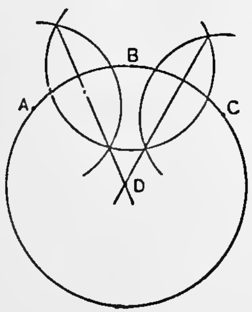
8 To bisect an angle. Let it be required to bisect angle B C A. With A for centre and any convenient radius draw arc B C, then with B and C as centres and radius greater than half B C draw intersecting arcs at D. Join D A.



9 Through two given points draw an arc of circle with a given radius. Let A and B be the given points; then with radius equal to the given radius draw intersecting arcs at C. C will be the centre from which to draw the required arc.

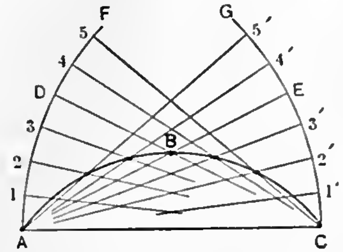


10 To find the centre of a circle or of an arc of a circle. Take any three points in the circumference well separated as A, B and C. With these points as centres draw the intersecting arcs, and through these intersections draw straight lines intersecting at D. D will be the required centre.

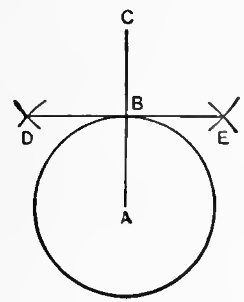


11 To draw a circle through three given points use the same construction as used for No. 10, the centre D being found by the same method.

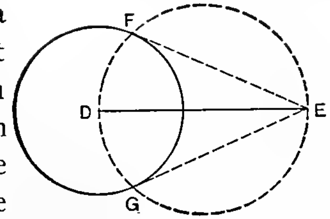
12 To draw an arc of a circle through three given points when the centre is not available. Let it be required to draw an arc of a circle through points A, B and C. With A and C for centres and radius A C draw the indefinite arcs A F and C G. Draw straight lines A B E and C B D. Divide the arcs A D and C E into any number of equal parts and space off D F and E G with the same divisions. Draw A1′, A2′, A3′, etc., and C1, C2, C3, etc., the intersections of these lines will be the points in the required arc.



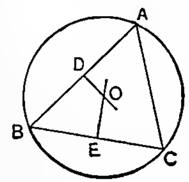
13 To draw a tangent to a circle from a given point in the circumference. Let B be the given point. From the centre of the circle draw the radius A B and prolong it to C, making B C equal to A B. With A and C as centres draw arcs intersecting at D and E; draw D E, which is the required tangent.



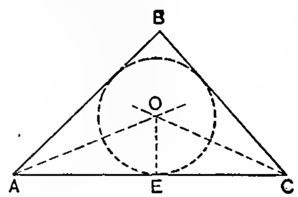
14. To draw tangents to a circle from a point without the circle. Let E be the given point. Join D and E and on D E as a diameter draw the circumference intersecting the given circumference at F and G, draw E F and E G, which will be the required tangents.



15 To describe a circle about a triangle. Bisect any two sides of the triangle as A B at D and B C at E and erect perpendiculars at their point of intersection. O will be the centre of the circle.

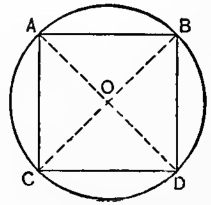


16 To inscribe a circle in a triangle. Draw A D bisecting the angle A and C D bisecting the angle C. With their point of intersection O as centre and radius O E draw the required circle.

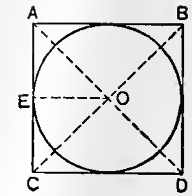


17 To describe a circle about a square. Draw diagonals A D and B C. Their intersection O will be the centre of the circle.

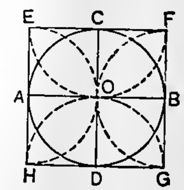
18. To inscribe a square in a circle. Draw diameters A D and B C perpendicular to each other. Draw A B, B D, D C and C A.



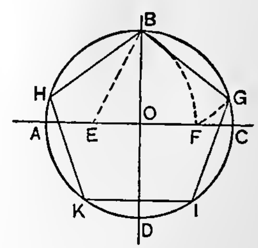
19 To inscribe a circle in a square. Draw diagonals A D and B C, with their intersection O for centre and O E for radius draw the required circle.



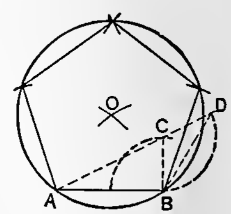
20 To describe a square about a circle. Draw diameters A B and C D perpendicular to each other, with A, B, C and D as centres and A O for radius, draw arcs cutting each other at E, F, G and H. Draw E F, F G, G H and H E.



21 To inscribe a pentagon in a circle. Draw diameters A C and B D cutting at O, bisect A O at E and from E with radius E B cut A C at F. From B with radius B F cut circumference at G and with same radius step off I, K and H. Draw B G, G I, I K, K H and H B.

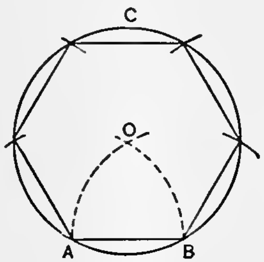


22 To construct a pentagon on a given straight line. Let A B be the given straight line. From B erect a perpendicular B C equal to half the length of A B. Draw A D through C. Make C D equal to B C, then B D is the radius of the circle circumscribing the pentagon. From A and B as centres and radius B D

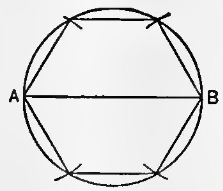


describe arcs cutting at O, which is the centre of the circle. Step off A B around the circumference and draw straight lines connecting the points.

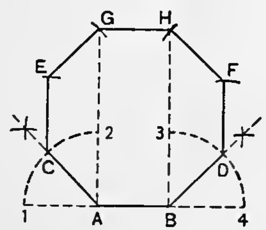
23 To construct a hexagon on a given straight line. Let A B be the given line or length of side of hexagon. With A and B for centres and A B as radius draw arcs cutting at O. From O with radius O A draw circle A B C, and with same radius step off points around the circumference; connect these points to complete the hexagon.



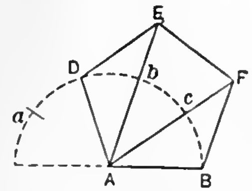
24 To inscribe a hexagon in a circle. Draw diameter A B and with radius equal to the radius of the circle step off points around the circumference; connect these points with straight lines to complete the hexagon.



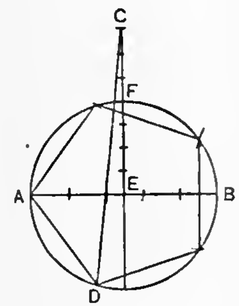
25 To describe an octagon on a given line. Let A B be the given line. Draw A 1 and B 4; also draw A G and B H perpendicular to A B. From A and B with radius A B draw arcs 1—2, 3—4, bisect angles G A 1 and H B 4 and draw A C and B D. With C and D as centres and radius A B draw arcs E and F, and draw C E and D F parallel to A G and B H. With E and F as centres and radius A B draw arcs cutting A G and B H. Draw E G, F H and G H.



26 To describe a polygon of any number of sides on a given straight line. Let A B be the given straight line, produce A B and with radius A B draw a semi-circle, divide this semi-circle into as many equal parts as the polygon is to have sides. Draw line from A through the divisions D, b and c, omitting one point a. With D and B for centres and radius A B cut A b at E and A c at F. Draw D E, E F and B F.



27 To inscribe a polygon of any number of sides within a circle. Draw A B through centre E, draw E C perpendicular to A B cutting circumference at F. Divide E F into four equal parts and point off three of these points from F to C. Divide the diameter A B into as many equal parts as polygon is to have sides, and from C draw C D through the second point cutting the circle at D. Then A D is equal to one side of the polygon. Step around the circumference of the circle with the length A D to complete the polygon.



CHAPTER III.

Drawing Instruments, How to Select, Care for and Use Them.

How to Select Instruments.—The metals usually used for drawing instruments are German silver of varying quality and steel or iron. Iron is used only in the cheapest instruments, and therefore merits no further attention.

The steel should be of the best quality, and properly tempered. The cheaper grades of instruments are made from *castings* of German silver, and because of the softness of the metal the instruments must be made bulky and heavy, in order to secure the requisite stiffness. The makers resort to hammering and swaging to overcome this objection, but the remedy is only partial, and as a consequence the cheap instruments are always clumsy and of poor finish, with badly fitted joints, which soon become loose, rendering the instrument—a compass or dividers, for instance—useless. The points are rarely tempered, and the soft metal is easily bent and always dull. In the best instruments the German silver parts are made from *hard rolled* sheet stock, the blanks being first cut by sawing, and are gradually reduced to form by milling and filing. The joints are carefully fitted, and the hard metal will withstand constant use for many years. They are of graceful form, light in weight and rigid, the finish is of the highest order, the high polish derived from the buffing wheel being conspicuous by its absence, but in its place is found the exquisite finish known as the "mathematical instrument finish."

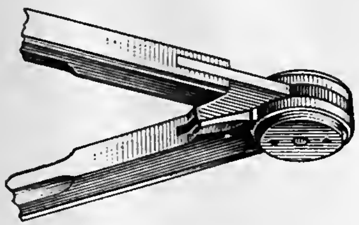
This finish brings out all the beauty of the metal, leaves all corners clean and smooth, but does not hide faults in the material or workmanship.

The most important instruments are Compasses (including Dividers), Ruling Pens and Bows, which are described in detail below.

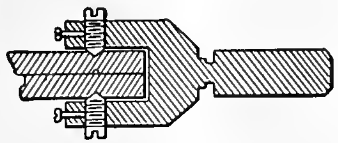
Compasses.—The most essential part of a pair of compasses is the head, which forms the joint. There are two kinds of joints—the *tongue joint,* in which the head of one leg has a tongue, generally of steel, which moves between two lugs on the other leg, and the *pivot joint,* in which each leg is reduced to half thickness at the head. These are embraced by a clamp or yoke, which carries a conical pointed screw in each side, the points of the screws working in sinks in the compass head. The yoke is further provided with a handle with which to manipulate the tool.

The head joint should move freely and evenly throughout its entire range—not stiff at one point and loose at another. It should, however, be tight enough to hold its adjustment when set.

Another important feature in the compass is the socket joint for the several "points." In the following



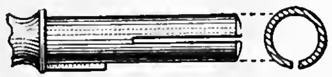
TONGUE JOINT.



PIVOT JOINT.

illustrations are shown two good forms, the long and strong pentagonal shape and the round shank with steel feather or tongue. The former should fit snugly into a socket of the same shape and be held there by a set-screw. The latter (the round shank) is held by the spring of the socket, while the

PENTAGONAL SHANK.



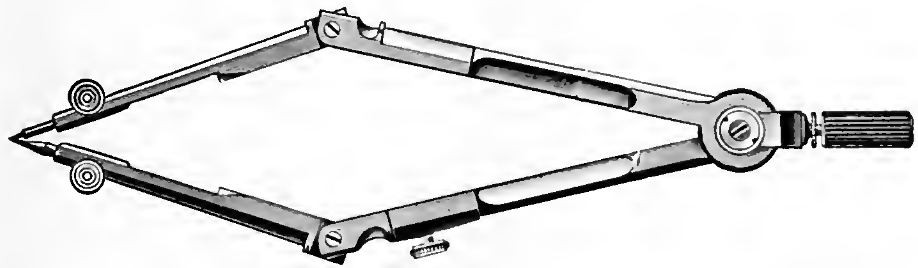
ROUND SHANK WITH STEEL FEATHER.

tongue insures proper alignment; the absence of the set-screw is considered by some a desirable feature.

This is readily tested by inserting the several parts and then bending them, as shown by the cut, when their points should meet. This is also a good test for the alignment of the shank in the socket, and every good instrument should stand the test.

The compass with fixed needle point and interchangeable pen and pencil points and lengthening bar is probably the most convenient instrument, as the steel points are only of use when the compasses are employed as dividers, which is very seldom, as every draughtsman should have in his set of tools a hairspring divider.

To sum up, compasses should be of good material of proper hardness and of sufficient weight to insure



COMPASS IN POSITION FOR TESTING ALIGNMENT.

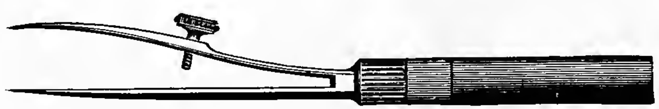
rigidity in all positions. All joints should move in one plane; the shanks of the several "points" should be properly fitted, and the workmanship should be perfect throughout. The finish should be put on with care, and *the instruments should not have a glossy polish,* as this is only a substitute for the proper finish, and is resorted to for the purpose of hiding defects and because it is cheap.

The Drawing Pen is the instrument of a Draughtsman's outfit which is in nearly constant use, and in which defects would therefore become obvious most readily.

Drawing pens are of two different constructions, one kind with a hinge joint to allow the blades to be thrown apart for cleaning, and the other without a joint. The

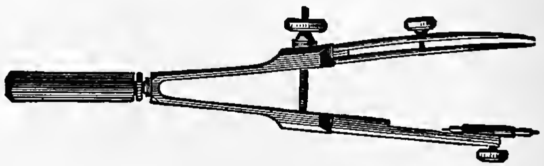
PEN WITH JOINT.

joint should, of course, be very carefully made, otherwise the upper blade soon becomes shaky, and the pen consequently useless. Probably the best pen is the one shown in the cut below, in which the upper blade springs open when the screw is released from the lower blade. A good pen without a joint is to be preferred to the one with a joint, no matter how well it is made, and it costs less.



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 of 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 good quantity of ink without dropping it. The lower blade should be sufficiently firm, to prevent the approach of the blades of the pen when using it against a straight edge. The spring of the pen which separates the two blades should be strong enough to hold the upper blade in its position, but not so strong as to prevent easy adjustment by the thumbscrew. The thread of the thumbscrew should be deeply and evenly cut, so as not to strip easily.

Spring Bows were originally in the shape of small compasses, but have been gradually developed into the form shown in cut below. What is said in the description of ruling pens about the necessity for a sufficiently stiff spring, and about the relation between spring pressure and thumbscrew, applies to bows of spring steel, just as well as to blades of ruling pens.



CARE OF INSTRUMENTS.

Pens.—Keep a piece of soft cotton or muslin at hand and frequently wipe the pen, particularly between the blades, removing all ink scales that may be clinging to them, and always clean the pen thoroughly before laying it away after using. The blades being exposed to the moisture of the ink will in time become corroded. Careful cleaning is the best way to prevent it.

Never use ordinary writing inks. They contain acids which will soon destroy the pen points. When pen points become dull it is always best to have them put in order by a dealer; the cost is trifling, and the work will be properly done, whereas the beginner is liable to do more harm than good. Should there be no dealer accessible, the draughtsman must of course do his own sharpening, practicing on a pen of little value until he has acquired the knack. A good method is as follows: By means of the thumbscrew bring the points together and round them smoothly and evenly on a fine oilstone, a small Arkansas slip being the best for this purpose. This will leave the points thick, but properly rounded and of equal length. Now separate the blades about an eighth of an inch, take the pen in the left hand between the thumb and fore finger and the oilstone in the right hand. Bring the pen and stone together, holding the pen at a very acute angle to the surface of the stone to avoid making the points too short; hold the left hand still and *rub the stone against the pen,* all the time rolling the pen back and forth between the thumb and finger until both points are brought to a thin, smooth edge. Be careful not to get one blade shorter than the other, and never hone the inside of the blade unless it is so badly corroded that a smooth point cannot be secured otherwise. As the work progresses, the pen should be occasionally tried with ink until it will make a fine, clear line without scratching or cutting into the paper. A little practice will enable the average draughtsman to do this work with ease and certainty.

Dividers and Compasses.—Be careful of the points. Do not use them on metal; they are not intended for such use. When the points become dull they can easily be put into proper shape with the oilstone after the manner of pointing a pen. The needle points should be kept sharp, and when they become dull they may be repointed on the oilstone. If a lathe with a small chuck is available, catch the needle point in the chuck, and while it is revolving rapidly sharpen it with the oilstone, using it after the manner of a file. The Arkansas stone being very hard and fine, will retain its square corners indefinitely, if used only for this purpose.

The points of the Compass and Dividers should work freely, with just enough friction to hold them in position when the legs are well opened. If they are too tight it is difficult to adjust them accurately to a required position. The head joint is readily adjusted by means of a key, which is included with the fittings of the instrument, but a real good tool will not require adjustment even after many years of constant use. A cheap one will require very frequent setting. *Do not oil the joints.*

Bows.—What has been said with reference to pens applies equally well to bow pens, and but little further can be said in regard to them except that the adjusting nut and screw should occasionally be oiled and then wiped, so that the fingers and consequently the drawing do not become soiled.

Do not get into the habit of tossing the instruments into a box or drawer; there is always danger of breaking or bending their points. If you do not have a case with compartments to fit the various instruments, get a piece of chamois leather and roll the tools in it, keeping the pieces separate as you roll them.

The T square and triangles, also the scale, should be properly protected, otherwise their edges will become nicked, and consequently useless.

It is well to bear in mind that the draughtsman who is careless of his tools is very apt to be careless in his work.

Use of the Various Tools.—The large Compass is for drawing circles of say from 1½ inches diameter up to their limit, which, with the six-inch size, and using the lengthening bar, will be about 20 inches diameter.

The Hair Spring Dividers are used for dividing lines and circles, and these, by means of the hair spring, are capable of very accurate adjustment.

The small Bow Pen and Pencil are for small circles, 1½ inches diameter and under; also for drawing fillets, rounding corners, etc., while the small spacing or spring divider is used for minute subdivisions for which the large hair spring divider would be unhandy because of its size. The drawing pen is for straight or curved lines, where it is guided by the T square, triangle or curve. This pen is adjusted by means of the thumbscrew to draw fine or coarse lines at will, and in use should be held vertical, or nearly so, that the point, and not the side of the pen, is in contact with the paper, and it should be pressed firmly but lightly against the guiding edge, otherwise the line drawn will not be true and clean.

When using the Compass, always have the needle point in place; thus you will avoid boring large, unsightly holes in the paper and the inaccuracies that would naturally result therefrom.

The T square head should be placed against the left hand end of the drawing board, and should be used only for drawing horizontal lines, while the triangles are for angles of 30°-60° and 90°, and 45° and 90° to these horizontal lines, the blade of the T square being the guide for the triangles. The T square is manipulated by the left hand, the triangles being moved by the right hand to position and held by the left hand while the line is drawn, the blade of the T square being held by the left fore arm or wrist. The 30°-60° triangle can also be used for drawing hexagon bolt heads and nuts, for dividing a circle into six or twelve equal parts, while the 45° triangle will serve for square bolt heads or nuts and for dividing a circle into four or eight equal parts. See Figs. 1 and 2.

They can also be used for drawing parallel lines at other angles than those given. Place the two triangles together, as in Fig. 3, and bring one edge of one of them to the line to which the parallel is to be drawn.

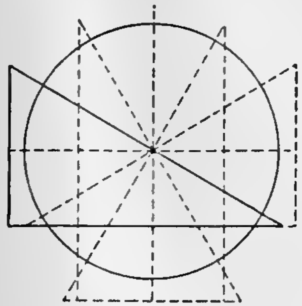


Fig. 1.

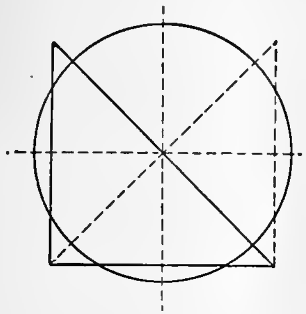


Fig. 2.

Hold triangle A firmly with the left hand and slide triangle B along in either direction, holding it firmly against A, to the point through which the line is to be drawn.

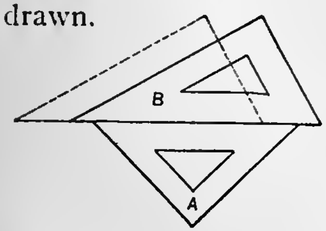


Fig. 3.

The Pencil should be sharpened at both ends, the lead quite long, and brought to a fine round point at one end and to a chisel point at the other. The round point is for marking off from the scale, the other for drawing the lines. The reason for sharpening one lead flat is that it will wear longer than a round point, but it is not suited for laying off from the scale, hence the round point for that purpose. A fine file or piece of fine sand or emery paper is used for sharpening the lead, preferably the former. Lines should be drawn firm and clear, but not too hard, as it is difficult to erase them when they are cut deep into the paper through too great pressure on the hard lead. For compass points and bow pencil use Faber's 6H artists' leads, and sharpen them to the chisel point as described above.

To mount a sheet of paper on the drawing board proceed as follows:

In Fig. 4, A is the drawing board, B the paper. First pin the upper left hand corner to the board at C, stretch the paper from C to the lower right hand corner D by drawing the palm of the hand in the direction of the arrow, using enough pressure to draw the paper, but not sufficient to tear it away from C, and put in pin D. Next beginning at the middle, stretch the paper toward the lower left hand corner and put in pin E, and finally stretch from centre and put in the remaining pin D. Except on large sheets of paper it is not necessary to use more than the four pins at the corners of the sheet.

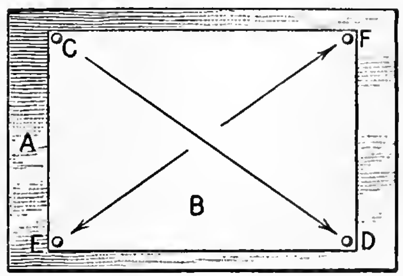


Fig. 4.

The beginner should practice on the figures of Chapter II until he is thoroughly familiar with them, at first using the pencil only until he has acquired neatness of execution, and not until then should he resort to the pens. In fact, he would do well to work at the exercises in projection, sections and the construction of the various curves and other figures, doing each lesson over repeatedly until he is not only familiar with them, but can as well make a clean, neat pencil drawing. Then will be time enough for ink drawing.

Lines.—The lines usually employed in mechanical drawing are:

The *fine full* line for the figure to be represented.

The *heavy full* line, shade or shadow lines.

The *dot* and *dash* for centre lines. ·——·——·——·——

The *dash* and *two dots* for centre lines. ——··——··——··

The *dot* - - - - - - - - - - - - - - - - - - - for indicating internal parts or parts that may be behind others; also to indicate dimensions. When the dotted line is used to mark dimensions the arrow head or witness mark > is placed at each end, to indicate the points between which the measurement is taken, and the dimension is marked on the line in figures thus

←- - - - - $1\frac{1}{4}''$ - - - - -→

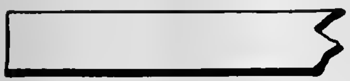
In addition to the figures indicating dimensions, there are other instructions to be given the mechanic, such as directions in regard to *finish* or machining. When a piece of machinery is to be worked or machined in every detail, the general direction "Finish all over" tells the mechanic it is to be turned, planed, filed, or otherwise worked to bring it to the required dimensions. Further, the expression informs the pattern maker or smith that additional metal over the dimensions given is to be left to be removed in the operation of *finishing*. When only certain surfaces are to be finished, leaving the remaining parts rough, the mark "f" is placed upon the surface.

When one piece is to be fitted to another hard or tight, such as a bolt into a hole, the kind of fit is marked on the particular piece, such as "driving fit," which means that the bolt is to be turned of such a size that it must be driven to place with a hammer. Again, "reamed fit" would mean that the bolt should be turned so that it can be pushed or lightly tapped to place, and yet must fit so perfectly that it will not admit of the slightest movement.

Any special directions can be given, but they should be stated concisely. When the directions cannot be marked directly upon the object, an arrow connecting the explanation with the point or part referred to must be used. Examples of these directions are given in the several lessons on shop drawings.

In drawing these broken lines, acquire the habit of making all the dots equal in length; also the spaces between them.

Where it is desired to show only a portion of an object it is represented as broken. If the object is square or rectangular in section the break is represented by



a ragged line, thus:
If round, thus:

Shade lines, while not necessary, always improve the appearance of the drawing, making it stand out from the paper, and aiding the eye in taking in the form. The rule to be followed in putting them in a drawing is simple. The light is supposed to strike the upper and left hand sides of the object—that is, to strike at an angle of 45°, thus putting the right hand side and bottom in shadow, or rather making them cast a shadow. This is shown in the figure of a square (Fig. 5), the arrow indicating the direction of the light rays. Objects having corners or edges are plainly shown by means of these shade lines. A cylinder in elevation should not be shaded, but the square end should be shaded, as in Fig. 6. A cylinder in plan would show a circle, and this should be shaded, the shade line extending around half the circumference, the heaviest part of the line being opposite the highest light and gradually reducing in width to that of the light line. To do this, draw first the line representing the cylinder, then find a new centre in a line following the direction of the light, and with the same radius draw another line on the lower right side for the outside, and the upper left for the inside of the cylinder. In Fig. 7 this is shown with lines exaggerated in order to show how the compass point is to be placed.

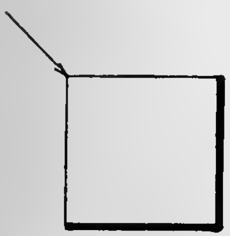


FIG. 5.

FIG. 6.

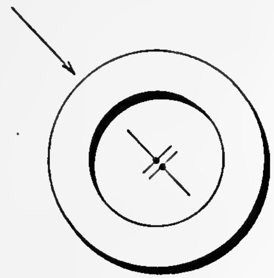


FIG. 7.

An object shown in section is indicated by "section lines"—that is, by parallel lines at the angle of 45° to the main lines of the object. When the object is made up of two or more pieces the section lines for one piece are drawn at right angles, or 90°, to those of the next piece. See Fig. 8 and the lesson plates.

Lines are also used to represent the various materials of construction when shown in section. These are shown on Plate 39.

The light lines should be uniform in breadth, as well as the shade lines, while section lines should vary according to material to be represented. Many draughtsmen do not use the

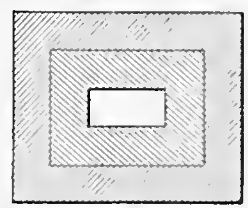


FIG. 8.

"conventional" lines referred to above, but instead employ only the simple fine line as in Fig. 8, and indicate the material to be used by marking its name upon the figure.

Line Shading is sometimes employed, but not often, as when it is considered necessary to make some particular piece or part of a drawing conspicuous, or it is desired to make a *picture* of the drawing, as, for instance, a complete machine. This is accomplished by varying the widths or thickness of the lines and the spaces between them. Several examples of line shading are given in Plate **42.**

Fig. 1. End and side elevation of a cylinder. The rule to be followed is for the direction of light the same as for shade lines. Objects in elevation are lighted from the upper left hand corner, therefore the highest light would be at the point where the light strikes full upon the surface and the darkest point about at right angles to the high light. This is clearly shown in Fig. 1. A hollow object, such as a cylinder in section, would show light and shadow just the opposite of what would appear on the outside surface of the cylinder. (See Fig. 2.)

Figs. 3 and 4 show a square and hexagonal prism in elevation; above them the plans. In the case of the plan the light will strike from the lower left hand, as shown. In this case, the surfaces being flat, the lines are equally spaced over the surface. The flat side, receiving the light direct, being covered with light lines equally spaced, while the side away from the light is covered with heavy lines, also equally spaced. In Fig. 4, there being three sides, each one being lined differently, the lightest side next the light and the darkest farthest from the light. In Fig. 5 is shown a flat surface, and to show the effect of the slightest variation, either in the width or spacing of the lines, one of the spaces is purposely increased; this at once makes a break in the surface. This shows at once the necessity for absolute accuracy in both spacing and thickness of the lines. In Fig. 6 is shown a waving or corrugated surface, while Fig. 7 shows how a sphere should be shaded. The point of high light would be a small circle somewhat less in diameter than the radius of the sphere.

Lettering.—Plain, strong letters and figures only should be used, fancy lettering being out of place on a mechanical drawing; they are also liable to be confusing to the mechanic who is to work from the drawing. There are two styles that are particularly suited to drawings. The Roman for titles and the Italic, with figures to correspond, for notes on the body of the drawing and for dimensions. The light-faced Roman may also be used for this purpose. These several alphabets are given on Plate 40.

As to titles, these are gradually being discontinued by most of the large workshops, and the simple system of numbering substituted therefor. The drawing under this system bears in one of its corners a large number or letter, which indicates its class, or the group to which it belongs, and another number the drawer in which it is filed; also in small letters the scale or scales, if more than one on the sheet, the date of completion, as well as the initials of the draughtsman and the checker. If there is more than one sheet to a given machine then these sheets should be plainly numbered consecutively.

An index is kept, which gives the name of the machine and the part or parts represented on each sheet, as well as the number of the sheet and the drawer in which it is kept, so that any particular drawing can be found instantly.

A sample of a form used very generally is given in the annexed figure, in which all of the means or marks for identification are given.

Mark............	*Drawer*............
No. Sheets............	*Sheet No.*............
Drawn by............	*Checked by*............
Traced by............	*Date*............
Scale............	
Smith, Jones & Co.	

Should the drawing be changed at any subsequent time, the changes are noted on the drawing and the record of the change is made above the title in the form of a sub-title, thus:

Altered	*Date* 5/10/03	*Parts* 27
"	"	"

Example: It is learned that a certain machine can be improved by making a slight change in a particular casting. Said change is a minor one, and will not necessitate a new drawing. Accordingly, the old drawing is changed, and the date and number of the part recorded as above. That is, part No. 27 was altered May 10th, 1903. If more than one part is altered these changes are duly recorded, one beneath the other, as indicated. If the change requires a new drawing, this drawing is given a new number, and the fact noted on the old drawing, which is preserved, thus making the history of the development of the machine complete. This follows upon the practice of numbering each individual piece of the machine as is indicated on Plate 52.

Some of the large shops simply mark in the lower right hand corner of their drawings in large figures and letters, as: **36-A-5.** *3-27-03* meaning Machine No. 36, Drawer A, Sheet No. 5, March 27th, 1903. All other data being recorded in the index book.

Dimensions.—In putting the figures or dimensions on a drawing, do not be afraid of putting on too many. The drawing should answer every question the mechanic can ask—in short, should give full information upon every point and for every class of mechanic. Therefore the draughtsman should consider who will work from the drawing; if pattern makers, machinists and blacksmiths, supply full information for each one. In fact, let the drawing be looked upon as something to indicate certain forms, and make it supply full information from which to reproduce these forms in the metals or other materials. Feet are indicated by a single mark and inches by two marks, and are separated by a dash. Two feet six and one-half inches would be written on the drawing thus, $2'—6\frac{1}{2}''$. Three feet and one-quarter of an inch thus, $3'—0\frac{1}{4}''$.

The Scales.—Those usually employed are half size, in which a half inch on the drawing represents an inch on the machine, then each eighth of an inch is equal to a quarter of an inch, and each sixteenth to an eighth; quarter size, or three inches to a foot; eighth size, or one and a half inches to one foot; one-twelfth, or one inch to one foot; one-sixteenth, or three-quarters of an inch to the foot; one twenty-fourth, or half inch to the foot, and so on down. Smaller than one-quarter inch to the foot is rarely used. The larger the scale the better, as it is easier to show detail on a large scale than a small one; also large scale drawings are more likely to be accurate. Whatever the unit chosen to represent a foot it is divided into twelve equal parts, representing inches, and if the unit is large enough these are further divided into halves, quarters and even eighths, as in the scale of $3''=1$ foot.

The beginner should acquire accuracy in drawing the lines, as well as in figuring the drawing. Certain main dimensions are always required to begin the drawing, but when it is completed and the dimensions are to be put in, these must be taken from the drawing with the scale. When there are a number of intermediate dimensions, be sure that their sum is equal to the extreme or over all dimension, as in the sketch for a crank shaft (Fig. 9).

Freehand sketching should be acquired by every

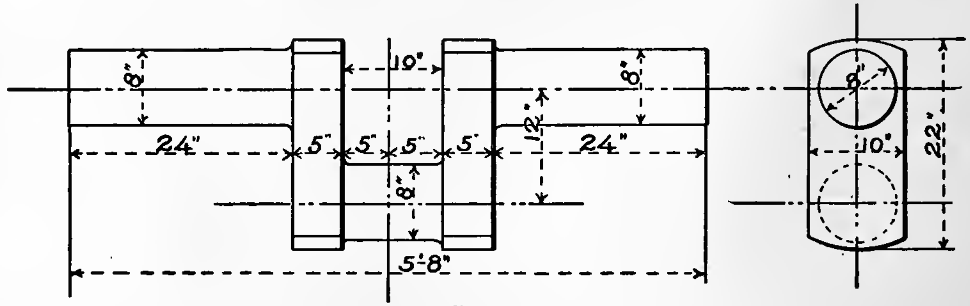


FIG. 9.

draughtsman, as he is frequently called upon to make sketches from broken pieces of machinery, to be afterwards used as notes from which to make drawings. These sketches consist of outlines giving the form of the object in as many views as may be necessary to show its form and bearing the measurements required for making a correct drawing.

In taking a dimension from the scale—for instance an inch—do not mark it off either full or scant, but let it be just an inch. Always draw the centre line or lines about which the figures are to be constructed as the starting point, and work from these centre lines.

Do not consume needless space. Place the several views of an object near enough to each other that their relation will be established at a glance, and do not make needless views. Consider the form and decide what are the best points from which to view it, and make the drawing accordingly.

In drawing a tangent to an arc or a circle, make it truly tangent; also in putting in fillets or in rounding corners do it thus:  Not thus: 

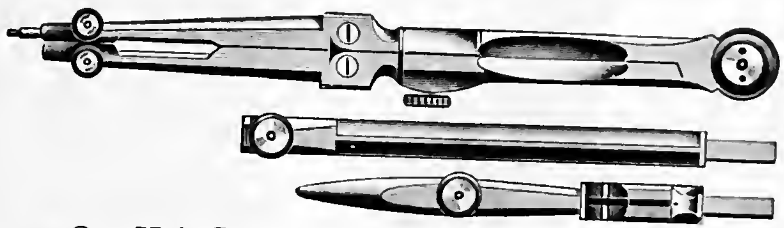
Or thus: 

In drawing or finishing a drawing with ink it is best to fill in the circles and arcs first, afterwards drawing the straight lines, the reason being that it is easier to fit a tangent or straight line to an arc or curve than is the reverse process.

INSTRUMENTS REQUIRED.

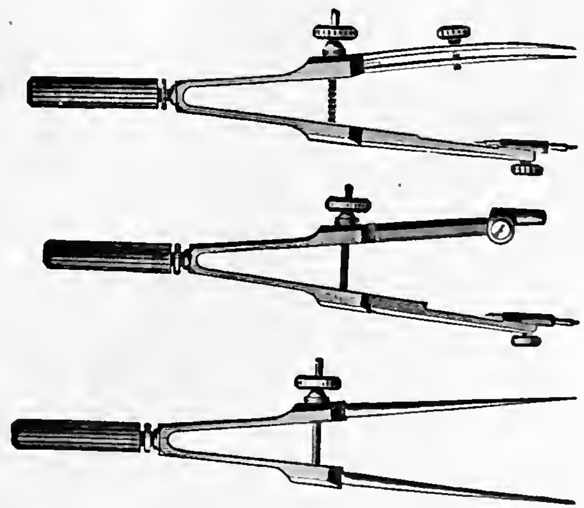
The mechanical or architectural draughtsman may do his work with comparatively few instruments, therefore there should be no real excuse for his buying any but the best quality, and the beginner is urged to bear in mind the various descriptions given at the beginning of this chapter when making his selection. The following tools and supplies will be required, and they will be found ample in number and size for the average of the work done by the draughtsman:

One Compass $5\frac{1}{2}$ inches or 6 inches long, with fixed needle point, pen and pencil points and lengthening bar.



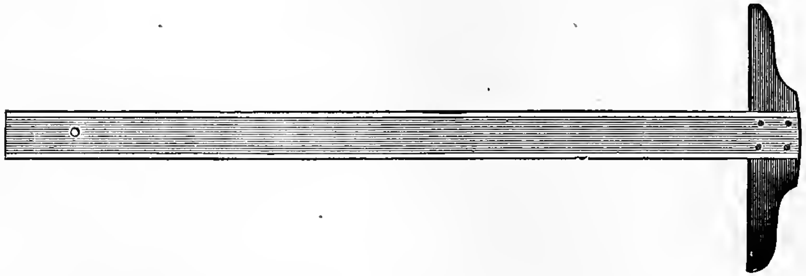
One Hair Spring Divider, 4 inches long.

One Set Spring Bows $3\frac{1}{2}$ inches long, consisting of pen, pencil and spacer.



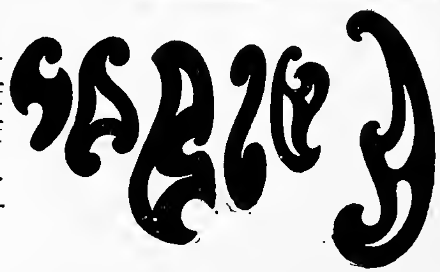
One Drawing Pen, $4\frac{1}{2}$ or 5 inches long.

One T Square with blade of 36 inches or more.

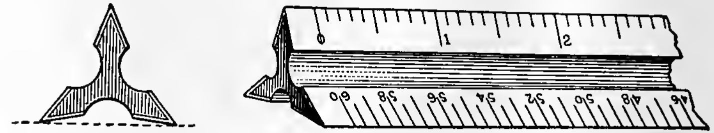


One Triangle 7″ 45°, of celluloid or rubber. One Triangle 9″ 30°-60°, of celluloid or rubber.

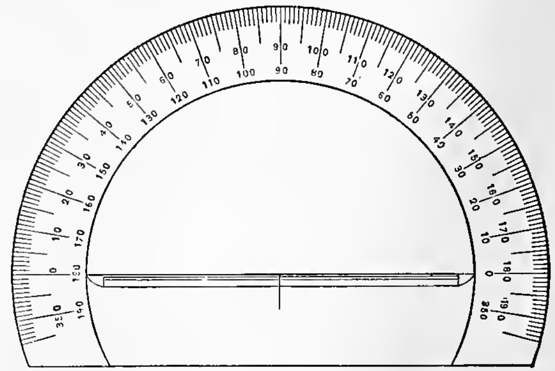
Two or more Irregular Curves. Some of the many forms of these are shown in cut. They should be either of celluloid or rubber.



One Triangular Scale 12 inches long, with divisions in twelfths, those coated with white celluloid being the best.



One Protractor, 4-inch or 5-inch, of German silver, graduated to degrees or half degrees, to be used for measuring and laying off angles.



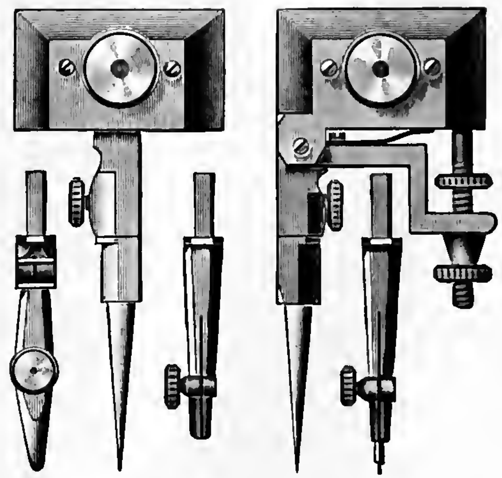
One Drawing Board, not less than 20x26 inches.

A few Thumb Tacks, a piece of good Rubber, a 6H Pencil, either Hardmuth's or Faber's; a 6H Artist's Lead for compass points, and a few sheets of good detail drawing paper, about 16x20 inches.

There are many other instruments which are convenient, but not necessary, such as $3\frac{1}{2}$ inch Compasses with fixed needle and pen or pencil points. These in range come between the large compass and the spring bows, and as the points are fixed there is no changing

from pencil to pen. Further, the majority of the arcs and circles the draughtsman deals with come within their range.

Another very useful tool is the Beam Compass, which is used for drawing very large circles. It takes its name from the fact that the two heads are



clamped to a wood bar or beam. It is fitted with pen, pencil and needle points.

CHAPTER IV.

Mensuration, Mechanical Powers and Tables.

Symbols and abbreviations:

The sign for equality is $=$ and is read equal to.

The sign for addition is $+$ and is read plus.

The sign for subtraction is $-$ and is read minus.

The sign for multiplication is $\times$ and is read multiplied by.

The sign for division is $\div$ and is read divided by.

When a number is multiplied by itself several times this operation is indicated by writing to the right and above it a small figure denoting the number of times the multiplication is performed or the number of times the number is taken as a factor. Thus 6^2 indicates that 6 is taken twice as a factor and is read *six square;* 5^3 indicates that 5 is taken three times and is read *five cube;* while 7^5 means that 7 is taken five times and is read *seven to the fifth power.* The factor of which a power is composed is called the *root,* and is indicated in the radical sign $\sqrt{}$, and the operation of finding the factor is called the "extraction of the root." The power is written under the radical sign and a small figure called the index, or exponent, is written above it to indicate the root to be extracted. Thus $\sqrt[3]{27}$ indicates that the cube root of twenty-seven is to be ascertained, $\sqrt[5]{243}$ indicates that the fifth root of two hundred and forty-three is to be extracted. When no index or exponent is written it is understood that the square root is to be extracted thus: $\sqrt{100}$

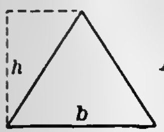
The operation of extracting roots can be learned from any arithmetic.

Diameter is written Diam. Radius is written Rad. Circumference is written Circ. Perpendicular is written Perp. The sign π, called Pi, indicates ratio of diameter of circle to circumference.

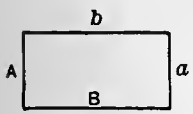
The Circle.

Diam. squared $\times$ .7854 $=$ area.
Diam. $\times$ circ. $\div$ 4 $=$ area.
Rad. $\times$ $\frac{1}{2}$ circ. $=$ area.
Diam. $\times$ 3.1416 $=$ circ.
Circ. $\times$ .31831 $=$ diam.
Circ. $\div$ 3.1416 $=$ diam.
Square root of area $\times$ 1.1284 $=$ diam.
$\pi = 3.1416$.
Diam. of a sphere $\times$ .806 $=$ dimensions of an equal cube.

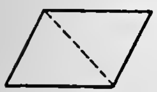
Diam. of a sphere $\times$ .6667 = length of equal cylinder.
Diam. $\times$ .8862 = side of an equal square.
Side of a square $\times$ 1.128 = diam. of an equal circle.
Square of the diam. of a sphere $\times$ 3.1416 = convex surface.
Cube of the diam. of a sphere $\times$ .5236 = solidity.
Sqr. inches $\times$ .00695 = square feet.
Cubic inches $\times$ .00058 = cubic feet.
Cubic feet $\times$ .03704 = cubic yards.



Area $\left\{ \begin{array}{l} = \text{Base} \times \frac{1}{2} \text{ height h.} \\ = \dfrac{bh}{2}. \end{array} \right.$

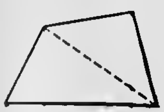


Area = Side A $\times$ side B.

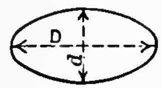


Area { Divide into two triangles and take the sum of their areas.

Area { Divide into two triangles and take the sum of their areas.

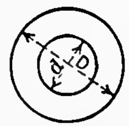


Area { Divide into two triangles and take the sum of their areas.



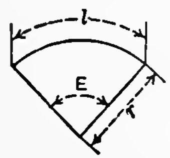
$$\text{Perimeter} = \pi \sqrt{\frac{D^2+d^2}{2} - \frac{(D-d)^2}{8.8}}.$$

$$\text{Area} = \frac{\pi}{4}\,Dd = 0.7854\ Dd.$$



Area = area of D — area of d.
Area = 0.7854 (D^2-d^2).

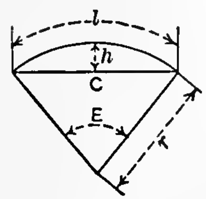
Sector.



Area = $\frac{1}{2}$ l r = half length of arc $\times$ rad. or rad. $\times$ arc $\div$ 2.

$$\text{Area} = \frac{\pi\, r^2\, E}{360} = .008727\ r^2\ E.$$

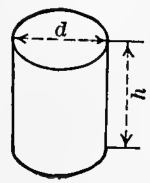
Segment.



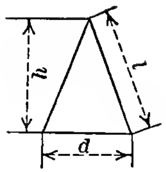
$$\text{Area} = \tfrac{1}{2}\,[l\ r - c\ (r-h)]\ \text{or}\ \frac{\pi\, r^2\, E}{360} - \frac{C}{2}\,(r-h) \qquad l = \frac{\pi\, r\, E}{180} = 0.0175\ r\ E.$$

$$E = \frac{180\, l}{\pi\, r} = 57.2956\,\frac{l}{r}.$$

Cylinder.

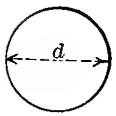


Convex surface = circumference $\times$ height. Entire surface = area of two ends + convex surface. Volume = area of one end $\times$ height.



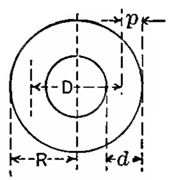
Cone.

Convex surface $= \frac{1}{2}\ \pi\ \mathrm{d\,l} =$ circumference of base $\times\ \frac{1}{2}$ slant height. Entire surface = area of base + convex surface. Volume $= \dfrac{0.7854\ d^2\ h}{3}$.



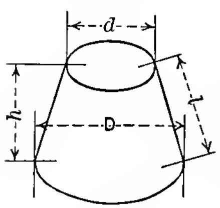
Sphere.

Entire surface $= 4\ \pi\ r^2$ or $\pi\ d^2$ or $d^2 \times 3.1416$. Volume $= 0.5236\ d^3$.



Annulus.

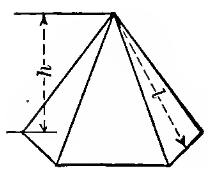
Entire surface $= 4\ \pi^2\ Rr = 9.8696$ Dd.
Volume $= 2\ \pi^2\ Rr^2 = 2.4674\ Dd^2$.



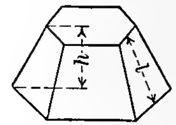
Truncated Cone.

Convex surface $= \dfrac{\pi\,l}{2}\ (D + d)$.

Entire surface = convex surface + area of both ends. Volume $= .2618h\ (D^2 + Dd + d^2)$.



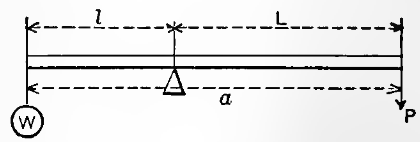
Convex surface = perimeter of base $\times\ \frac{1}{2}$ l. Entire surface = convex surface + area of base. Area of base, divide into triangles and take sum of their areas. Volume = 1-3 area of base $\times$ h.



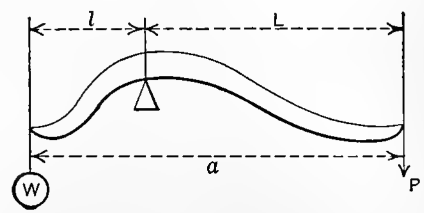
Convex surface $= \frac{1}{2}\,l\ (P + p)$. Entire surface = convex surface + sum of areas of upper and lower bases. Volume $= \dfrac{h}{3}\ (A + a + \sqrt{Aa})$; a = area upper base or surface, A = area lower base or surface; p = perimeter upper base, P = perimeter of lower base.

The Mechanical Powers.

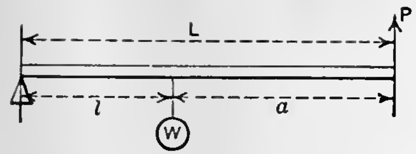
The Statistical Law for levers is: The weight multiplied by its distance from the fulcrum is equal to the power multiplied by its distance from the fulcrum, or PL = Wl, then,



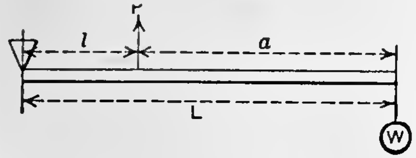
$$P = \frac{W\,l}{L},\quad W = \frac{P\,L}{l},\quad l = \frac{P\,a}{W + P},\quad L = \frac{W\,a}{W + P}.$$



Bent levers are treated the same as straight levers, as in the figure annexed.

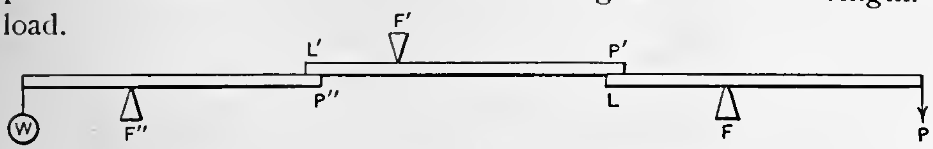


$$P = \frac{W\,l}{L},\quad W = \frac{P\,l}{l},\quad L = \frac{W\,a}{W - p},\quad l = \frac{P\,a}{W - P}.$$

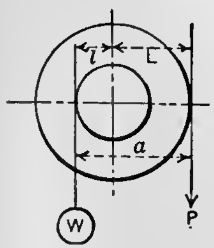


$$P = \frac{W\,l}{L},\quad W = \frac{P\,L}{l},\quad l = \frac{P\,a}{P - W},\quad L = \frac{W\,a}{P - W}.$$

Compound Levers.—When a compound lever is in equilibrium, the power multiplied by the continued product of the alternate arms commencing with the power, is equal to the load multiplied by the continued product of the alternate arms commencing with the load.



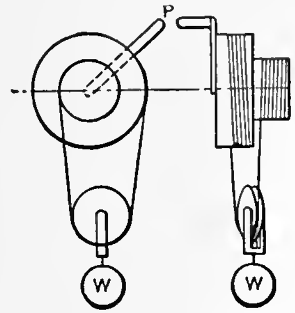
$$P \times PF \times P'F' \times P''F'' = W \times WF'' \times L' — F' \times LF.$$



Wheel and Axle.

$$P = \frac{W\,l}{L},\quad W = \frac{P\,L}{l},\quad l = \frac{P\,a}{W + P},$$

$$L = \frac{W\,a}{W + P}.$$



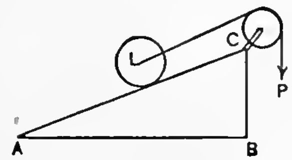
Differential Block.

Power multiplied by radius of crank is equal to the load multiplied by half the difference of the radii of the two parts of the axle or drum.

Pulley.—Load is equal to the power multiplied by the number of parts of rope supporting the load or running block. This law applies only when one continuous rope passes through the whole system, and when its parts are parallel.

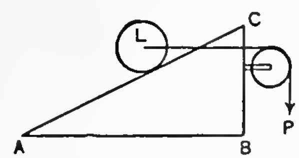
Inclined Plane.

The power = load $\times$ ratio of the vertical height of the plane to its length.

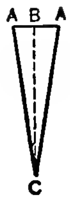


$$P = \frac{L \times \text{side BC.}}{\text{Side AC.}}\qquad L = \frac{P \times \text{side AC.}}{\text{Side BC.}}$$

Power = load $\times$ ratio of vertical height of plane to its base.



$$P = \frac{L \times \text{side BC.}}{\text{Side AB.}}\qquad L = \frac{P \times \text{side AB.}}{\text{Side BC.}}$$

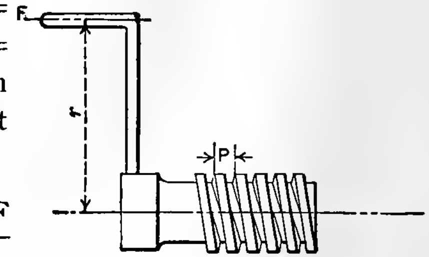


The Wedge.—

$$P = \frac{L \times \text{side BC.}}{\text{Side AB.}} \qquad L = \frac{P \times \text{side AB.}}{\text{Side BC.}}$$

Law.—The power is to the load as the height of the wedge is to its base. These laws are of no practical value beyond the fact shown: that the efficiency of the wedge or its power increases with its thinness. The reasons for this are that the power is applied *not* by continuous force but by *percussion*, for which there are no numerical standards of comparison.

The Screw. — P = pitch of screw, r = radius through which force acts, W = weight or resistance.



$$F = \frac{W\ P}{2\ \pi\ r}, \quad W = \frac{2\ \pi\ r\ F}{P}$$

TABLES.

TABLE I.

Decimal Parts of an Inch for Each $\frac{1}{64}$th.

Fraction.	$\frac{1}{32}$*ds.*	$\frac{1}{64}$*ths.*	*Decimal.*	*Fraction.*	$\frac{1}{32}$*ds.*	$\frac{1}{64}$*ths.*	*Decimal.*	*Fraction.*	$\frac{1}{32}$*ds.*	$\frac{1}{64}$*ths.*	*Decimal.*	*Fraction.*	$\frac{1}{32}$*ds.*	$\frac{1}{64}$*ths.*	*Decimal.*
		1	.015625			17	.265625			33	.515625			49	.765625
	1	2	.03125		9	18	.28125		17	34	.53125		25	50	.78125
		3	.046875			19	.296875			35	.546875			51	.796875
$\frac{1}{16}$	2	4	.0625	$\frac{5}{16}$	10	20	.3125	$\frac{9}{16}$	18	36	.5625	$\frac{13}{16}$	26	52	.8125
		5	.078125			21	.328125			37	.578125			53	.828125
	3	6	.09375		11	22	.34375		19	38	.59375		27	54	.84375
		7	.109375			23	.359375			39	.609375			55	.859375
$\frac{1}{8}$	4	8	.125	$\frac{3}{8}$	12	24	.375	$\frac{5}{8}$	20	40	.625	$\frac{7}{8}$	28	56	.875
		9	.140625			25	.390625			41	.640625			57	.890625
	5	10	.15625		13	26	.40625		21	42	.65625		29	58	.90625
		11	.171875			27	.421875			43	.671875			59	.921875
$\frac{3}{16}$	6	12	.1875	$\frac{7}{16}$	14	28	.4375	$\frac{11}{16}$	22	44	.6875	$\frac{15}{16}$	30	60	.9375
		13	.203125			29	.453125			45	.703125			61	.953125
	7	14	.21875		15	30	.46875		23	46	.71875		31	62	.96875
		15	.234375			31	.484375			47	.734375			63	.984375
$\frac{1}{4}$	8	16	.25	$\frac{1}{2}$	15	32	.5	$\frac{3}{4}$	24	48	.75	1	32	64	1.000

TABLE II.—DECIMAL EQUIVALENTS OF A FOOT FOR EACH $\frac{1}{32}$D OF AN INCH.

Inches.		0″	1″	2″	3″	4″	5″	6″	7″	8″	9″	10″	11″
	0	0	.0833	.1667	.2500	.3333	.4167	.5000	.5833	.6667	.7500	.8333	.9167
	$\frac{1}{32}$	.0026	.0859	.1693	.2526	.3359	.4193	.5026	.5859	.6693	.7526	.8359	.9193
$\frac{1}{16}$	$\frac{2}{32}$	.0052	.0885	.1719	.2552	.3385	.4129	.5052	.5885	.6719	.7552	.8385	.9219
	$\frac{3}{32}$	.0078	.0911	.1745	.2578	.3411	.4245	.5078	.5911	.6745	.7578	.8411	.9245
$\frac{1}{8}$	$\frac{4}{32}$	.0104	.0937	.1771	.2604	.3437	.4271	.5104	.5937	.6771	.7604	.8437	.9271
	$\frac{5}{32}$	.0130	.0964	.1797	.2630	.3464	.4297	.5130	.5964	.6797	.7630	.8464	.9297
$\frac{3}{16}$	$\frac{6}{32}$	.0156	.0990	.1823	.2656	.3490	.4323	.5156	.5990	.6823	.7656	.8490	.9323
	$\frac{7}{32}$	.0182	.1016	.1849	.2682	.3516	.4349	.5182	.6016	.6849	.7682	.8516	.9349
$\frac{1}{4}$	$\frac{8}{32}$	.0208	.1042	.1875	.2708	.3542	.4375	.5208	.6042	.6875	.7708	.8542	.9375
	$\frac{9}{32}$	.0234	.1068	.1901	.2734	.3568	.4401	.5234	.6068	.6901	.7734	.8568	.9401
$\frac{5}{16}$	$\frac{10}{32}$	.0260	.1094	.1927	.2760	.3594	.4427	.5260	.6094	.6927	.7760	.8594	.9427
	$\frac{11}{32}$	.0286	.1120	.1953	.2786	.3620	.4453	.5286	.6120	.6953	.7786	.8620	.9453
$\frac{3}{8}$	$\frac{12}{32}$	.0312	.1146	.1979	.2812	.3646	.4479	.5312	.6146	.6979	.7812	.8646	.9479
	$\frac{13}{32}$	.0339	.1172	.2005	.2839	.3672	.4505	.5339	.6172	.7005	.7839	.8672	.9505
$\frac{7}{16}$	$\frac{14}{32}$	.0365	.1198	.2031	.2865	.3698	.4531	.5365	.6198	.7031	.7865	.8698	.9531
	$\frac{15}{32}$	.0391	.1224	.2057	.2891	.3724	.4557	.5391	.6224	.7057	.7891	.8724	.9557
$\frac{1}{2}$	$\frac{16}{32}$	.0417	.1250	.2083	.2917	.3750	.4583	.5417	.6250	.7083	.7917	.8750	.9583
	$\frac{17}{32}$	.0443	.1276	.2109	.2943	.3776	.4609	.5443	.6276	.7109	.7943	.8776	.9609
$\frac{9}{16}$	$\frac{18}{32}$	.0469	.1302	.2135	.2969	.3802	.4635	.5469	.6302	.7135	.7969	.8802	.9635
	$\frac{19}{32}$	.0495	.1328	.2161	.2995	.3828	.4661	.5495	.6328	.7161	.7995	.8828	.9661
$\frac{5}{8}$	$\frac{20}{32}$	.0521	.1354	.2188	.3021	.3854	.4688	.5521	.6354	.7188	.8021	.8854	.9688
	$\frac{21}{32}$	.0547	.1380	.2214	.3047	.3880	.4714	.5547	.6380	.7214	.8047	.8880	.9714
$\frac{11}{16}$	$\frac{22}{32}$	.0573	.1406	.2240	.3073	.3906	.4740	.5573	.6406	.7240	.8073	.8906	.9740
	$\frac{23}{32}$	.0599	.1432	.2266	.3099	.3932	.4766	.5599	.6432	.7266	.8099	.8932	.9766
$\frac{3}{4}$	$\frac{24}{32}$	.0625	.1458	.2292	.3125	.3958	.4792	.5625	.6458	.7292	.8125	.8958	.9792
	$\frac{25}{32}$	.0651	.1484	.2318	.3151	.3984	.4818	.5651	.6484	.7318	.8151	.8984	.9818
$\frac{13}{16}$	$\frac{26}{32}$	.0677	.1510	.2344	.3177	.4010	.4844	.5677	.6510	.7344	.8177	.9010	.9844
	$\frac{27}{32}$	.0703	.1536	.2370	.3203	.4036	.4870	.5703	.6536	.7370	.8203	.9036	.9870
$\frac{7}{8}$	$\frac{28}{32}$	.0729	.1562	.2396	.3229	.4062	.4896	.5729	.6562	.7396	.8229	.9062	.9896
	$\frac{29}{32}$	.0755	.1589	.2422	.3255	.4089	.4922	.5755	.6589	.7422	.8255	.9089	.9922
$\frac{15}{16}$	$\frac{30}{32}$	.0781	.1615	.2448	.3281	.4115	.4948	.5781	.6615	.7448	.8281	.9115	.9948
	$\frac{31}{32}$	.0807	.1641	.2474	.3307	.4141	.4974	.5807	.6641	.7474	.8307	.9141	.9974
1													1.0000

To use the above table:

Find the decimal equivalent of $9\frac{31}{32}$ inches.

Follow the horizontal line of figures marked $\frac{31}{32}$ until it intersects the vertical column headed 9″; at the intersection find .8307. Again, find the fraction for .6380. The quantity .6380 is at the intersection of column headed 7″ and horizontal line marked $\frac{21}{32}$, therefore the decimal quantity is equal to $7\frac{21}{32}$ inches.

TABLE III.

Circumference and Area of Circles.

Diameter.	*Circumference.*	*Area.*	*Diameter.*	*Circumference.*	*Area.*	*Diameter.*	*Circumference.*	*Area.*	*Diameter.*	*Circumference.*	*Area.*
1/64	.4900	.000192	3/4	8.6394	5.9396	5/8	20.8131	34.4717	1/2	32.9868	86.5903
1/32	.09818	.000767	7/8	9.0321	6.4918	3/4	21.2058	35.7848	5/8	33.3795	88.6643
1/16	.19635	.003068	**3**	9.4248	7.0686	7/8	21.5985	37.1224	3/4	33.7722	90.7628
1/8	.3927	.012272	1/8	9.8175	7.6699	**7**	21.9912	38.4846	7/8	34.1649	92.8858
3/16	.589	.027612	1/4	10.2102	8.2958	1/8	22.3839	39.8713	**11**	34.5576	95.0334
1/4	.7854	.049087	3/8	10.6029	8.9462	1/4	22.7766	41.2826	1/8	34.9503	97.2055
5/16	.98175	.076699	1/2	10.9956	9.6211	3/8	23.1693	42.7184	1/4	35.343	99.4022
3/8	1.11781	.110447	5/8	11.3883	10.3206	1/2	23.562	44.1787	3/8	35.7357	101.6234
7/16	1.37445	.15033	3/4	11.781	11.0447	5/8	23.9547	45.6636	1/2	36.1284	103.8691
1/2	1.5708	.19635	7/8	12.1737	11.7933	3/4	24.3474	47.1731	5/8	36.5211	106.1394
9/16	1.76715	.248505	**4**	12.5664	12.5664	7/8	24.7401	48.7071	3/4	36.9138	108.4343
5/8	1.9635	.306796	1/8	12.9591	13.3641	**8**	25.1328	50.2656	7/8	37.3065	110.7537
11/16	2.15985	.371224	1/4	13.3518	14.1863	1/8	25.5255	51.8487	**12**	37.6992	113.098
3/4	2.3562	.441787	3/8	13.7445	15.033	1/4	25.9182	53.4563	1/8	38.0919	115.466
13/16	2.55255	.518487	1/2	14.1372	15.9043	3/8	26.3109	55.0884	1/4	38.4846	117.859
7/8	2.7489	.601322	5/8	14.5299	16.8002	1/2	26.7036	56.7451	3/8	38.8773	120.277
15/16	2.94525	.690292	3/4	14.9226	17.7206	5/8	27.0963	58.4264	1/2	39.27	122.719
1	3.1416	.7854	7/8	15.3153	18.6655	3/4	27.489	60.1322	5/8	39.6627	125.185
1/8	3.5343	.99402	**5**	15.708	19.635	7/8	27.8817	61.8625	3/4	40.0554	127.677
1/4	3.927	1.2272	1/8	16.1007	20.629	**9**	28.2744	63.6174	7/8	40.4481	130.192
3/8	4.3197	1.4849	1/4	16.4934	21.6476	1/8	28.6671	65.3968	**13**	40.8408	132.733
1/2	4.7124	1.7671	3/8	16.8861	22.6907	1/4	29.0598	67.2008	1/8	41.2335	135.297
5/8	5.1051	2.0739	1/2	17.2788	23.7583	3/8	29.4525	69.0293	1/4	41.6262	137.887
3/4	5.4978	2.4053	5/8	17.6715	24.8505	1/2	29.8452	70.8823	3/8	42.0189	140.501
7/8	5.8905	2.7612	3/4	18,0642	25.9673	5/8	30.2379	72.7599	1/2	42.4116	143.139
2	6.2832	3.1416	7/8	18.4569	27.1086	3/4	30.6306	74.6621	5/8	42.8043	145.802
1/8	6.6759	3.5466	**6**	18.8496	28.2744	7/8	31.0233	76.5888	3/4	43.197	148.49
1/4	7.0686	3.9761	1/8	19.2423	29.4648	**10**	31.416	78.54	7/8	43.5897	151.202
3/8	7.4613	4.4301	1/4	19.635	30.6797	1/8	31.8087	80.5158	**14**	43.9824	153.938
1/2	7.854	4.9087	3/8	20.0277	31.9191	1/4	32.2014	82.5161	1/8	44.3751	156.7
5/8	8.2467	5.4119	1/2	20.4204	33.1831	3/8	32.5941	84.5409	1/4	44.7678	159.485

Diameter.	Circumference.	Area.
3/8	45.1065	162.296
1/2	45.5532	165.13
5/8	45.9459	167.99
3/4	46.3386	170.874
7/8	46.7313	173.782
15	47.124	176.715
1/8	47.5167	179.673
1/4	47.9094	182.655
3/8	48.3021	185.661
1/2	48.6948	188.692
5/8	49.0825	191.748
3/4	49.4802	194.828
7/8	49.8729	197.933
16	50.2656	201.062
1/8	50.6583	204.216
1/4	51.051	207.395
3/8	51.4437	210.598
1/2	51.8364	213.825
5/8	52.2291	217.077
3/4	52.6218	220.354
7/8	53.0145	223.655
17	53.4072	226.981
1/8	53.7999	230.331
1/4	54.1926	233.706
3/8	54.5853	237.105
1/2	54.978	240.529
5/8	55.3707	243.977
3/4	55.7634	247.45
7/8	56.1561	250.948
18	56.5488	254.47
1/8	56.9415	258.016
1/4	57.3342	261.587
3/8	57.7269	265.183
1/2	58.1196	268.803
5/8	58.5123	272.448
3/4	58.905	276.117
7/8	59.2977	279.811
19	59.6904	283.529
1/8	60.0831	287.272
1/4	60.4758	291.04
3/8	60.8685	294.832
1/2	61.2612	298.648
5/8	61.6539	302.489
3/4	62.0466	306.355
7/8	62.4393	310.245
20	62.832	314.16
1/8	63.2247	318.099
1/4	63.6174	322.063
3/8	64.0101	326.051
1/2	64.4028	330.064
5/8	64.7955	334.102
3/4	65.1882	338.164
7/8	65.5809	342.25
21	65.9736	346.361
1/8	66.3663	350.497
1/4	66.759	354.657
3/8	67.1517	358.842
1/2	67.5444	363.051
5/8	67.9371	367.285
3/4	68.3298	371.543
7/8	68.7225	375.826
22	69.1152	380.134
1/8	69.5079	384.466
1/4	69.9006	388.822
3/8	70.2933	393.203
1/2	70.686	397.609
5/8	71.0787	402.038
3/4	71.4714	406.494
7/8	71.8641	410.973
23	72.2568	415.477
1/8	72.6495	420.004
1/4	73.0422	424.558
3/8	73.4349	429.135
1/2	73.8276	433.737
5/8	74.2203	438.364
3/4	74.613	443.015
7/8	75.0057	447.69
24	75.3984	452.39
1/8	75.7911	457.115
1/4	76.1838	461.864
3/8	76.5765	466.638
1/2	76.9692	471.436
5/8	77.3619	476.259
3/4	77.7546	481.107
7/8	78.1473	485.979
25	78.54	490.875
1/8	78.9327	495.796
1/4	79.3254	500.742
3/8	79.7181	505.712
1/2	80.1108	510.706
5/8	80.5035	515.726
3/4	80.8962	520.769
7/8	81.2889	525.838
26	81.6816	530.93
1/8	82.0743	536.048
1/4	82.467	541.19
3/8	82.8597	546.356
1/2	83.2524	551.547
5/8	83.6451	556.763
3/4	84.0378	562.003
7/8	84.4305	567.267
27	84.8232	572.557
1/8	85.2159	577.87
1/4	85.6086	583.209
3/8	86.0013	588.571
1/2	86.394	593.959
5/8	86.7867	599.371
3/4	87.1794	604.807
7/8	87.5721	610.268
28	87.9648	615.754
1/8	88.3575	621.264
1/4	88.7502	626.798
3/8	89.1429	632.357
1/2	89.5356	637.941
5/8	89.9283	643.549
3/4	90.321	649.182
7/8	90.7137	654.84
29	91.1064	660.521
1/8	91.4991	666.228
1/4	91.8918	671.959
3/8	92.2845	677.714
1/2	92.6772	683.494
5/8	93.0699	689.299
3/4	93.4626	695.128
7/8	93.8553	700.982
30	94.248	706.86
1/8	94.6407	712.763
1/4	95.0334	718.69
3/8	95.4261	724.642
1/2	95.8188	730.618
5/8	96.2115	736.619
3/4	96.6042	742.645
7/8	96.9969	748.695
31	97.3896	754.769
1/8	97.7823	760.869
1/4	98.175	766.992

Diameter.	Circumference.	Area.
⅜	98.5677	773.14
½	98.9604	779.313
⅝	99.3531	785.51
¾	99 7458	791.732
⅞	100.1385	797.979
32	100.5312	804.25
⅛	100.9239	810.545
¼	101.3166	816.865
⅜	101.7093	823.21
½	102.102	829.579
⅝	102.4947	835.972
¾	102.8874	842.391
⅞	103.2801	848.833
33	103.673	855.301
⅛	104.065	861.792
¼	104.458	868.309
⅜	104.851	874.85
½	105.244	881.415
⅝	105.636	888.005
¾	106.029	894.62
⅞	106.422	901.259
34	106.814	907.922
⅛	107.207	914.611
¼	107.6	921.323
⅜	107.992	928.061
½	108.385	934.822
⅝	108.778	941.609
¾	109.171	948.42
⅞	109.563	955.255
35	109.956	962.115
⅛	110.349	969.
¼	110.741	975.909
⅜	111.134	982.842
½	111.527	989.8
⅝	111.919	996.783
¾	112.312	1003.79
⅞	112.705	1010.822
36	113.098	1017.878
⅛	113.49	1024.96
¼	113.883	1032.065
⅜	114.276	1039.195
½	114.668	1046.349
⅝	115.061	1053.528
¾	115.454	1060.732
⅞	115.846	1067.96
37	116.239	1075.213
⅛	116.632	1082.49
¼	117.025	1089.792
⅜	117.417	1097.118
½	117.81	1104.469
⅝	118.203	1111.844
¾	118.595	1119.244
⅞	118.988	1126.669
38	119.381	1134.118
⅛	119.773	1141.591
¼	120.166	1149.089
⅜	120.559	1156.612
½	120.952	1164.159
⅝	121.344	1171.731
¾	121.737	1179.327
⅞	122.13	1186.948
39	122.522	1194.593
⅛	122.915	1202.263
¼	123.308	1209.958
⅜	123.7	1217.677
½	124.093	1225.42
⅝	124.486	1233.188
¾	124.879	1240.981
⅞	125.271	1248.798
40	125.664	1256.64
⅛	126.057	1264.51
¼	126.449	1272.4
⅜	126.482	1280.31
½	127.235	1288.25
⅝	127.627	1296.22
¾	128.02	1304.21
⅞	128.413	1312.22
41	128.806	1320.26
⅛	129.198	1328.32
¼	129.591	1336.41
⅜	129.984	1344.52
½	130.376	1352.66
⅝	130.769	1360.82
¾	131.162	1369.
⅞	131.554	1377.21
42	131.947	1385.45
⅛	132.34	1393.7
¼	132.733	1401.99
⅜	133.125	1410.3
½	133.518	1418.63
⅝	133.911	1426.99
¾	134.303	1435.37
⅞	134.696	1443.77
43	135.089	1452.2
⅛	135.481	1460.66
¼	135.874	1469.14
⅜	136.267	1477.64
½	136.66	1486.17
⅝	137.052	1494.73
¾	137.445	1503.3
⅞	137.838	1511.91
44	138.23	1520.53
⅛	138.623	1529.19
¼	139.016	1537.86
⅜	139.408	1546.56
½	139.801	1555.29
⅝	140.194	1564.04
¾	140.587	1572.81
⅞	140.979	1581.61
45	141.372	1590.43
⅛	141.765	1599.28
¼	142.157	1608.16
⅜	142.55	1617.05
½	142.943	1625.97
⅝	143.335	1634.92
¾	143.728	1643.89
⅞	144.121	1652.89
46	144.514	1661.91
⅛	144.906	1670.95
¼	145.299	1680.02
⅜	145.692	1689.11
½	146.084	1698.23
⅝	146.477	1707.37
¾	146.87	1716.54
⅞	147.262	1725.73
47	147.655	1734.95
⅛	148.048	1744.19
¼	148.441	1753.45
⅜	148.833	1762.74
½	149.226	1772.06
⅝	149.619	1781.4
¾	150.011	1790.76
⅞	150.404	1800.15
48	150.797	1809.56
⅛	151.189	1819.
¼	151.582	1828.46

Diameter.	*Circumference.*	*Area.*
⅜	151.975	1837.95
½	152.368	1847.46
⅝	152.76	1856.99
¾	153.153	1866.55
⅞	153.546	1876.14
49	153.938	1885.75
⅛	154.331	1895.38
¼	154.724	1905.04
⅜	155.116	1914.72
½	155.509	1924.43
⅝	155.902	1934.16
¾	156.295	1943.91
⅞	156.687	1953.69
50	157.08	1963.5
⅛	157.473	1973.33
¼	157.865	1983.18
⅜	158.258	1993.06
½	158.651	2002.97
⅝	159.043	2012.89
¾	159.436	2022.85
⅞	159.829	2032.82
51	160.222	2042.83
⅛	160.614	2052.85
¼	161.007	2062.9
⅜	161.4	2072.98
½	161.792	2083.08
⅝	162.185	2093.2
¾	162.578	2103.35
⅞	162.97	2113.52
52	163.363	2123.72
⅛	163.756	2133.94
¼	164.149	2144.19
⅜	164.541	2154.46
½	164.934	2164.76
⅝	165.327	2175.08
¾	165.719	2185.42
⅞	166.112	2195.79
53	166.505	2206.19
⅛	166.897	2216.61
¼	167.29	2227.05
⅜	167.683	2237.52
½	168.076	2248.01
⅝	168.468	2258.53
¾	168.861	2269.07
⅞	169.254	2279.64
54	169.646	2290.23
⅛	170.039	2300.84
¼	170.432	2311.48
⅜	170.824	2322.16
½	171.217	2332.83
⅝	171.61	2343.55
¾	172.003	2354.29
⅞	172.395	2365.05
55	172.788	2375.83
⅛	173.181	2386.65
¼	173.573	2397.48
⅜	173.966	2408.34
½	174.359	2419.23
⅝	174.751	2430.14
¾	175.144	2441.07
⅞	175.537	2452.03
56	175.93	2463.01
⅛	176.322	2474.02
¼	176.715	2485.05
⅜	177.108	2496.11
½	177.5	2507.19
⅝	177.893	2518.3
¾	178.286	2529.43
⅞	178.678	2540.58
57	179.071	2551.76
⅛	179.464	2562.97
¼	179.857	2574.2
⅜	180.249	2585.45
½	180.642	2596.73
⅝	181.035	2608.03
¾	181.427	2619.36
⅞	181.82	2630.71
58	182.213	2642.09
⅛	182.605	2653.49
¼	182.998	2664.91
⅜	183.391	2676.36
½	183.784	2687.84
⅝	184.176	2699.33
¾	184.569	2710.86
⅞	184.962	2722.41
59	185.354	2733.98
⅛	185.747	2745.57
¼	186.14	2752.2
⅜	186.532	2768.84
½	186.925	2780.51
⅝	187.318	2792.21
¾	187.711	2803.93
⅞	188.103	2815.67
60	188.496	2827.44
⅛	188.889	2839.23
¼	189.281	2851.05
⅜	189.674	2862.89
½	190.067	2874.76
⅝	190.459	2886.65
¾	190.852	2898.57
⅞	191.245	2910.51
61	191.638	2922.47
⅛	192.03	2934.46
¼	192.423	2946.48
⅜	192.816	2958.52
½	193.208	2970.58
⅝	193.601	2982.67
¾	193.994	2994.78
⅞	194.386	3006.92
62	194.779	3019.08
⅛	195.172	3031.26
¼	195.565	3043.47
⅜	195.957	3055.71
½	196.35	3067.97
⅝	196.743	3080.25
¾	197.135	3092.56
⅞	197.528	3104.89
63	197.921	3117.25
⅛	198.313	3129.64
¼	198.706	3142.04
⅜	199.099	3154.47
½	199.492	3166.93
⅝	199.884	3179.41
¾	200.277	3191.91
⅞	200.67	3204.44
64	201.062	3217.
⅛	201.455	3229.58
¼	201.848	3242.18
⅜	202.24	3254.81
½	202.633	3267.46
⅝	203.026	3280.14
¾	203.419	3292.84
⅞	203.811	3305.56
65	204.204	3318.31
⅛	204.597	3331.09
¼	204.989	3343.89

Diameter.	*Circumference.*	*Area.*	*Diameter.*	*Circumference.*	*Area.*	*Diameter.*	*Circumference.*	*Area.*	*Diameter.*	*Circumference.*	*Area.*
3/8	205.382	3356.71	5/8	218.734	3807.34	7/8	232.086	4286.33	1/8	245.437	4793.7
1/2	205.775	3369.56	3/4	219.127	3821.02	**74**	232.478	4300.85	1/4	245.83	4809.05
5/8	206.167	3382.44	7/8	219.519	3834.73	1/8	232.871	4315.39	3/8	246.223	4824.43
3/4	206.56	3395.33	**70**	219.912	3848.46	1/4	233.264	4329.96	1/2	246.616	4839.83
7/8	206.953	3308.26	1/8	220.305	3862.22	3/8	233.656	4344.55	5/8	247.008	4855.26
66	207.346	3421.2	1/4	220.697	3876.	1/2	234.049	4359.17	3/4	247.401	4870.71
1/8	207.738	3434.17	3/8	221.09	3889.8	5/8	234.442	4373.81	7/8	247.794	4886.18
1/4	208.131	3447.17	1/2	221.483	3903.63	3/4	234.835	4388.47	**79**	248.186	4901.68
3/8	208.524	3460.19	5/8	221.875	3917.49	7/8	235.227	4403.16	1/8	248.579	4917.21
1/2	208.916	3473.24	3/4	222.268	3931.37	**75**	235.62	4417.87	1/4	248.972	4932.75
5/8	209.309	3486.3	7/8	222.661	3945.27	1/8	236.013	4432.61	3/8	249.364	4948.33
3/4	209.702	3499.4	**71**	223.054	3959.2	1/4	236.405	4447.38	1/2	249.757	4963.92
7/8	210.094	3512.52	1/8	223.046	3973.15	3/8	236.798	4462.16	5/8	250.15	4979.55
67	210.487	3525.66	1/4	223.839	3987.13	1/2	237.191	4476.98	3/4	250.543	4995.19
1/8	210.88	3538.83	3/8	224.832	4001.13	5/8	237.583	4491.81	7/8	250.935	5010.86
1/4	211.273	3552.02	1/2	224.624	4015.16	3/4	237.976	4506.67	**80**	251.328	5026.56
3/8	211.665	3565.24	5/8	225.017	4029.21	7/8	238.369	4521.56	1/8	251.721	5042.28
1/2	212.058	3578.48	3/4	225.41	4043.29	**76**	238.762	4536.47	1/4	252.113	5058.03
5/8	212.451	3591.74	7/8	225.802	4057.39	1/8	239.154	4551.41	3/8	252.506	5073.79
3/4	212.843	3605.04	**72**	226.195	4071.51	1/4	239.547	4566.36	1/2	252.899	5089.59
7/8	213.236	3618.35	1/8	226.588	4085.66	3/8	239.94	4581.35	5/8	253.291	5105.41
68	213.629	3631.69	1/4	226.981	4099.84	1/2	240.332	4596.36	3/4	253.684	5121.25
1/8	214.021	3645.05	3/8	227.373	4114.04	5/8	240.725	4611.39	7/8	254.077	5137.12
1/4	214.414	3658.44	1/2	227.766	4128.26	3/4	241.118	4626.45	**81**	254.47	5153.01
3/8	214.807	3671.86	5/8	228.159	4142.51	7/8	241.151	4641.53	1/8	254.862	5168.93
1/2	215.2	3685.29	3/4	228.551	4156.78	**77**	241.903	4656.64	1/4	255.255	5184.87
5/8	215.592	3698.76	7/8	228.944	4171.08	1/8	242.296	4671.77	3/8	255.648	5200.83
3/4	215.985	3712.24	**73**	229.337	4185.4	1/4	242.689	4686.92	1/2	256.04	5216.82
7/8	216.378	3725.75	1/8	229.729	4199.74	3/8	243.081	4702.1	5/8	256.433	5232.84
69	216.77	3739.29	1/4	230.122	4214.11	1/2	243.474	4717.31	3/4	256.826	5248.88
1/8	217.163	3752.85	3/8	230.515	4228.51	5/8	243.867	4732.54	7/8	257.218	5264.94
1/4	217.556	3766.43	1/2	230.908	4242.93	3/4	244.259	4747.79	**82**	257.611	5281.03
3/8	217.948	3780.04	5/8	231.3	4257.37	7/8	244.652	4763.07	1/8	258.004	5297.14
1/2	218.341	3793.68	3/4	231.693	4271.84	**78**	245.045	4778.37	1/4	258.397	5313.28

Diameter.	Circumference.	Area.
⅜	258.789	5329.44
½	259.182	5345.63
⅝	259.575	5361.84
¾	259.967	5378.08
⅞	260.36	5394.34
83	260.753	5410.62
⅛	261.145	5426.93
¼	261.538	5443.26
⅜	261.931	5459.62
½	262.324	5476.01
⅝	262.716	5492.41
¾	263.109	5508.84
⅞	263.502	5525.3
84	263.894	5541.78
⅛	264.287	5558.29
¼	264.68	5574.82
⅜	265.072	5591.37
½	265.465	5607.95
⅝	265.858	5624.56
¾	266.251	5641.18
⅞	266.643	5657.84
85	267.036	5674.51
⅛	267.429	5691.22
¼	267.821	5707.94
⅜	268.214	5724.69
½	268.607	5741.47
⅝	268.999	5758.27
¾	269.392	5775.1
⅞	269.785	5791.94
86	270.178	5808.82
⅛	270.57	5825.72
¼	270.963	5842.64
⅜	271.356	5859.59
½	271.748	5876.56

Diameter.	Circumference.	Area.
⅝	272.141	5893.55
¾	272.534	5910.58
⅞	272.926	5927.62
87	273.319	5944.69
⅛	273.712	5961.79
¼	274.105	5978.91
⅜	274.497	5996.05
½	274.89	6013.22
⅝	275.283	6030.41
¾	275.675	6047.63
⅞	276.068	6064.87
88	276.461	6082.14
⅛	276.853	6099.43
¼	277.246	6116.74
⅜	277.629	6134.08
½	278.032	6151.45
⅝	278.424	6168.84
¾	278.817	6186.25
⅞	279.21	6203.69
89	279.602	6221.15
⅛	279.995	6238.64
¼	280.388	6256.15
⅜	280.78	6273.69
½	281.173	6291.25
⅝	281.566	6308.84
¾	281.959	6326.45
⅞	282.351	6344.08
90	282.744	6361.74
⅛	283.137	6379.42
¼	283.529	6397.13
⅜	283.922	6414.86
½	284.315	6432.62
⅝	284.707	6450.4
¾	285.1	6468.21

Diameter.	Circumference.	Area.
⅞	285.493	6486.04
91	285.886	6503.9
⅛	286.278	6521.78
¼	286.671	6539.68
⅜	287.064	6557.61
½	287.456	6575.56
⅝	287.849	6593.54
¾	288.242	6611.55
⅞	288.634	6629.57
92	289.027	6647.63
⅛	289.42	6665.7
¼	289.813	6683.8
⅜	290.205	6701.93
½	290.598	6720.08
⅝	290.991	6738.25
¾	291.383	6756.45
⅞	291.776	6774.68
93	292.169	6792.92
⅛	292.562	6811.2
¼	292.954	6829.49
⅜	293.347	6847.82
½	293.74	6866.16
⅝	294.132	6884.53
¾	294.525	6902.93
⅞	294.918	6921.35
94	295.31	6939.79
⅛	295.703	6958.26
¼	296.096	6976.76
⅜	296.488	6995.28
½	296.881	7013.82
⅝	297.274	7032.39
¾	297.667	7050.98
⅞	298.059	7069.59
95	298.452	7088.23

Diameter.	Circumference.	Area.
⅛	298.845	7106.9
¼	299.237	7125.59
⅜	299.63	7144.31
½	300.023	7163.04
⅝	300.415	7181.81
¾	300.808	7200.6
⅞	301.201	7219.41
96	301.594	7238.35
⅛	301.986	7257.11
¼	302.379	7275.99
⅜	302.772	7294.91
½	303.164	7313.84
⅝	303.557	7332.8
¾	303.95	7351.79
⅞	304.342	7370.79
97	304.735	7389.83
⅛	305.128	7408.89
¼	305.521	7427.97
⅜	305.913	7447.08
½	306.306	7466.21
⅝	306.699	7485.37
¾	307.091	7504.55
⅞	307.484	7523.75
98	307.877	7542.98
⅛	308.27	7562.24
¼	308.662	7581.52
⅜	309.055	7600.82
½	309.448	7620.15
⅝	309.84	7639.5
¾	310.233	7658.88
⅞	310.626	7678.28
99	311.018	7697.71
⅛	311.411	7717.16
¼	311.804	7736.63
⅜	312.196	7756.13
½	312.589	7775.66
⅝	312.982	7795.21
¾	313.375	7814.78
⅞	313.767	7834.38
100	314.16	7854.

To ascertain circumference of other circles than those in table multiply the diameter in inches by 3.1416.

To ascertain the area of other circles than those in table, multiply the square of the diameter in inches by .7854.

To ascertain the area of a circular ring, subtract area of inner diameter from the area of outside diameter.

To ascertain solidity in cubic inches of a cylinder, multiply area of one end in square inches by the length of the cylinder in inches.

To ascertain solidity in cubic inches of a hollow cylinder, subtract the area of the inside diameter in square inches from the area of the outside diameter in inches, and multiply the remainder by the length of cylinder in inches.

To find the weight in pounds of a hollow cylinder of cast iron, multiply the solidity in cubic inches by .26.

Example.—Find the weight of a cylinder of cast iron whose dimensions are:

Outside diameter, 34"; inside diameter, 24"; length, 36".

By table, area 34 inches	907.922	square inches.
" 24 "	452.39	" "
	455.532	
Multiply by length	36	inches.
	2733192	
	1366596	
	16399.152	= solidity in cubic inches.
	.26	
	98394912	
	32798304	
	4263.77952	= weight in pounds.

If the cylinder were made of brass the multiplier would be .291, instead of .26, as above.

TABLE IV.

Ultimate Resistance to Tension (Tensile Strength) in Pounds per Square Inch.

	Average.
Aluminum bronze, 10% al. and 90% copper	85,000 lbs.
Aluminum bronze, 1¼% al. and 98¾% copper	28,000 lbs.
Brass, cast	18,000 lbs.
Brass wire	49,000 lbs.
Bronze or gun metal	36,000 lbs.
Copper, cast	19,000 lbs.
Copper, sheet	30,000 lbs.
Copper bolts	36,000 lbs.
Copper wire (unannealed)	60,000 lbs.
Iron, cast, 13,400 to 29,000	16,500 lbs.
Iron, wrought, round or square bars, 1 to 2 inch diameter, double refined	50,000 to 54,000 lbs.
Iron wire	70,000 to 100,000 lbs.
Iron wire ropes	90,000 lbs.
Lead, sheet	3,300 lbs.
Steel	65,000 to 120,000 lbs.
Tin, cast	4,600 lbs.
Zinc	7,000 to 8,000 lbs.

Weights per Cubic Foot of Various Substances.

	Lbs.
Aluminum	162
Anthracite, solid	93
Anthracite, broken, loose	54
Anthracite, broken, shaken	58
Anthracite, heaped, bushel	80
Brass, cast	504
Brass, rolled	524
Brick, pressed	150
Brick, common, hard	125
Brick, soft, inferior	100
Brick, laid in wall, pressed	140
Brick, laid in wall, common	112
Coal, bituminous, solid	84
Coal, bituminous, broken, loose	49
Coal, bituminous, heaped bushel	74
Copper, cast	542
Copper, rolled	548
Gold, cast, pure, or 24 carat	1,204
Gold, pure, hammered	1,217
Iron, cast	450
Iron, wrought	480
Lead	711
Granite	170
Limestone and marble	168
Mercury, at 32° Fahr	849
Platinum	1,342
Silver	655
Steel	490
Tin, cast	459
Water, pure rain, at 60° Fahr	62½
Water, sea	64
Zinc or spelter	43.7

Weights per Cubic Inch.

	Lb.
Aluminum	.0937
Brass, cast	.291
Brass, rolled	.303
Bronze, cast	.315
Copper, cast	.313

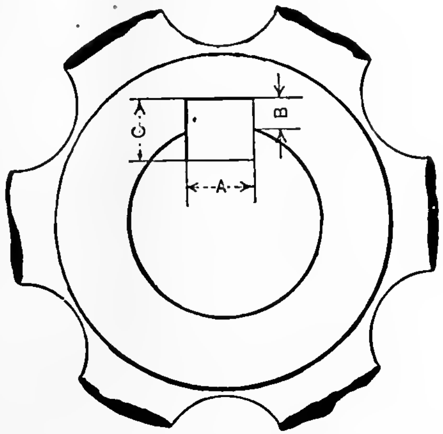
	Lb.
Copper, rolled	.317
Tin	.265
Zinc	.260
Lead	.411
Platinum	.776
Silver	.379
Gold	.696
Iron, cast	.261
Iron, wrought	.281
Steel	.283
Rubber	.0338

To obtain weight per cubic inch of other substances, divide weight given in table for one cubic foot by 1,728.

NOTE.—In figuring the weight of castings of iron it is usual to add to the weight calculated from the drawing from 5% to 10%, to make up for "straining" of the casting in the sand or mould, the allowance depending upon the nature of the casting.

TABLE V.

STANDARD KEY SEATS.



Diameter of Shaft.	A	B	C
$\frac{3}{4}''$ to $1\frac{1}{4}''$ inclusive	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{4}$
$1\frac{5}{16}''$ " $1\frac{3}{4}''$ "	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{3}{8}$
$1\frac{13}{16}''$ " $2\frac{1}{4}''$ "	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{2}$
$2\frac{5}{16}''$ " $2\frac{3}{4}''$ "	$\frac{5}{8}$	$\frac{5}{16}$	$\frac{5}{8}$
$2\frac{13}{16}''$ " $3\frac{1}{4}''$ "	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{4}$
$3\frac{5}{16}''$ " $3\frac{3}{4}''$ "	$\frac{7}{8}$	$\frac{7}{16}$	$\frac{7}{8}$
$3\frac{13}{16}''$ " $4\frac{1}{4}''$ "	1	$\frac{1}{2}$	1
$4\frac{5}{16}''$ " $4\frac{3}{4}''$ "	$1\frac{1}{8}$	$\frac{9}{16}$	$1\frac{1}{8}$

Diameter of Shaft.	A	B	C
$4\frac{13}{16}''$ " $5\frac{1}{4}''$ inclusive	$1\frac{1}{4}$	$\frac{5}{8}$	$1\frac{1}{4}$
$5\frac{5}{16}''$ " $5\frac{3}{4}''$ "	$1\frac{3}{8}$	$\frac{11}{16}$	$1\frac{3}{8}$
$5\frac{13}{16}''$ " $6\frac{1}{4}''$ "	$1\frac{1}{2}$	$\frac{3}{4}$	$1\frac{1}{2}$
$6\frac{5}{16}''$ " $7\frac{1}{4}''$ "	$1\frac{3}{4}$	$\frac{3}{4}$	$1\frac{1}{2}$
$7\frac{5}{16}''$ " $8\frac{1}{4}''$ "	2	$\frac{3}{4}$	$1\frac{1}{2}$
$8\frac{5}{16}''$ " $9\frac{1}{4}''$ "	$2\frac{1}{4}$	$\frac{3}{4}$	$1\frac{1}{2}$
$9\frac{5}{16}''$ " $10\frac{1}{4}''$ "	$2\frac{1}{2}$	$\frac{3}{4}$	$1\frac{1}{2}$
$10\frac{5}{16}''$ " $11\frac{1}{4}''$ "	$2\frac{3}{4}$	$\frac{3}{4}$	$1\frac{1}{2}$

CHAPTER V.

Plate I. The Planes of Projection and Projections.

A solid of any desired form can be shown in many different views, which, summed up, are the plan—upper and under—and the elevation, end and side or longitudinal.

The names given to the views are according to the positions from which the object is seen. These are clearly shown in the several views of a cube (Plate I). In the upper left hand corner is shown a perspective (isometrical) of the cube, with its several faces numbered; the sides immediately in front or full view are represented by full lines and figures, while the sides or faces at the back are shown by dotted lines and figures. This figure is given for the purpose of showing the relation the several sides bear to each other, and by comparing with the figures in projection it will be seen clearly the positions taken by the object in bringing its different sides into view.

Front Elevation.—The central figure shows a cube resting on one of its *edges,* the sides taking the direction of 45° to the horizontal. Being a cube, all the faces are squares, and all its edges of equal length; therefore the dimensions being known the figure would be drawn as follows: First draw a circle whose diameter is equal to the length of a side, next with T square and 45° triangle draw the sides 2-3-4-5 tangent to the circle and intersecting at the corners. This completes the front elevation.

Left Side Elevation.—With T square project the corners *a-b-c* to the left and measure off the length of a side and draw lines 1 and 6 completing the figure, showing the sides 4 and 2.

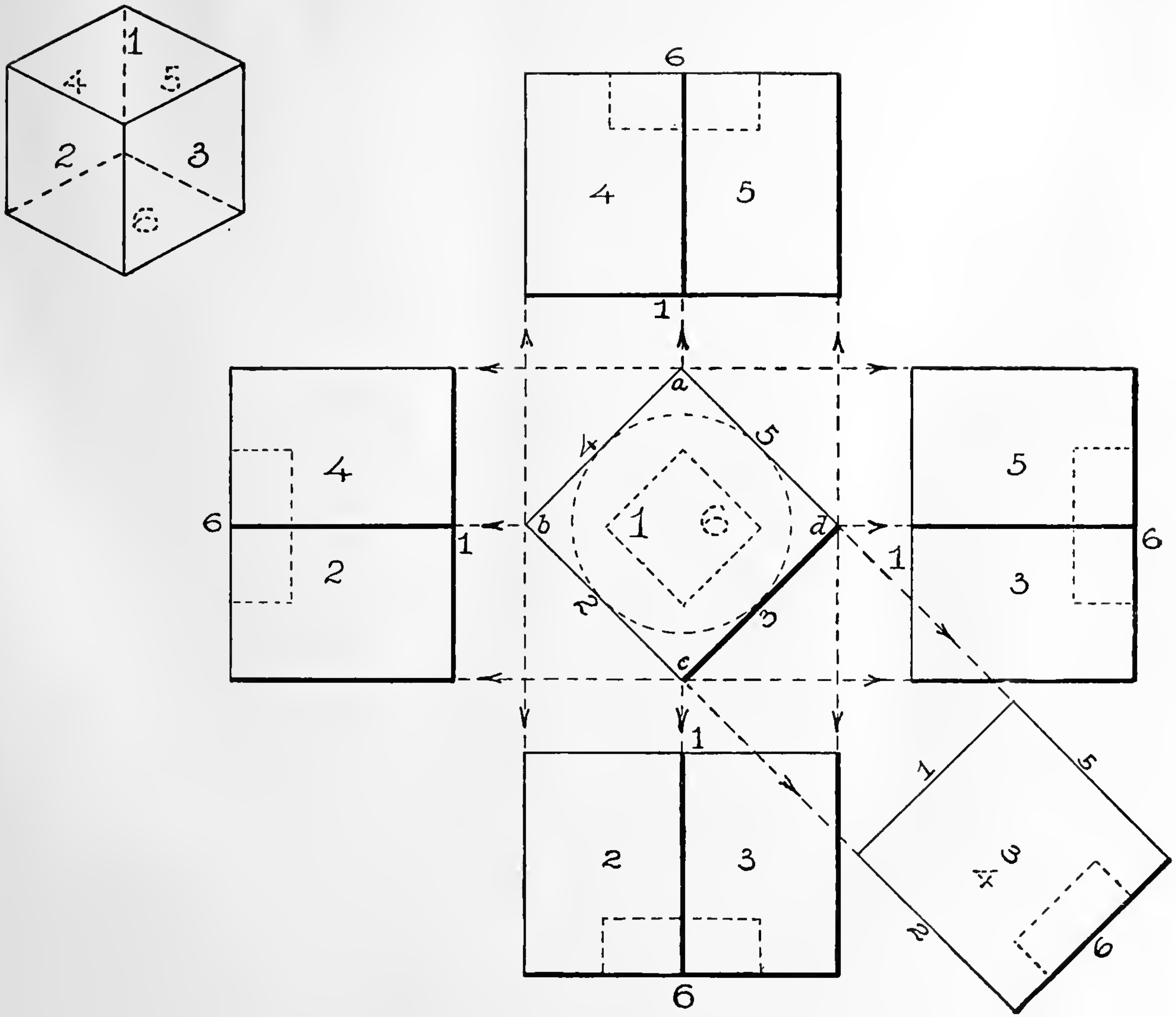
Right Side Elevation.—Project corners *a-d-c* and complete figure as for left side elevation, thus showing sides 3 and 5.

Plan or Top View.—Project corners *b-a-d* upward, using the 90° angle, and complete figure as in elevations, giving sides 4—5.

Inverted Plan.—Project corners *b-c-d* downward and complete figure by measuring off the length of a side on the projected lines, and draw lines 6 and 1, thus giving view of sides 2 and 3.

In the foregoing figures or views of the cube all the sides are brought into view except side 6. The figure being a cube, this side would be exactly the same as side 1, but should there be some peculiarity in this side, such as a depression, it could be shown by making a *rear elevation,* which would be a continuation of the projection of either side elevation, which would bring

PLATE I



into view another square on which would be marked the lines defining the depression, while its depth would be laid off on the elevations and plans, as shown by dotted lines. The depression could also be shown by dotted lines on front elevation, the fact of the lines being dotted indicating that the form shown is behind the face or front of the figure. In making a drawing, the principal face or view of the object to be represented is first drawn, and the other views necessary to show the form fully are derived from it and placed in the positions that will most clearly show the form required. Thus, should it be desired for some reason to show a full view of side 3, the lines *a-d* and *b-c* would be prolonged or projected, as indicated, and a square completed upon these projected lines would be a full view of the side. These same methods are followed in all the succeeding lessons. For convenience the plan is sometimes placed above and sometimes below the elevation, depending upon what is to be shown, and in all cases the most *direct* method is employed. This should be the aim of the draughtsman—to follow the shortest method that will fully explain his object.

Plate 2. Projections of a Rectangular Prism and Cube.

Fig. 1.—A rectangular prism, whose sides or faces are each 1 inch (1″) wide and 2 inches (2″) long is first drawn in end elevation, as shown at *a-b-c-d*. In this case the prism is resting upon one of its faces, and is drawn as follows: Draw a circle 1″ diam., and with T square and 90° angle draw the four sides tangent to the circle to complete the elevation.

To draw the plan, project sides *a c* and *b d*, indefinitely, as indicated by the arrow heads, using 90° angle; with T square draw side *e f*, in required position, from *e* or *f* lay off the length 2″ as at *h*, and with T square draw *g h*, completing the plan. To complete an elevation showing the other end of the prism, continue the projection indefinitely, as indicated, and draw *i k* in desired position; with *i k* for radius and *i* and *k* as centres, draw the arcs at *l* and *m*, connect *l* and *m*, or measure *i l* equal to *i k*, and with T square draw *l m*.

Fig. 2.—The same prism is shown in end elevation, but in this case it is resting upon one edge, with its sides placed at the angles of 30° and 60° to the horizontal. As for Fig. 1, first draw a circle of 1″ diameter and tangent to this circle draw the four sides of the square, using the 30° and 60° angles as indicated. The plan is drawn as in Fig. 1, except that two sides of the prism will show; therefore the three corners or angles will need to be projected as at *e, f* and *g*. The elevation of the opposite end is drawn exactly as for Fig. 1, only the 30° and 60° angles are to be used instead of the 90° angle. The pupil must clearly fix in his mind the relation that each of these views bears to the other, and for this purpose should use Plate 1 to aid him to establish this relation.

PLATE 2

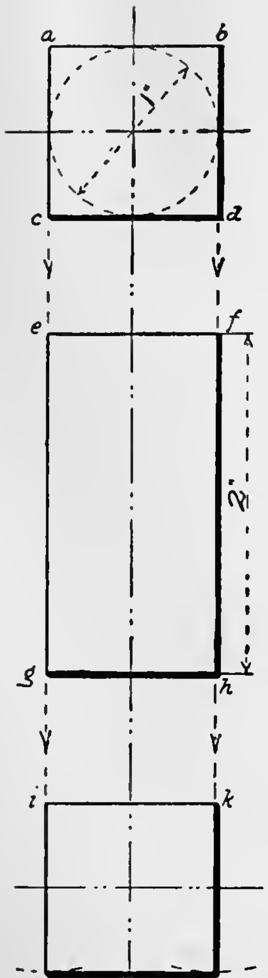


Fig. 1

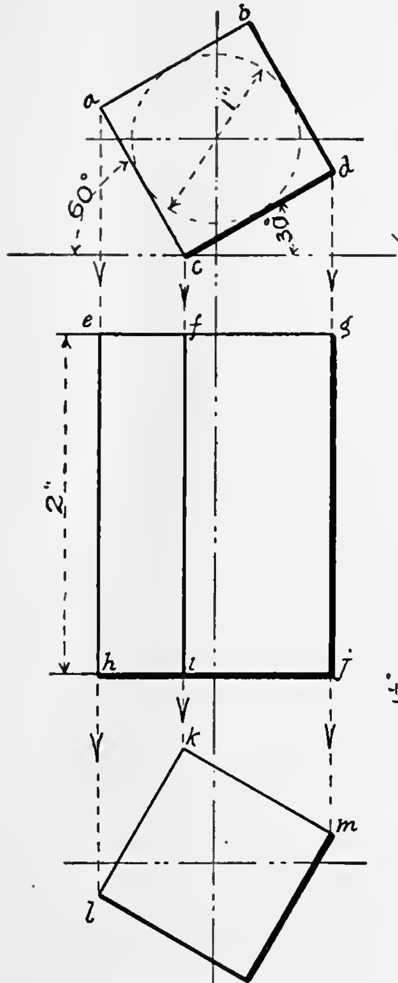


Fig 2

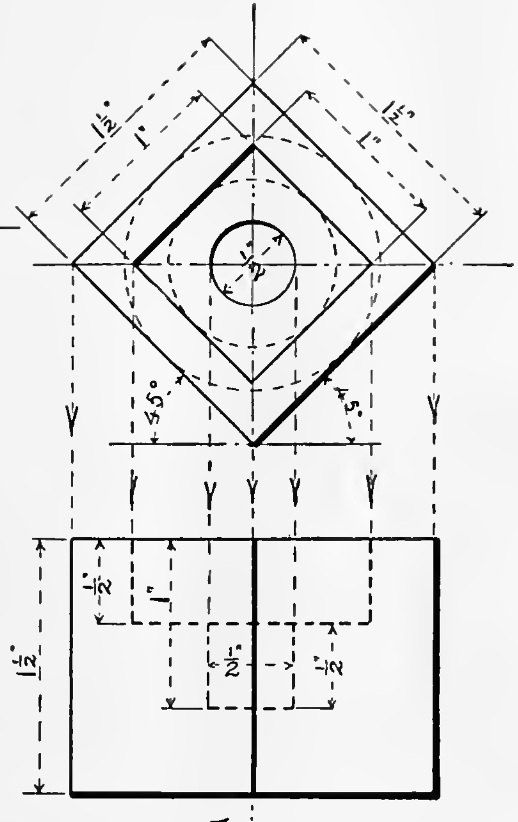


Fig 3.

FIG. 3.—A cube resting upon one of its edges with sides at angles of 45° to horizontal. In one face of the cube is a depression 1″ square, ½″ deep, while in the centre of this depression is a further depression, round ½″ diameter, ½″ deep, the cube being 1½″ square on each face.

First draw a circle 1½″ diameter and two others 1″ and ½″ diameter, respectively, using the same centre for all, or in other words make the circles *concentric*.

With 45° angle draw the sides of the cube, also of the square depression, making their sides tangent to the circles; this completes the elevation. To draw the plan, project the corners or angles, as indicated, and measure the length of a side, as shown, and with T square draw lines representing the faces. Project the angles of the depression and measure its depth from the face ½″, and draw line defining this depth. Project lines tangent to the inner circle, which represents the round depression, measuring its depth 1″ from face of cube, and draw with T square the line representing the bottom of this depression. As both of these depressions are *within* the cube, the lines indicating them would be *dotted* to show that they define something behind the surface.

PLATE 3. PROJECTIONS OF THE TRIANGULAR PRISM.

FIG. 1.—A triangular prism, whose sides are all equal, and consequently the ends of which are equilateral triangles, is to be shown in end and side elevations and in plan.

With T square draw the side *b-c* of the required length, and with *b-c* as radius and *b* and *c* for centres sweep arcs intersecting at *a*, draw *a-b* and *a-c*, completing the end elevation. Project *a* and *c* to the right indefinitely, measure *a′-j* equal to length of prism and draw *a′-c′* and *j-k* to complete the side elevation.

With *c* for centre draw arcs *c′-c″* and *k-h* and tangent to these arcs, using T square, draw *c″ b″* and *h-g*, with 90° angle draw or project *b-a* and *c* downward, connecting *b″ g*, *a″ l* and *c″ h*, completing the plan. This method places the side elevation and plan at equal distances from the end elevation. If this is not required, draw *b″ c″*, as may be necessary; using T square, as before, project *b-a* and *c* and measure off *b″ g* equal to *c′ k*, and with T square draw *g-h*.

In the elevation dimension *a′-c′* does not show the *true* width of the side *a-c*. With *c* for centre and *c′-a′* for radius, draw arc cutting *a-c* at *f*. The difference *a-f* between *a-c* and *f-c* will be amount of the *foreshortening*, and this will vary, according to the angle at which the side *a-c* may be placed. From this it is seen that objects to be represented true to size by projection must be represented by views so placed that when possible surfaces will be perpendicular to each other. This is shown in Fig. 2, which represents a triangular prism in end elevation. In one side or face of this prism is a depression $\frac{5}{16}$″ deep, round bot-

PLATE 3

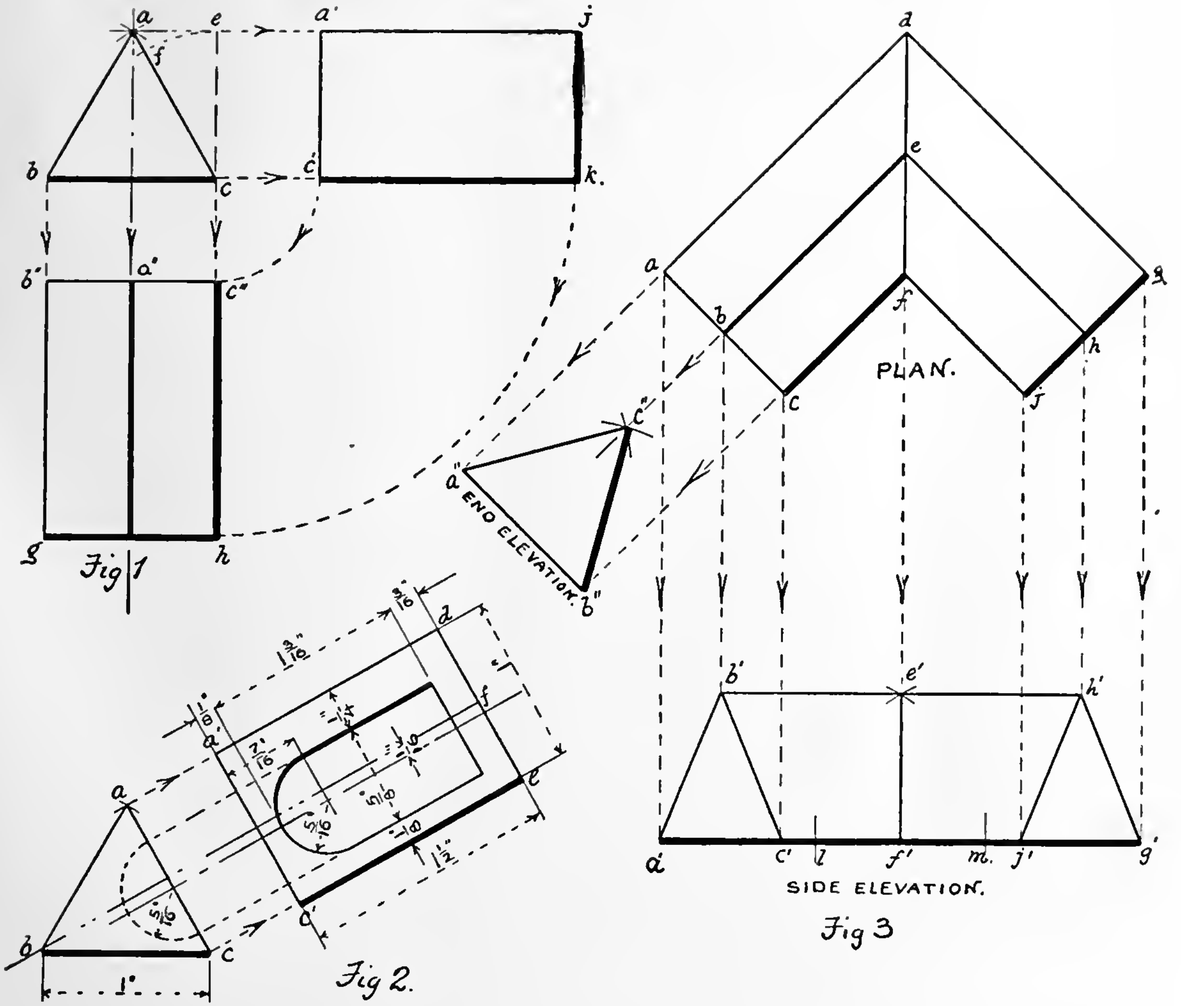


Fig 1

Fig 2.

Fig 3

tomed $\frac{5}{8}''$ wide, round at one end and square at the other end; a line passing through the centre of this depression is $\frac{1}{16}''$ off the centre of the prism. The round end of the depression is $\frac{1}{8}''$ from the end of the prism, while the opposite ends are $\frac{3}{16}''$ apart. The depression is $1\frac{3}{16}''$ long, the prism $1\frac{1}{2}''$ long, and the centre from which the round end of depression is drawn is $\frac{7}{16}''$ from the end of the prism.

If this were shown on the side elevation of Fig. 1, all the dimensions of *width* would be foreshortened, and therefore not in true proportion to the length.

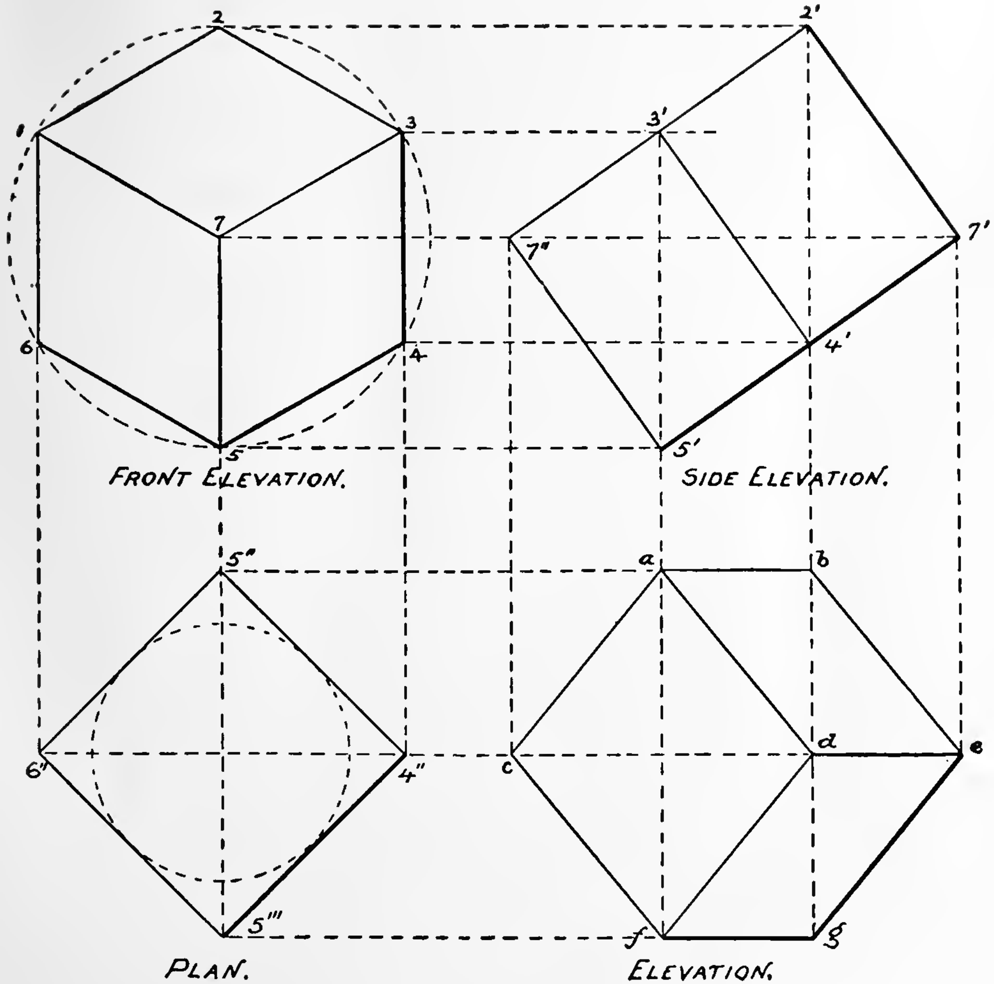
In Fig. 2 the side *a-c* is projected perpendicularly, therefore all the dimensions of *width,* as well as length, can be correctly measured and laid out, while the *dotted* semi-circle in the end elevation defines the form and depth of the depression. The end elevation of the prism being an equilateral triangle, the side *a-c* would be drawn with the 60° angle; consequently all lines projected with the 30° angle from *a-c* would be perpendicular to *a-c*. With this explanation the pupil should be able to work out this lesson. It must not be understood that all the information given in Fig. 2 cannot as well be conveyed by Fig. 1. It can, and in the majority of cases would be, but in that event all the dimensions of *width* would be taken from the end elevation, and would not be so clear. There are many cases where the method shown in Fig. 2 would be necessary, because the forms to be shown would be too intricate to be *safely* shown otherwise.

In Fig. 3 is given another illustration of the effect of foreshortening. In this case all dimensions would be taken from the end elevation and plan, as no measurements could be taken from the side elevation. To draw this exercise, first lay out the plan to any required dimensions, and by projecting *a-b* and *c,* as indicated by the arrow heads, and complete as in Fig. 1. Project *a-b-c-f-j-h* and *g,* using 90° angle, draw *a′ g′*, using T square. Make *j′ l* and *j′ m* each equal to half *a-c,* with radius *l-m* and *l* and *m* for centres, sweep arcs cutting at *e′*, through *e′* and parallel with *a′ g′* draw *b′ h′*, draw *b′ a′*, *b′ c′*, *e′ f′* and *h′ g′*.

Plate 4. Projections of a Cube Standing Upon One of Its Corners.

First draw the centre lines of the *plan,* and on them a circle whose diameter is equal to the side of a face, and complete the plan by drawing with 45° triangle sides, 5″—6″, 6″—5‴, 5‴—4″ and 4″—5″. Project corners 6″—5″—4″ upwards (using 90° angle), then with 30° angle draw 5—4 and 5—6. Make 5—7 equal to 5—4, with 7 as centre and rad. 5—7 draw circle which will circumscribe the hexagon representing the cube. With 30° angle draw 1—2, 2—3, 3—7, 7—1, and with 90° angle draw 1—6 and 3—4. With T square project points 2—3—4—5 and 7 to the right. Take point 5′ on line with 5—5′ as centre and radius equal to diagonal

PLATE 4



2
2'
1
3
3'
7
7"
7'
6
4
4'
5
5'
FRONT ELEVATION.
SIDE ELEVATION.
5"
a
b
6"
4"
c
d
e
5'''
f
g
PLAN.
ELEVATION.

6″—4″ in plan, mark off point 7′ on line 7—7′, draw 5′—4′—7′. Projection of point 4 will cut line 5′—7′ at its middle 4′, draw 4′—3′ perpendicular to 5′—7′ and 2′—7′ and 5′—7″ parallel to 4′—3′, draw 2′—7″ through 3′, thus completing the front and side elevations. To draw the fourth figure or elevation, project the points 5″—4″ and 5‴ to the right, using the T square, then with 90° angle project point 7″ to *c*, 3′ to *a* and produce to *f*, 2′ to *b* and produce to *d* and *g*, and 7′ to *e*. Connect *c-a, c-f, a-d, d-f, a-b, d-e, f-g, b-e* and *e-g*.

NOTE.—In all of these lessons the student should use the T square for all horizontal lines, and the 90° angles for perpendicular or vertical lines; 30°-60° and 45° angles are to be drawn with the 30°-60° and 45° sides of the triangle, using the T square as the base upon which to guide the triangles.

PLATE 5. PROJECTIONS OF AN HEXAGONAL PRISM.

Draw centre lines A B and *c-f*. With their intersection *g* as centre, draw circumscribing circle of required diam., then with 60° angle draw *c-b, c-d, a-f* and *f-e,* and with T square draw *b-a* and *d-e,* completing the plan.

With 90° angle project corners *c-d-e-f* to *m-n-o-p*, and draw base line *m-p,* lay off from scale the required height of prism *m-h,* and draw *h-l,* thus completing the front elevation.

Draw side 1—2 of side elevation and produce to intersect with *d-e* of plan produced; through this intersection with 45° angle draw line 7—8—9, produce *b-a* on *c-f* until they intersect line 7—8 at 9 and 8. With 90° angle project points of intersection 8 and 9 to 3—4 and 5—6, and with T square draw 1—5 and 2—6 continuations of *h-l* and *m-r,* completing side elevation.

Now suppose it necessary to draw a side elevation inclined toward observer and at an angle of 60° to the horizontal. With the 30° angle project the angles or corners of the upper and lower faces of the front elevation until they intersect a line C d drawn at the angle of 60° to the horizontal. Through C draw C E perp. and F T horizontal. With C as centre sweep arcs H I, J K, L M, N O, P Q, R S and D E, thus transferring the points from C D to C E. Lay off C G, G T equal to 2—4, 4—6, and through C, G and T draw indefinite perpendiculars. With T square project C, M, O and E to G, M′, O′ and E′, and I, K, Q and S to I′, K′, Q′ and S′. Connect these points, as shown in plate, completing the inclined front elevation. To transfer the dimensions of width in the plan to the side elevation, a second method is shown in which the compass is used as indicated by the dotted arcs. Any convenient point can be used for the centre from which to sweep these arcs, as at 5; the arcs must be drawn tangent to the lines projected from *a, f* and *e* of the plan.

PLATE 5

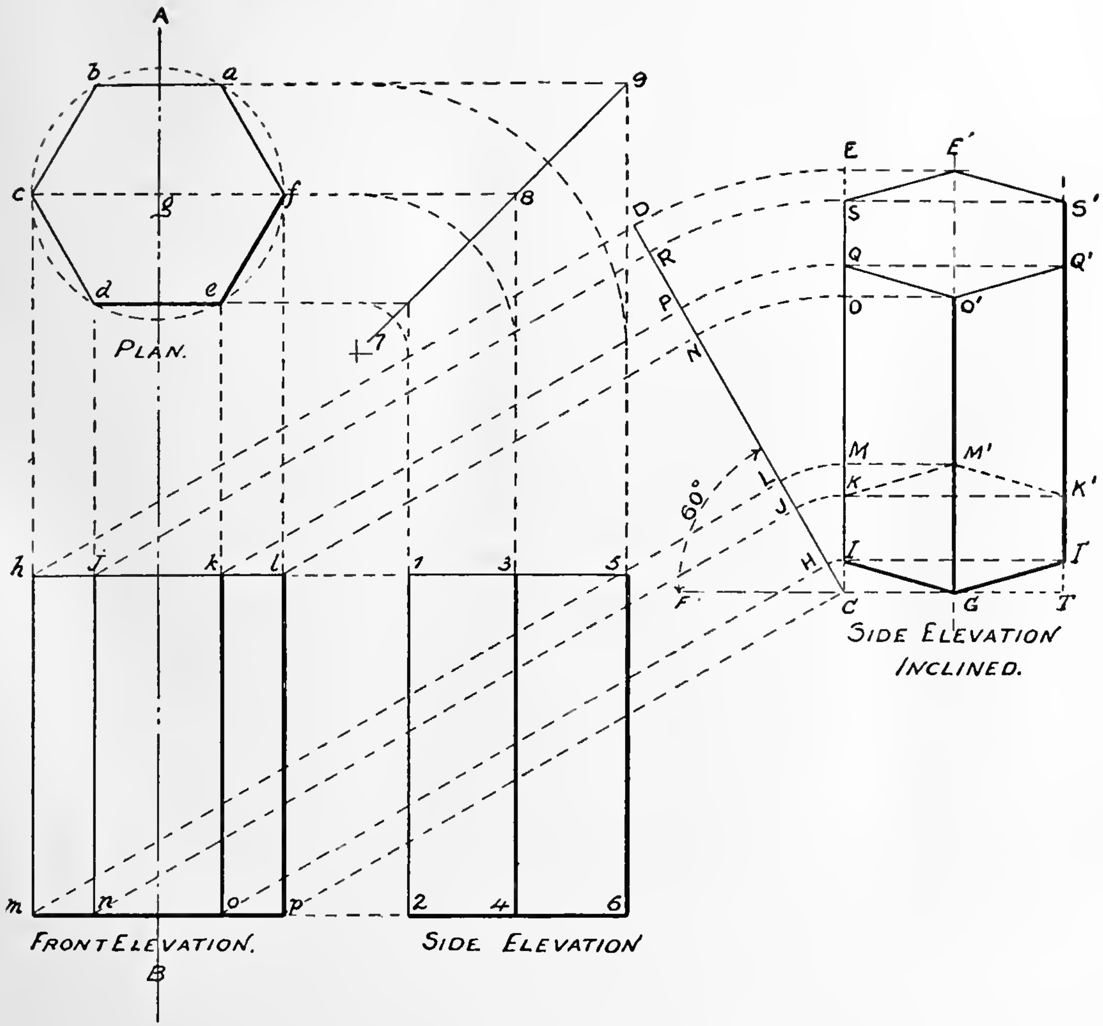

A
B
PLAN.
FRONT ELEVATION.
SIDE ELEVATION
SIDE ELEVATION
INCLINED.
60°

Plate 6. Projections of an Hexagonal Pyramid, which is Standing Upon One Corner, and Whose Centre Line is Inclined 30° from the Vertical.

Draw centre line A B, at angle of 60° to the horizontal or 30° from the vertical, using 60° side of triangle, and upon it draw a circle of a size to circumscribe the hexagonal base of the pyramid. With 30° and 90° angles draw diameters D G, E H and C F; also with the same angles draw sides C D, D E, E F, F G, G H and H C. This completes the plan. Project C D, H E and G F to the left indefinitely, using 30° angle, and with 60° angle project the angles or corners E, F, G and H of the plan downward and parallel with centre line A B to I, J, K and L, and with 30° angle draw base line I L perpendicular to A B. Measure off the height of the pyramid along the centre line from B to M, and draw M I, M J, M K, M L, completing the side elevation. With 30° angle project angles D, E and F indefinitely to the left, and with U as centre draw indefinite arcs and with 90° angle draw tangent to these arcs indefinite lines to P, O and Q. With T square project points I, J, K and L horizontally intersecting the vertical lines at T, R, S, P, Q and O. Draw T R, R P, P O, O Q, Q S and S T. With 90° angle draw indefinitely O N. With T square project the vertex of the pyramid to the left, intersecting O N at N. Draw N R, N P, N Q, N S. The sides R T and T S of the base being behind or on the side opposite the observer, would be dotted as shown.

PLATE 6

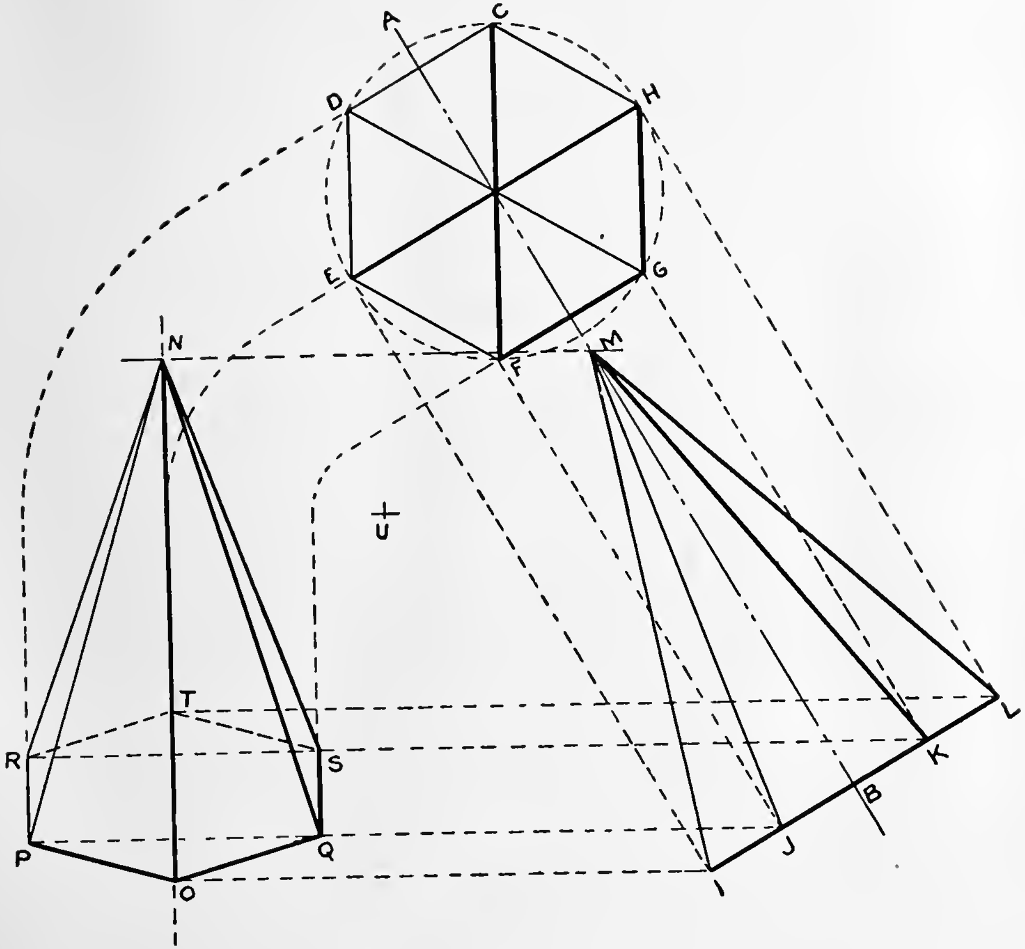


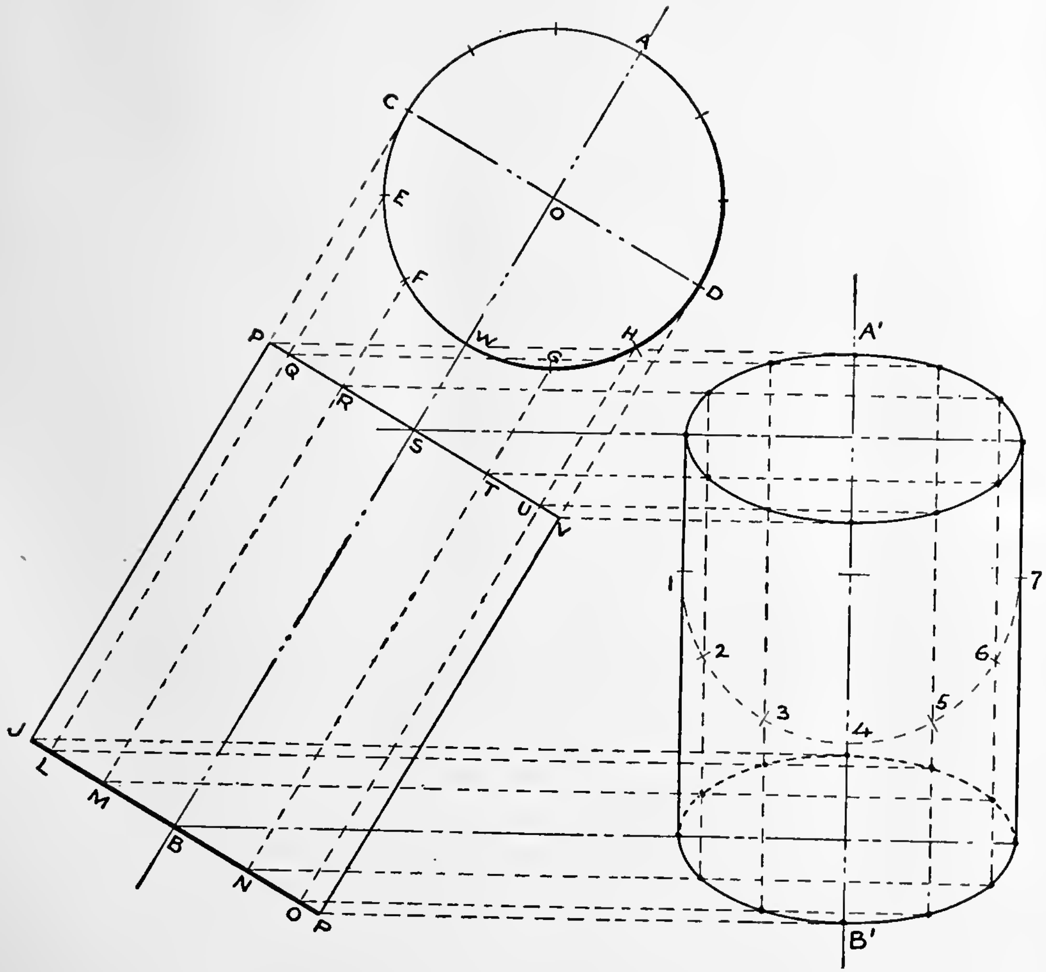
Plate 7. Projection of a Cylinder Whose Axis is Inclined at an Angle of 30° to the Vertical.

With 60° angle draw centre line A B, and at right angles to A B, using 30° angle, draw centre line C D. With O as centre and radius equal to half diam. of cylinder draw circle A C W D. This will be the plan of the cylinder.

With 30°-60° and 90° angles divide the semi-circumference into six equal parts, C E, E F, F W, W G, G H, H D, and with 60° angle project points C, E, F, G, H and D downward indefinitely, and with 30° angle draw base line J P. Measure off centre line B S equal to height of cylinder and draw P S V, completing side elevation.

At suitable distance to the right of side elevation draw centre line A′ B′, and on it draw a semi-circle with radius equal to O C, and with 30°-60° angles and T square divide into six equal parts as indicated in dotted lines on front elevation at 1, 2, 3, 4, 5, 6, 7, and through these points draw with 90° angle indefinite lines parallel with A′ B′. Now with T square project points P, Q, R, S, T, U, V and J, L, M, B, N, O, P to the right, intersecting the lines drawn through 1, 2, 3, etc. These intersections are points in a curved line forming an ellipse, which should be lightly and smoothly drawn in by hand and afterwards drawn firmly by means of irregular curves. This completes the front elevation. This and the following lessons show curves developed by intersecting lines, and all make the use of the irregular (sometimes called French curves) necessary, and the student should endeavor to acquire skill in using them. As an aid to the fitting of the curves to the points the lines should be sketched in freehand, but lightly.

PLATE 7



CHAPTER VI.

Plate 8. Conic Sections—The Parabola.

The parabola is a curve which is formed by a plane which cuts a cone in a line parallel with one of its sides, and is a curve of which any point is equally distant from a fixed point, called its *focus,* and from a given straight line called the *directrix.* (See Fig. 14, Plate 11.)

To develop the parabola from a cone:

Draw the centre lines A B and C D. With their point of intersection O for centre and radius equal to radius of the base of the cone draw the circle, A C J D, which will be the plane of the cone.

With 30°-60° and 90° angles divide the base into six equal parts, as 1, 2, 3, etc.

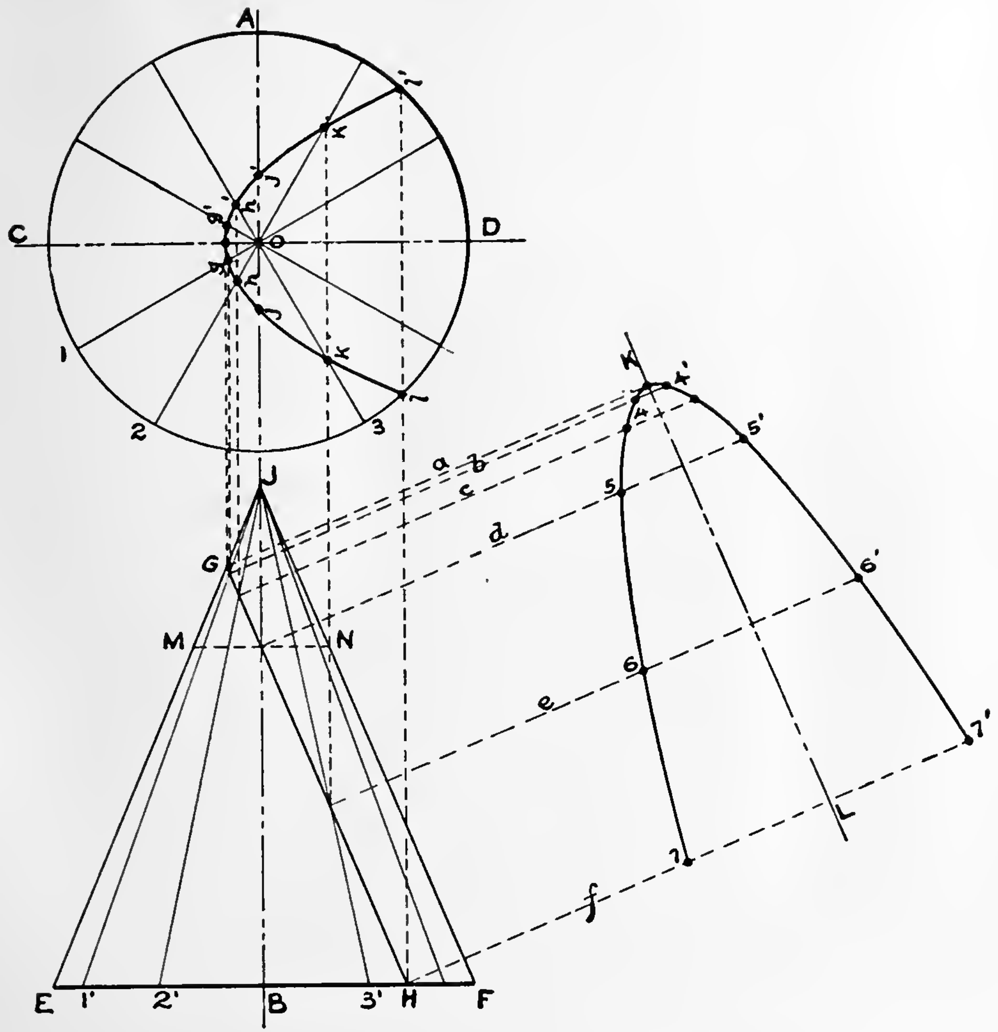
Lay off distance J B equal to height of cone, and through B draw E F, making B E equal to O C and B F equal to O D, and draw J E and J F to complete side elevation of cone.

Project points 1, 2, 3 upon the base E F as 1′, 2′, 3′, and draw lines J1′, J2′, J3′. Draw G H parallel with J F. G H represents the cutting plane. Perdendicular to G H and from the points of intersection of G H with the lines drawn from the vertex J of the cone to its base E F, draw the indefinite lines, a, b, c, d, e, f, and at L draw L K parallel with G H.

Returning to the plan: through the centre O draw the diameters from points 1, 2, 3, etc., and onto these diameters project the points of intersection of G H with J1′, J2′, J3′, as shown at gg′, hh′, JJ′, etc. These points are points through which the plan of the parabola is to be drawn, and all are determined by the intersections of the lines, except O J and O J′. Where the plane G H intersects the centre line J B of the cone draw M N parallel with the base, JJ′ is equal to M N.

To complete the elevation of the parabola, with the compasses transfer the distances gg′, hh′, etc., to 44′, 55′, etc., laying out equally each side of K L on the lines a, b, c, etc. Through the points thus found draw the curve.

PLATE 8



PLATES 9 AND 10. THE HYPERBOLA.

If a cone A B C (Fig. 10), of which A C is the base, is cut by a plane J K, parallel with but not through its axis, B G, and perpendicular to its base, the outline of the section thus obtained will be an open curve called a *hyperbola,* and shown by N J O (Fig. 11).

If two cones (A B C and D B E, Fig. 10) are placed so that their apexes join, and if their axes, B G, B F, are in the same straight line, and they are cut by the same plane, H I L J K, parallel with F B G, the sections thus obtained will form two hyperbolas, N J O and P I Q, as shown in Fig. 11, which are called the *branches* of the hyperbola. I and J are the *vertices* of the curves, and the line I J, the distance between the vertices, is the *transverse axis.* This is the same as I J in Fig. 10, and has been defined as that part of the axis which, if continued, would join an opposite cone. The *congregate axis,* L M, is a line drawn through the transverse axis and at right angles to it. It is equal to twice the distance L B (Fig. 10), of the intersecting plane I J, from the axis of the cone from which the cone is produced. R R′ (Fig. 11) are the *foci* of the two curves, and B, midway between I and J, is called the centre of the curve. The nature of the hyperbola is such that the *difference* of the distances of any point in the curve, from the foci, is always the same, and is equal to the transverse axis I J. Thus, if from the point 1 we draw lines 1 R and 1 R′ to the foci R and R′, then the difference of the length of these lines will be equal to I J.

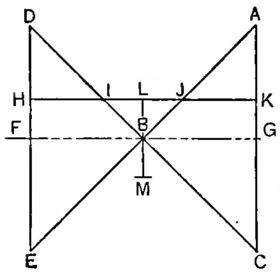


FIG. 10.

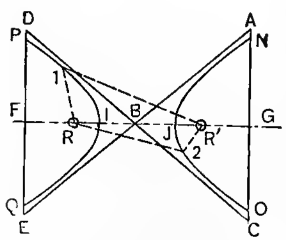


FIG. 11.

PLATE 9.—*Given the transverse and conjugate axes, to find the foci of an hyperbola:*

Let I J (Fig. 12) be the transverse axis of two branches of an hyperbola. The ends of the axis will coincide with the vertices of the two curves. From J erect J U, a perpendicular to I J, and make it equal to half the conjugate axis, or to the distance L B (Fig. 10), of the intersecting plane from the axis of the cone. Then from B (Fig. 12), the middle of I J as a centre, and with B U as radius, describe the circle U R V R′, cutting I J extended at R and R′, which will be the foci of the hyperbola.

The transverse and conjugate axes being given, to lay off an hyperbola:

Draw I J (Fig. 12) equal to the transverse axis. Find the foci R R′, as explained above. From R and R′ lay off any number of points, 1, 2, 3, etc., 1′, 2′, 3′, etc., at equal distances from R and R′ respectively. Then with radii I 1, I 2, I 3, etc., and from the foci as centres, describe arcs cutting each other at *a, b, c,* etc., and

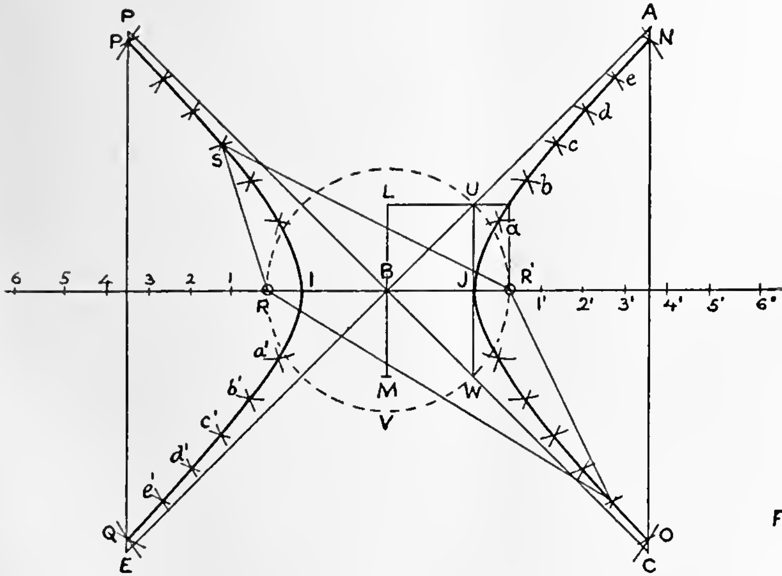

P
P
A
N
e
d
c
b
S
L
U
a
6
5
4
3
2
1
R
I
B
J
R'
1'
2'
3'
4'
5'
6'
a'
b'
M
W
V
c'
d'
e'
Q
E
O
C

FIG. 12

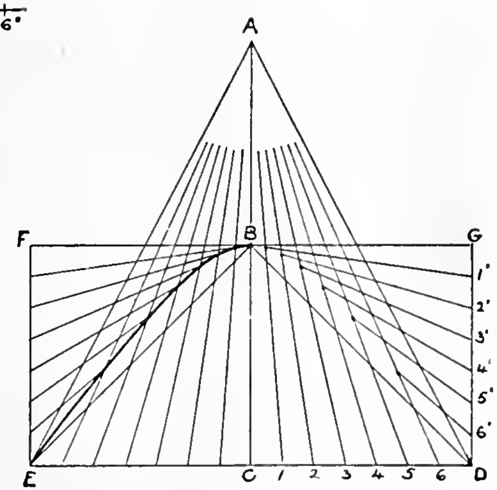

A
F
B
G
1'
2'
3'
4'
5'
6'
E
C
1
2
3
4
5
6
D

FIG. 13.

a′, *b′*, *c′*, etc. These will give points in the curve through which it may be drawn.

FIG. 13.—*To draw an hyperbola when its length B C, its breadth D E, and transverse axis A B are given:*

Construct the parallelogram D E F G and subdivide its sides G D and E F and each of the ordinates, C D and C E, into the same number of equal parts, 1, 2, 3, etc., and 1′, 2′, 3′, etc. From A draw lines to 1, 2, 3, etc., and B draw lines to 1′, 2′, 3′, etc.; where these lines cut those drawn from A to E D will be points through which the curve can be drawn.

PLATE 10.—The purpose of this plate is to show how the hyperbola is derived from the cone, and the method of procedure is exactly the same as explained in Plate 8 for the parabola. All reference letters and figures and particular explanation are omitted, and the student is expected to develop the curve as indicated in the plate without the aid of explanations.

PLATE 10

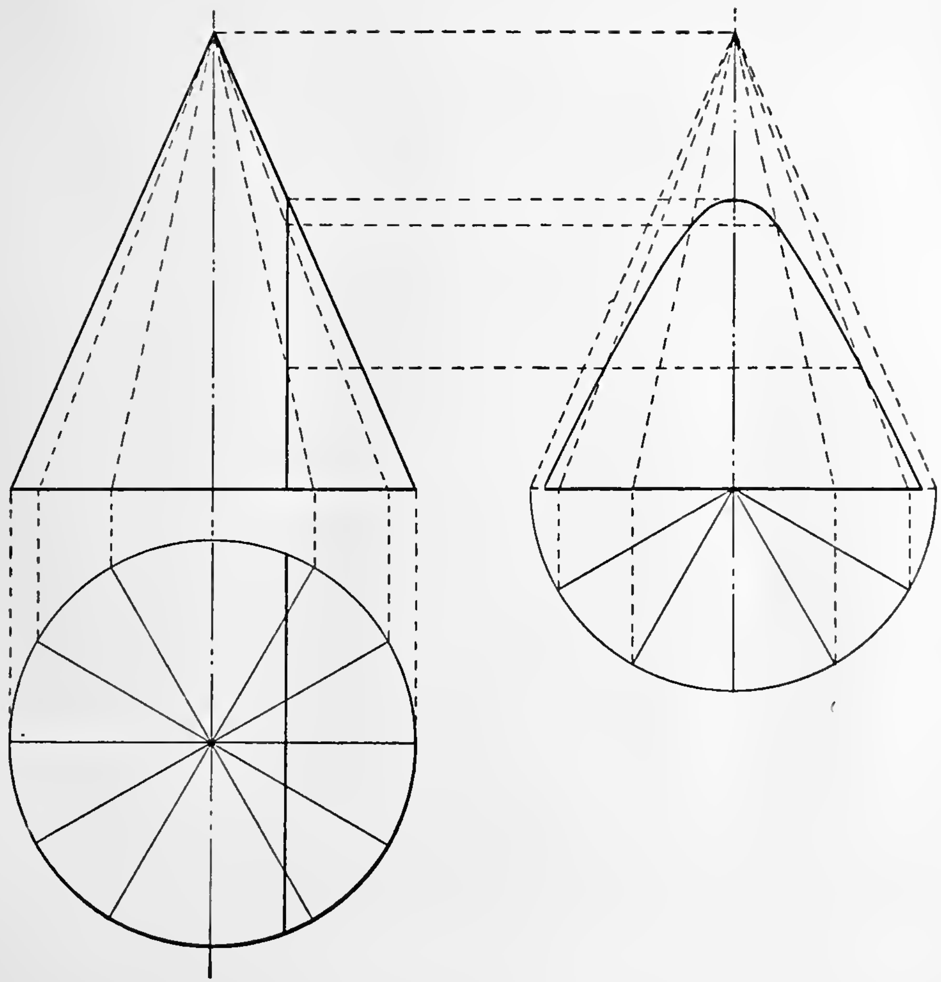


Plate 11. The Parabola.

Fig. 14.—*The length A B and breadth C D being given, to draw a parabola:*

Draw A B to the given length and produce beyond A and B, draw C D perpendicular to A B through B, making C B and B D equal to half the given breadth. Bisect the ordinate C B and draw A E, and at right angles to A E draw E F. Make A G and A J each equal to B F. G is the *focus* of the parabola, and H I drawn through J is the *directrix*. Divide A B into spaces as 1, 2, 3, etc., making spaces or intervals shortest near the vertex, and draw 1, 1′, 2, 2′, 3, 3′, etc., perpendicular to A B. Take distance 1 J in compass, and with the focus as centre sweep arc cutting ordinate 1-1′ at 1′. In like manner take distance of each ordinate from the directrix, and with focus as centre sweep arcs cutting the ordinates at 2′, 3′, 4′, etc. These will be points in the curve which can be drawn through them.

Fig. 15.—*Length and breadth being given, to draw the parabola:*

Construct the parallelogram F E C D. Subdivide the ordinates B C and B D into any number of equal parts; also divide F C and E D into a like number of equal parts. From A draw lines A 1′, A 2′, A 3′, etc., and from B D and B C draw from points 1, 2, 3, etc., lines parallel with A B and cutting the lines drawn to 1′, 2′, 3′, etc. These will be points in the curve through which it may be drawn.

Fig. 16.—Another method. Length A B and breadth C D being given. Produce A B, making A E equal to A B; draw E C and E D, and draw 4′—4 through A and parallel to C D. Divide E 4 and D 4 into the same number of equal parts, likewise E 4′ and C 4′, and draw lines 1-7′, 2-6′, 3-5′, 5-3′, etc. The curve will be *tangent* to these lines as shown.

PLATE II

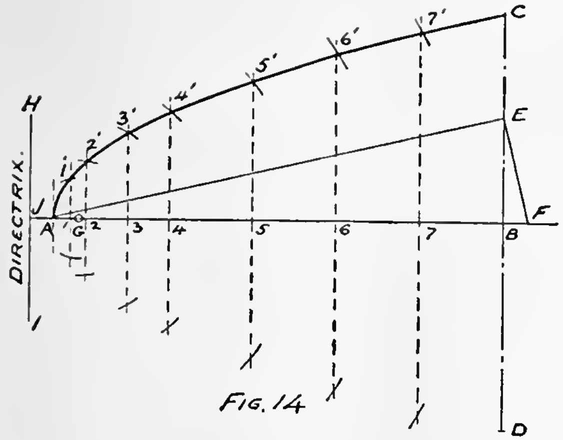


FIG. 14

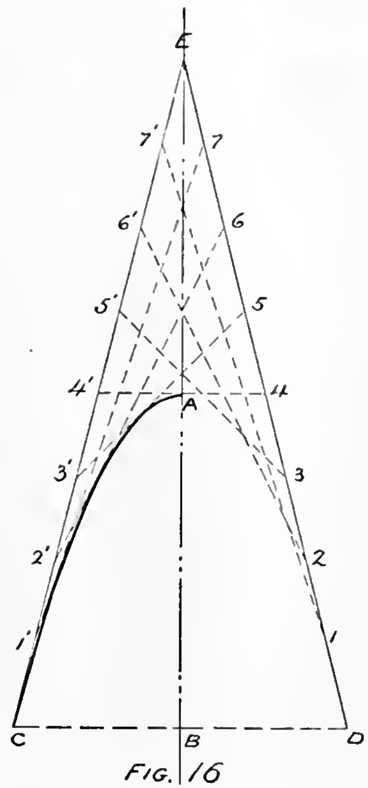


FIG. 16

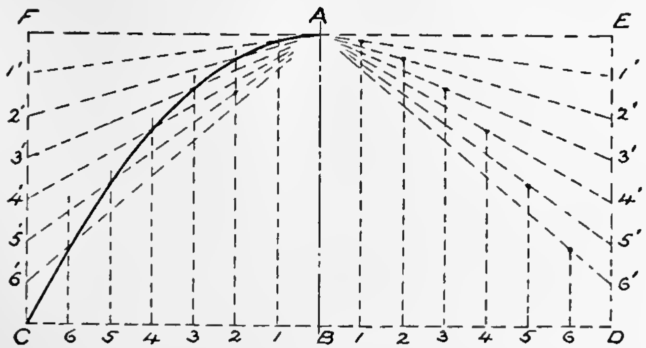


FIG. 15

Plates 12 and 13. The Ellipse.

If a cylinder or cone be cut by a plane at an angle to its axis, the outline of the curve obtained will be an *Ellipse.*

In Plate 12 is shown a cylinder E F G H cut by the plane J K. To develop the ellipse:

Draw the centre lines A B and C D perpendicular to each other, and with their point of intersection O as centre draw the circle C A D equal in diameter to the required cylinder, this will be the plane. Project the points C and D indefinitely to G and H. Draw G H perpendicular to A B, and measure G E the required height of the cylinder. Draw E F parallel with G H, completing the elevation of the cylinder. Draw J K at any required angle to represent the cutting plane.

With the 30°-60° and 90° angles divide the circle C A D into equal parts, as at 1, 2, 3, 4, and project these points upon the elevation, as at 1-1′, 2-2′, etc. From points of intersection of J K and the lines 1-1′, 2-2′, etc., draw the indefinite lines a, b, c, d, etc., and parallel with J K draw L M. With the intersection of lines g and L M as centre and radius equal to O C draw semi-circle 1″ M 4″, and subdivide into equal parts as 1″, 2″, M-3″-4″, corresponding with points 1, 2, 3, etc. From these points and parallel with L M draw lines, intersecting lines a, b, c, d, etc. These points of intersection will be points in the ellipse.

The cone treated in the same way as above would likewise develop the ellipse.

PLATE 12

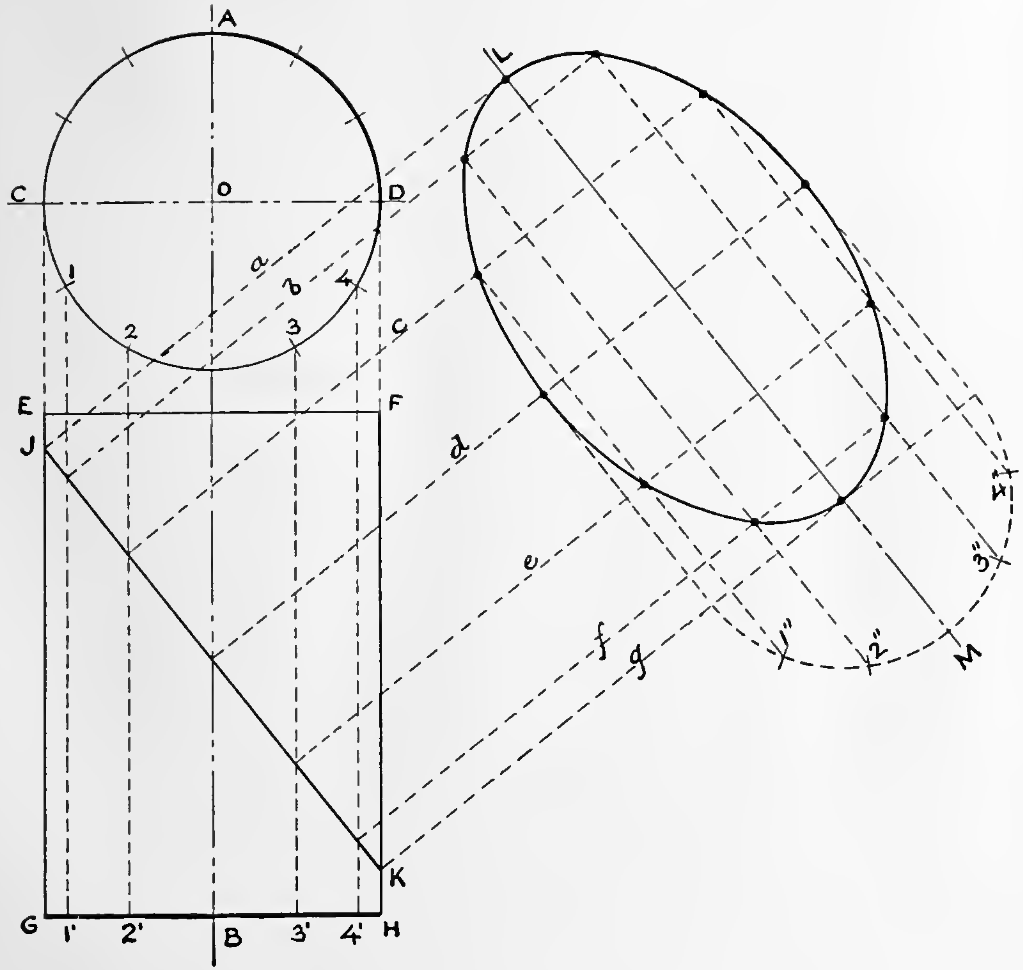


PLATE 13.—*To draw an ellipse when the long and short diameters are given:*

FIG. 17.—Draw the concentric circles A B C D and E F G H equal, respectively, to the long and short diameters. Divide these circles into any number of equal parts, and draw diameters as I M, J N, etc. Where these diameters intersect the circles draw horizontal and vertical lines, as J 2, J′ 2 and K 3, K′ 3, etc. These points, 1-2-3-4, etc., will be points in the ellipse, which can be drawn through them.

FIG. 18.—Another method. Draw rectangle whose sides, A D and B C, are equal to the long diameter, and A B and C D are equal to the short diameter of the required ellipse. Draw centre lines, F H and E G. Divide centre line F H into any number of equal parts, as O 3, 3-2, 2-1, etc. Also divide the short sides into the same number of equal parts, as A 3′, 3′-2′, 2′-1′, etc. From G draw lines through points 1-2-3, etc., and from E draw lines to 1′, 2′, 3′, etc., and cutting the lines drawn from G. The intersections of these lines will give points in the curve.

FIG. 19.—*To draw an ellipse whose axes are oblique:* Construct the parallelogram whose sides are parallel with the axes, and proceed as with Fig. 18.

The ellipses given on Plates 12 and 13 are true ellipses, such as would be developed from either a cylinder or cone cut by a plane. Many times an approximate ellipse, which can be drawn directly by means of the compass, will meet all requirements. Four methods are given on Plate 14.

FIG. 20.—*The Oval.*

Draw centre lines A B and C D. With their intersection O as centre describe a circle whose diameter is equal to the large end of the oval. From D draw D E and produce to F, likewise from C draw C E and produce to G. With C as centre and radius C D draw the arc D G, and with D as centre and radius D C draw the arc C F. Then with E as centre and radius E F draw arc F B G, completing the oval.

PLATE 13

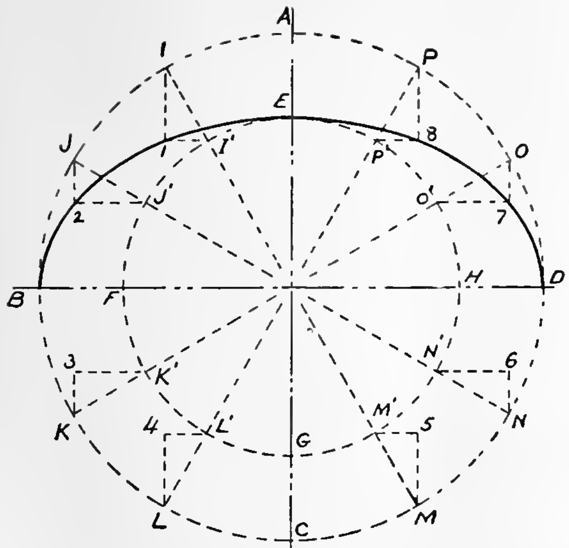


FIG. 17.

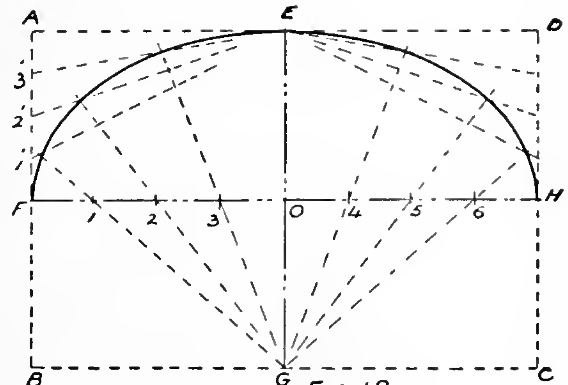


FIG. 18

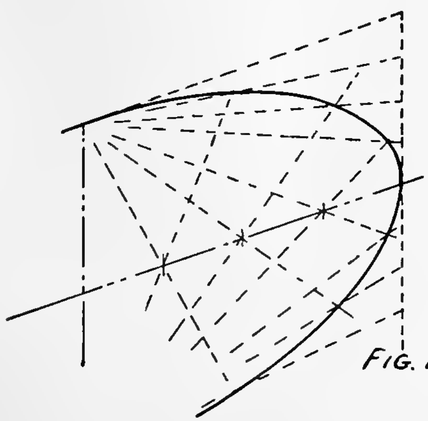


FIG. 19

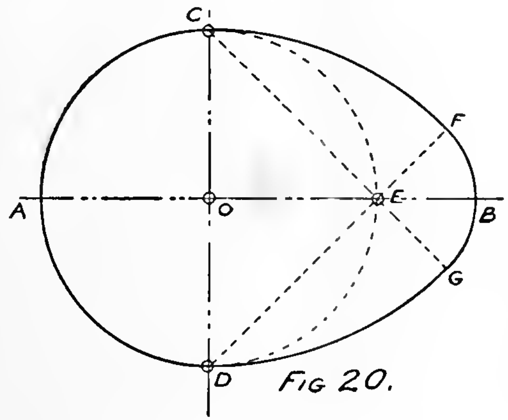


FIG 20.

Plate 14. Approximate Ellipses.

To draw an approximate ellipse with compass, the major axis only being given:

First Method. Fig. 1.

Draw A B equal to given length, divide into four equal parts A C, C D, D E and E B. With C and E for centres and radius C E draw intersecting arcs at F and G. From F and G through C and E draw indefinite lines G H, G I, F J and F K.

With C and E as centres and radius C A draw arcs J A H and I B K, and with F and G as centres and radius G H draw arcs H I and J K.

Second Method. Fig. 2.

This is an ellipse of different proportion from those by the first method.

Draw A B equal to the given length and divide into four equal parts, as A F, F E, E G and G B. Through E draw C D perpendicular to A B and make E H and E I equal to E F and E G. From H and I through F and C draw indefinite lines I K and I L and H J and H M. With F and G as centres and radius F A draw arcs K A J and L B M, and with I and H for centres and radius I K draw arcs K C L and J D M.

Third Method. Fig. 3.

To draw an approximate ellipse from four centres when both major and minor axes are given:

Draw A B and C D perpendicular to and bisecting each other at O. Draw A E parallel with D C and E C parallel with A B. Bisect A E in F and draw F C. Draw E D cutting F C in G. With G and C as centres and any radius greater than half of C G draw intersecting arcs at H and I. From H through I draw line cutting C D at K. This line will be perpendicular to and will bisect G C. Draw G K cutting A B at M, and make O N equal to O M. Make O L equal to O K, and from I and K through M and N draw indefinite lines L P, L R and K Q. With M and N as centres and radius M A draw arcs G A P and Q B R, and with centres at L and K and radius K G draw arcs G C Q and P D R.

Fourth Method. Fig. 4.

Giving different proportions from those by third method:

Draw A B and C D perpendicular to and bisecting each other at O. Make O E equal to O C, and make O F and O G equal to A E. Draw F G and bisect at H. Make F I equal to F H. Make O K, O J and O L equal to O I. From K and L through I and J draw indefinite lines K Q, K P, L M and L N. With I and J as centres and I A as radius draw arcs M A Q and N B P, and with K and L as centres and radius K Q draw arcs Q D P and M N C.

PLATE 14

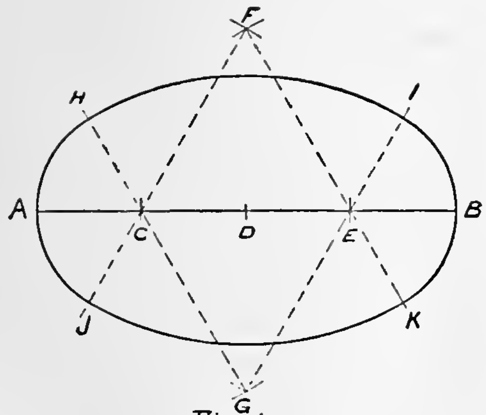


Fig. 1

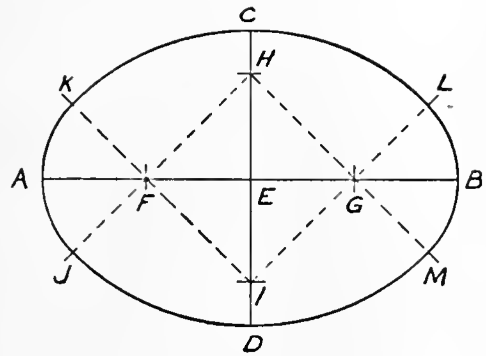


Fig. 2.

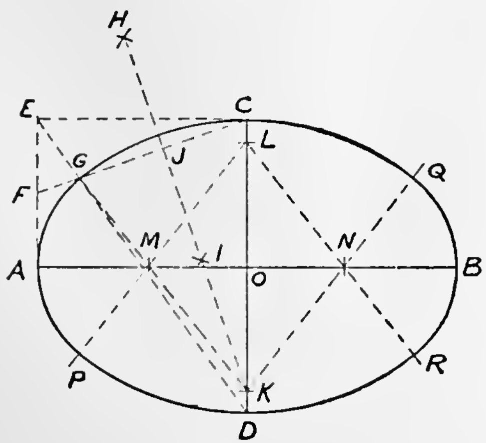


Fig. 3.

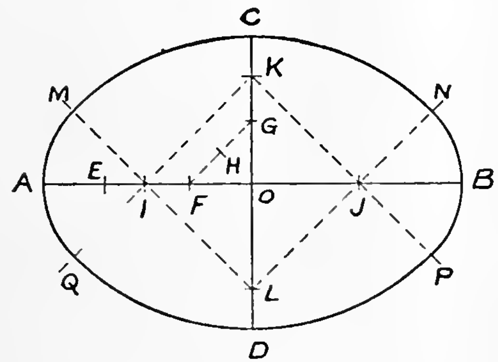


Fig. 4.

CHAPTER VII.

Various Curves.

Plate 15. Spirals.

Fig. 21.—*To draw an approximate spiral from two centres:*

Draw centre line A B, and on it mark the centres 1 and 2, whose distance apart shall be equal to one-half the distance between the turns of the spiral. With 1 for centre and radius 1-2 sweep the semi-circle 2-3; then with 2 as centre and radius 2-3 sweep the semi-circle 3-4, and proceed in this way, using centres 1 and 2 alternately.

Fig. 22.—*To draw an approximate spiral from three centres:*

Lay out an equilateral triangle whose sides are equal in length to one-third the distance between the turns of the spiral. Produce indefinitely the sides as 1 A, 2 B, 3 C. With 1 as centre and 1-3 as radius draw the arc 3-4, and with 2 as centre and 2-4 as radius draw the arc 4-5, and with 3 as centre and radius 3-5 draw arc 5-6, etc.

Fig. 23.—*To draw an approximate spiral from four centres:*

Lay out a square whose sides will each be one-fourth the distance between the turns of the spiral, produce the sides as 1-A, 2-B, 3-C, etc., and proceed as in previous examples, using the angles as centres, but starting the spiral with radius equal to half the diagonal of the square, or the side of the square may be used as the first radius.

Fig. 24.—*To draw a true spiral:*

Draw a circle whose diameter is equal to the sweep of the spiral when revolved upon its centre, and divide it into as many equal parts as may be desired, and draw diameters 1-7, 2-8, 3-9, etc. Divide one semi-diameter or radius into as many equal parts as for the circle, as 1′-2′-3′-4′, etc. With compass in 0 and radius 0-1′ sweep an arc cutting radius 1, with radius 0-2′ sweep an arc cutting radius 2, with radius 0-3′ sweep an arc cutting radius 3, and so on until all the points on the radius 12 have been used as radii for the arcs which cut the radii of the circumscribing circle. These intersections, *a, b, c, d,* etc., will be points through which the spiral can be drawn.

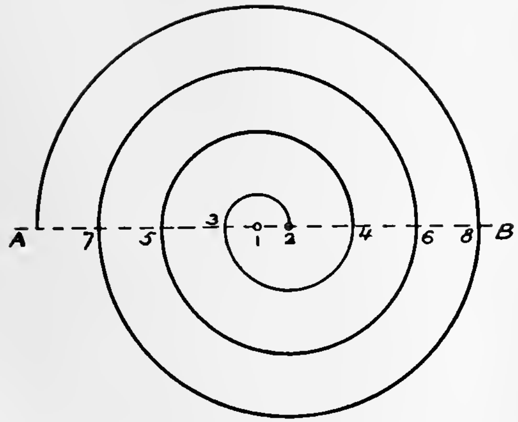


FIG. 21

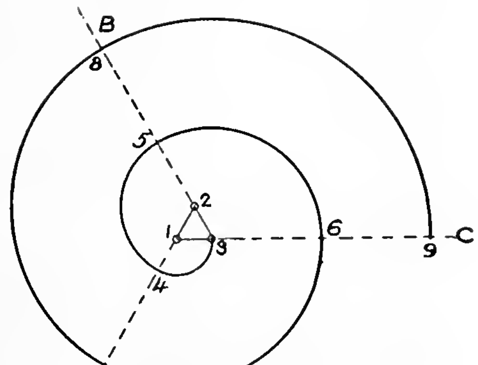


FIG. 22

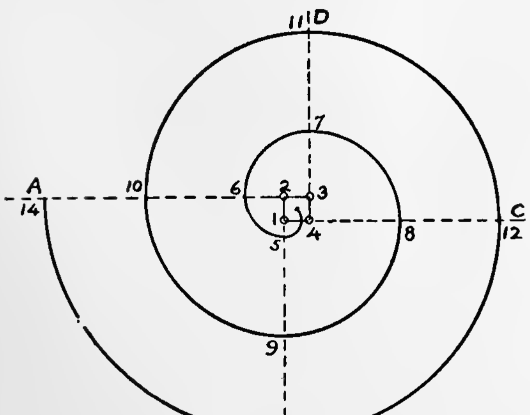


FIG. 23

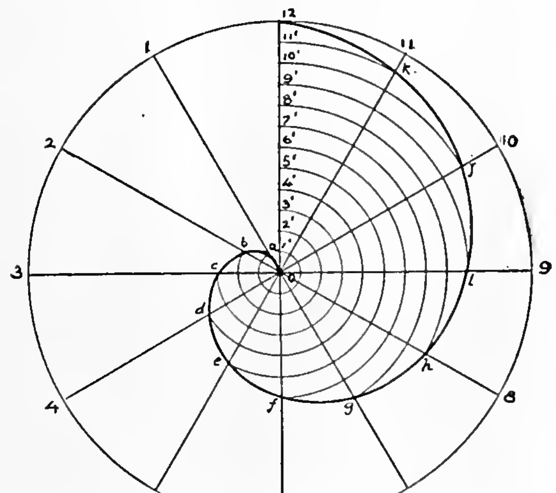


FIG. 24

In PLATE 16 is given a practical application of the approximate spiral drawn from four centres. This drawing shows the case of a blower. The centres from which the outer curve is drawn are 4″ apart, 2″ each side of the centre line of the blower case. The curve of the case ends at A, but is continued to B by the dotted line, to show that the distance between the turns of the spiral is just 4 times the distance between the centres from which they are drawn.

The 3-centre spiral could be used for this same purpose, and is sometimes so used, but the resulting form of the case is not so well adapted to the purpose for which these blowers—that of moving air—are used. The same objection holds good with reference to the 2-centre spiral. The draughtsman, however, finds numerous applications for all of these spirals in developing odd curves that are required in his everyday work.

In Fig. 27, Plate 16, is given a practical application of the *true spiral* in the development of the spiral or heart cam.

PLATE 16

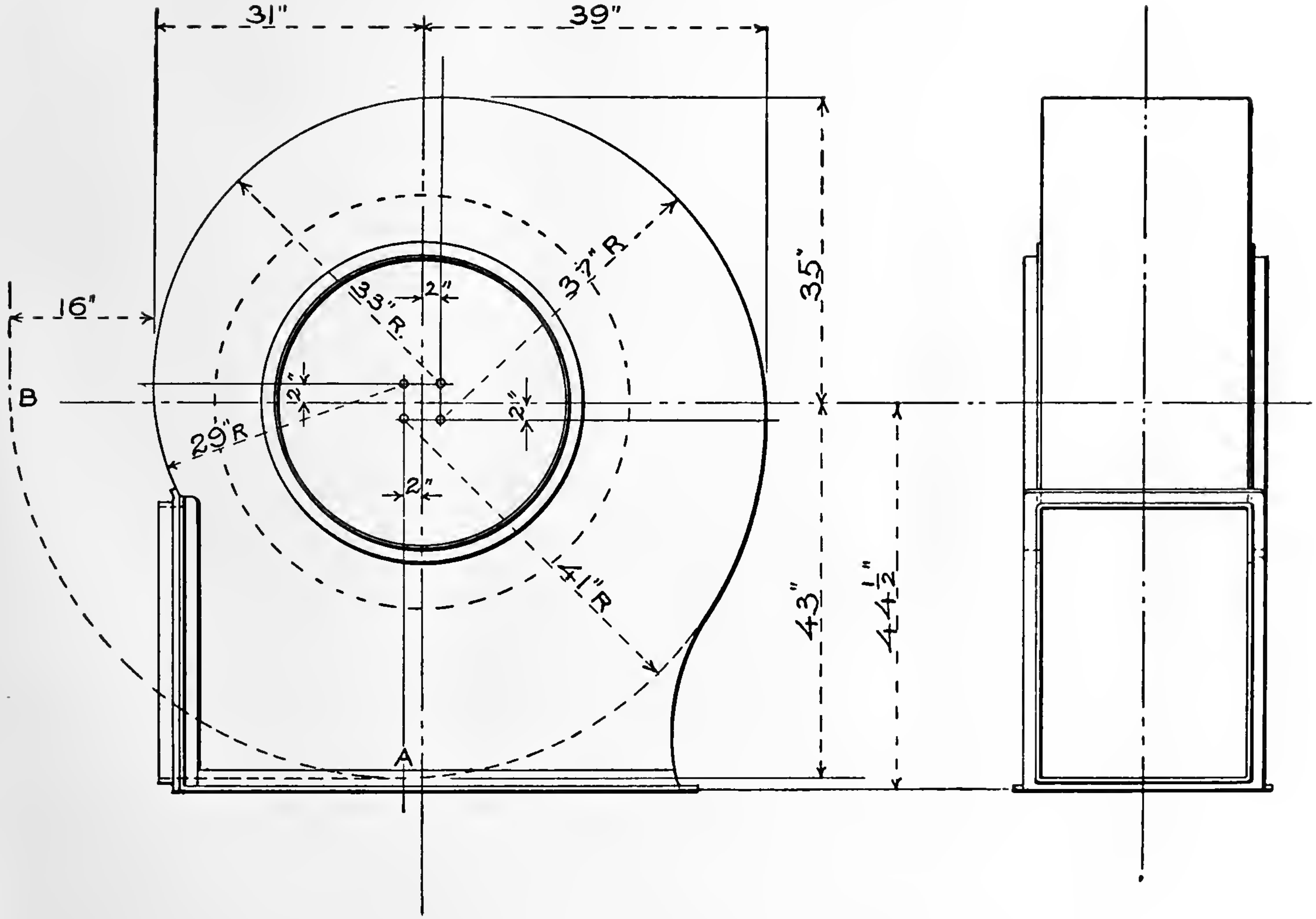


PLATE 17. THE INVOLUTE.

FIG. 25.—If a string be wound around a circular block and a pencil be attached to the free end, the block being held to a plane surface, the pencil will, if held taut, and the string unwound, describe a curve called the *involute* of a circle, generally called the *involute curve.*

About the centre A describe the required circle and divide it into any number of equal parts, 0-1, 1-2, 2-3, etc.; draw radii to these points, and to these radii draw tangents 1-1′, 2-2′, 3-3′, etc. Make one of these tangents 0-12 equal to the circumference of the circle A; and divide it into as many equal parts as was the circle. On tangent 1-1′ lay off one of these spaces, on tangent 2-2′ two, on tangent 3-3′ three, and so on until all of the tangents have been divided up or measured off, each succeeding tangent one space longer than the one preceding it. Through these points, 1′-2′-3′-4′, etc., the curve may be drawn.

PLATE 17 is introduced to illustrate a practical application of the involute curve to laying out the *single curve,* or involute gearing. As will be seen, but a small portion of the curve is employed—the beginning of the curve. This is shown in the lower corner of the plate.

In connection with the gear is shown a rack in "mesh." The rack is a straight gear, that is, the teeth, instead of being spaced around the periphery of a wheel, are equally spaced along a straight bar, and is employed to convert the rotary motion of the wheel into rectilinear motion, or the reverse. In the case of gear wheels the curve begins from an imaginary circle shown by dash and two dots, the other portion of the tooth being completed by radial lines.

This plate is not introduced as a lesson in drawing gear teeth, but merely as an illustration of one of the applications of the involute curve in practice.

FIG. 26.—*To draw a three-centred cam:*

Lay off an equilateral triangle and continue the sides as shown, using the angles as centres from which to describe the curves of the cam, as follows:

From A with radius A *h* describe the arc *h d;* from C with radius C *d* draw *d f;* from B with radius B *f* draw *f i;* from A with radius A *i* draw *i e;* from C with radius C *e* draw *e g*, and from B with radius B *g* draw *g h*. The centres A, B and C are not necessarily arranged in the form of an equilateral triangle; their positions will be determined by the circumstances for which the cam is to be used. Such a cam has the property that any two parallel lines drawn tangent to it will always be the same distance apart. (See lines 1′-2 and 5-6; also 3-4 and 7-8.)

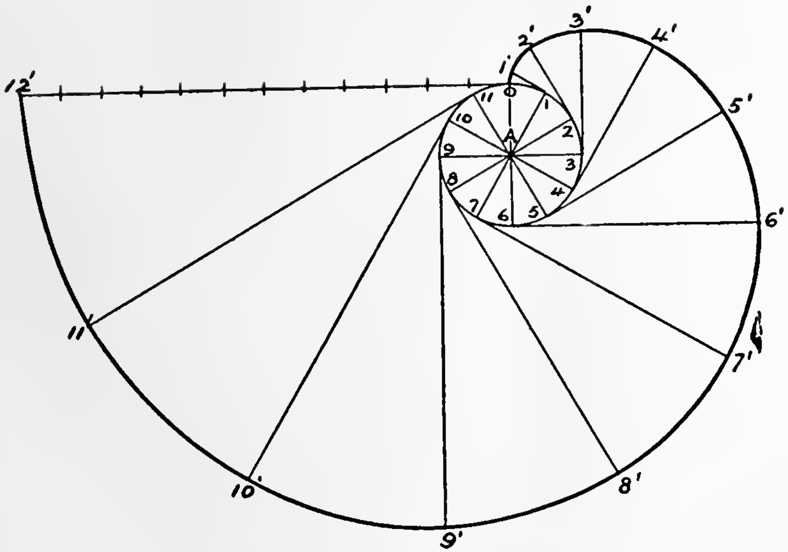


FIG 25

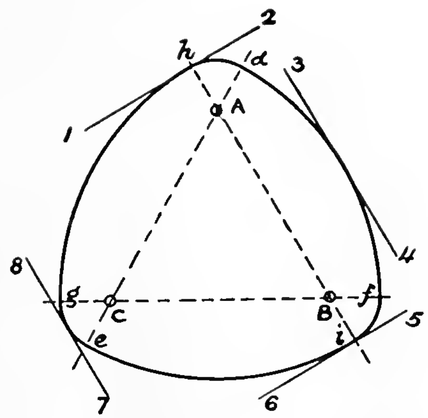


FIG. 26

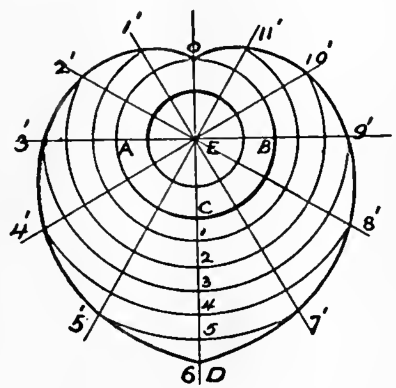


FIG. 27.

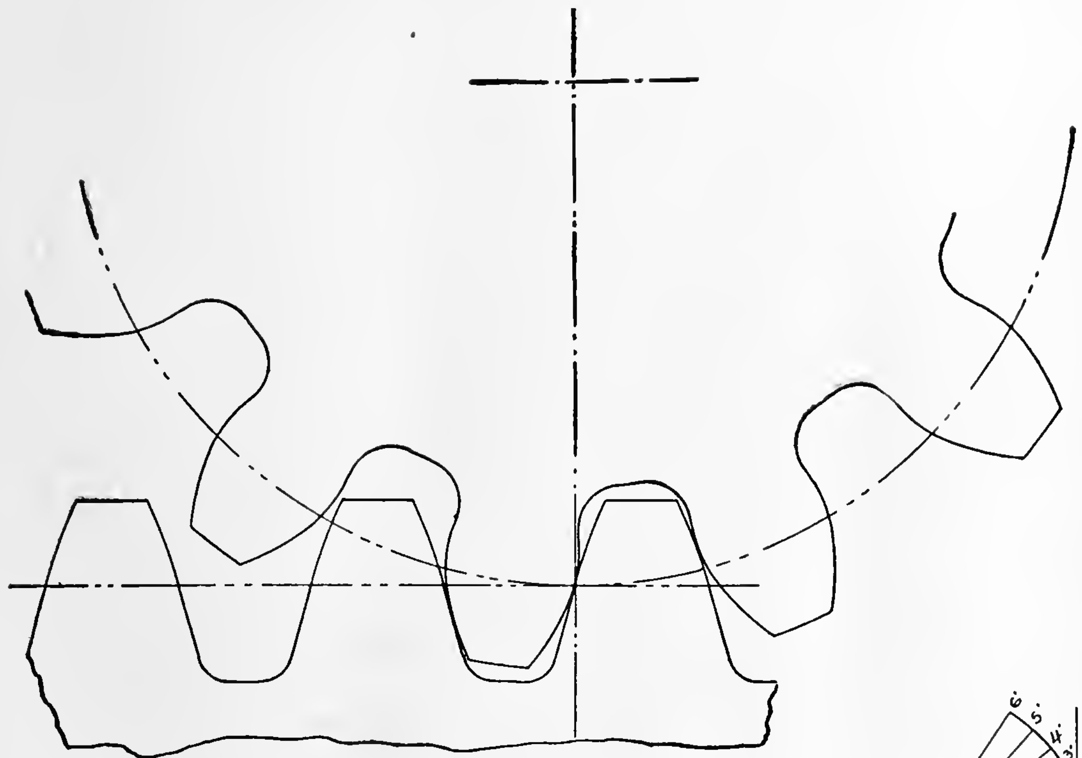
Plate 18. The Spiral Cam.

Fig. 27 represents a cam whose outline is formed of two spirals. It possesses the property of imparting a uniform motion to a reciprocating piece of machinery.

To lay out a spiral cam:

Let A B C represent the hub of the cam and C D its stroke. Divide the circle A C B into a certain number of equal parts, say 12, and draw radial lines through the centre and extend them indefinitely. Next divide the stroke C D into half the number of equal parts, as in this instance 6, Nos. 1, 2, 3, 4, etc. From the centre E with radius E 1 draw an arc cutting the radii 1′ and 11′; from same centre with radius E 2 draw an arc cutting the radial lines 2′ and 10′; from E with radius E 3 draw an arc cutting the radial lines 3′ and 9′. Continue this until all the radial lines have been marked off. Through the points thus measured the right and left curves may be drawn. The curve will begin at 0 and end at 6. Now suppose that the reciprocating part touches at 0 the beginning of the curve, it will have completed its stroke when the cam has made half a revolution, bringing the point 6 opposite the reciprocating part or piece of the machine in which the cam is employed. From this it will be seen that the reciprocating piece will make one-sixth of its stroke while the cam is moving through one-twelfth of its revolution.

PLATE 18



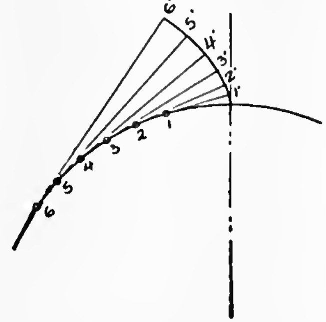


Plate 19. The Cycloid.

The Cycloid is a curve which is described by any point in the circumference of wheel rolling on a straight line.

In Fig. 28 let 0-3′-6′-9′ be a circle or wheel rolling on the straight line 0-12, equal in length to the circumference of the wheel. In rolling from 0 to 12 the point 0 in the circumference of the wheel will describe the curve *o a b c d*, etc. The circle 0, 3′, 6′, 9′ is called the *generating circle,* and the point *o* in the circle which describes the cycloid is the *generator.* The straight line on which the circle rolls is the *director,* and the line *f* 6 is the axis of the cycloid.

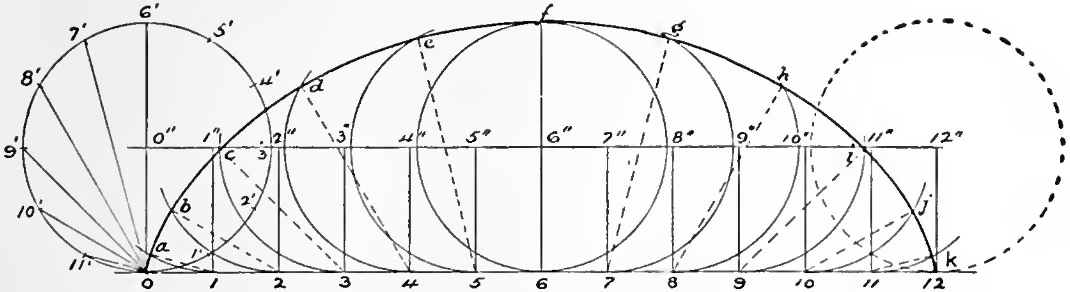
To lay off a cycloid for a wheel of any size:

Draw the generating circle of the required diameter, next tangent to it draw the director 0, 12, making it equal in length to the circumference of the generating circle. Draw 0″, 12″ through the centre of the circle and parallel with 0-12. Divide the generating circle into an even number of equal parts, as 0, 1′, 2′, 3′, etc.; draw the chords 0-11′, 0-10′, 0-9′, 0-8′, 0-7′, 0-6′. Now divide the director into the same number of equal parts as is the generating circle, and draw the perpendiculars, 1-1″, 2-2″, 3-3″, etc. With 1″, 2″, 3″, etc., as centres and radius equal to radius of generating circle sweep arcs 1 *a,* 2 *b,* 3 *c,* etc., then with compasses set to length of chord 0-11′ mark off points *a* and *k* from 1 and 11; likewise mark off *b* and *j* from 2 and 10, and so on until all the arcs have been measured off. These points, *a b c d,* etc., will be points in the cycloid.

The Epicycloid (Fig. 29) is a curve which is described by any point in the circumference of a wheel which is rolling on the *outside* of a curved line. The process for laying out this curve is the same as for the cycloid, except that the lines which intersect the centre line of the generating circle, and giving the centres from which the arcs are drawn, are radial lines drawn from the same centre as the director, the line of centres being a curve concentric with the director.

The arc of the director over which the generating circle rolls must be equal in length to the circumference of the generating circle. As it is somewhat difficult to get this length correctly, an approximate method, as follows, may be employed:

Divide the generating circle in equal parts, just as was done in the case of the cycloid; subdivide one of these parts into a number of small parts and space off on the director the same number of these small subdivisions. If this is carefully done the error is not appreciable.


6'
7'
5'
8'
4'
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10'
11'
a
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5"
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8"
9"
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FIG. 28

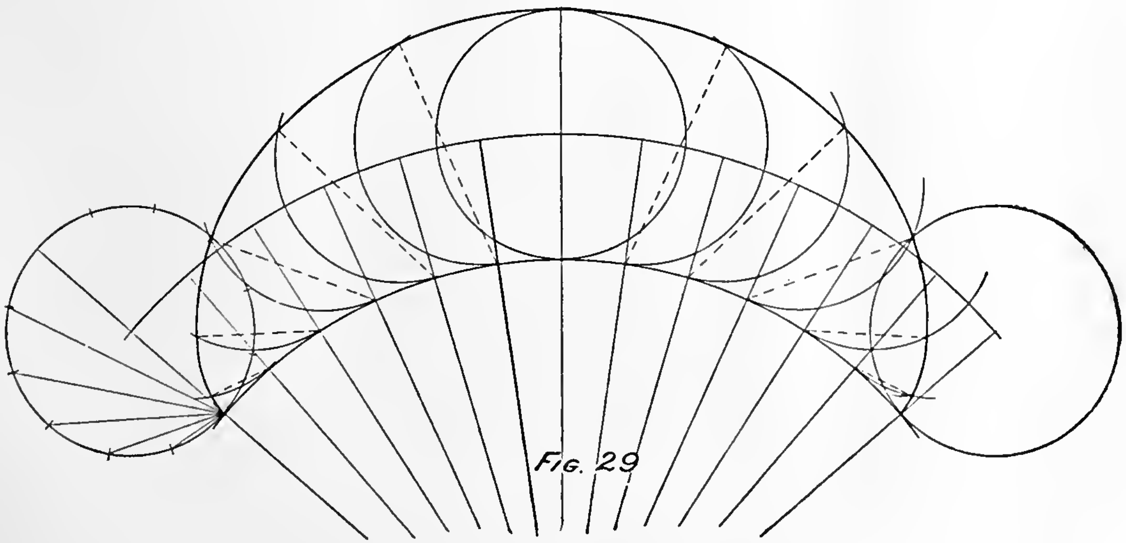


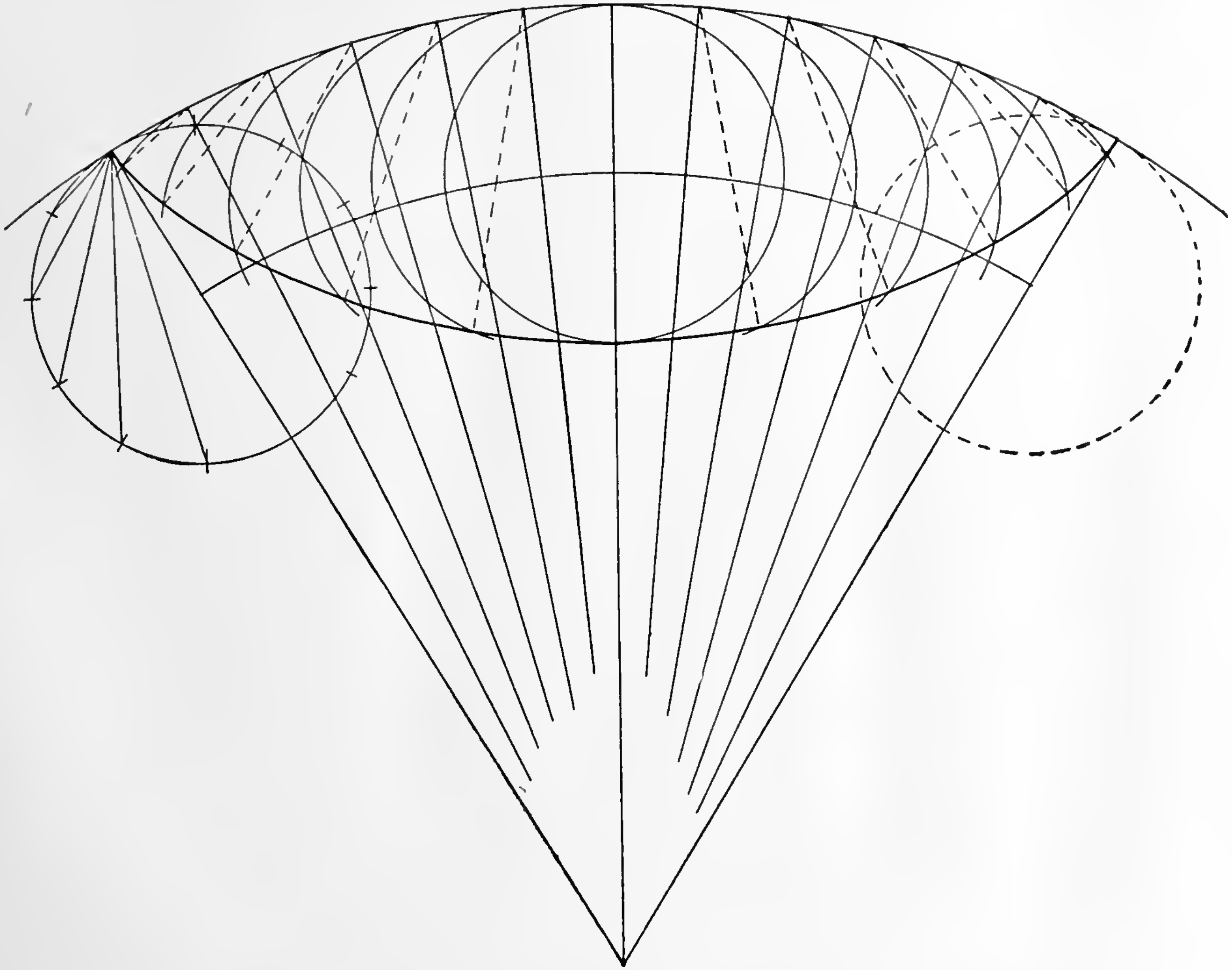
FIG. 29

Plate 20. The Hypocycloid.

This is a curve which is described by any point in the circumference of a wheel which is rolling on the *inside* of a curved line.

The method of drawing this curve is the same as that employed in drawing the epicycloid. A lengthy description would only be a repetition of what has been said in regard to the cycloid and epicycloid.

PLATE 20



In Plate 21 is given an illustration of the application of the epicycloid and the hypocycloid to the drawing of *cyclodial* gear teeth. The generating circle is rolled on the outside and inside of the "director," which in this instance is the imaginary or *pitch* circle of the wheel. Only a small portion at the beginning of each curve is employed, as is clearly shown. In laying out a number of gear wheels which are to run together the same generating circle would be used for all of them, no matter how they may vary in size. Should different generating circles be employed the wheels would not fit each other, because the curve developed varies with the size of the generating circle. This can be proven by using two different generating circles for developing the curves and then fitting the curves together.

In laying out a rack to work with a train of gears, the generating circles would be rolled on both sides of a straight line, thus developing the cycloid for both curves of the tooth—that is, above and below the *pitch* line.

PLATE 21

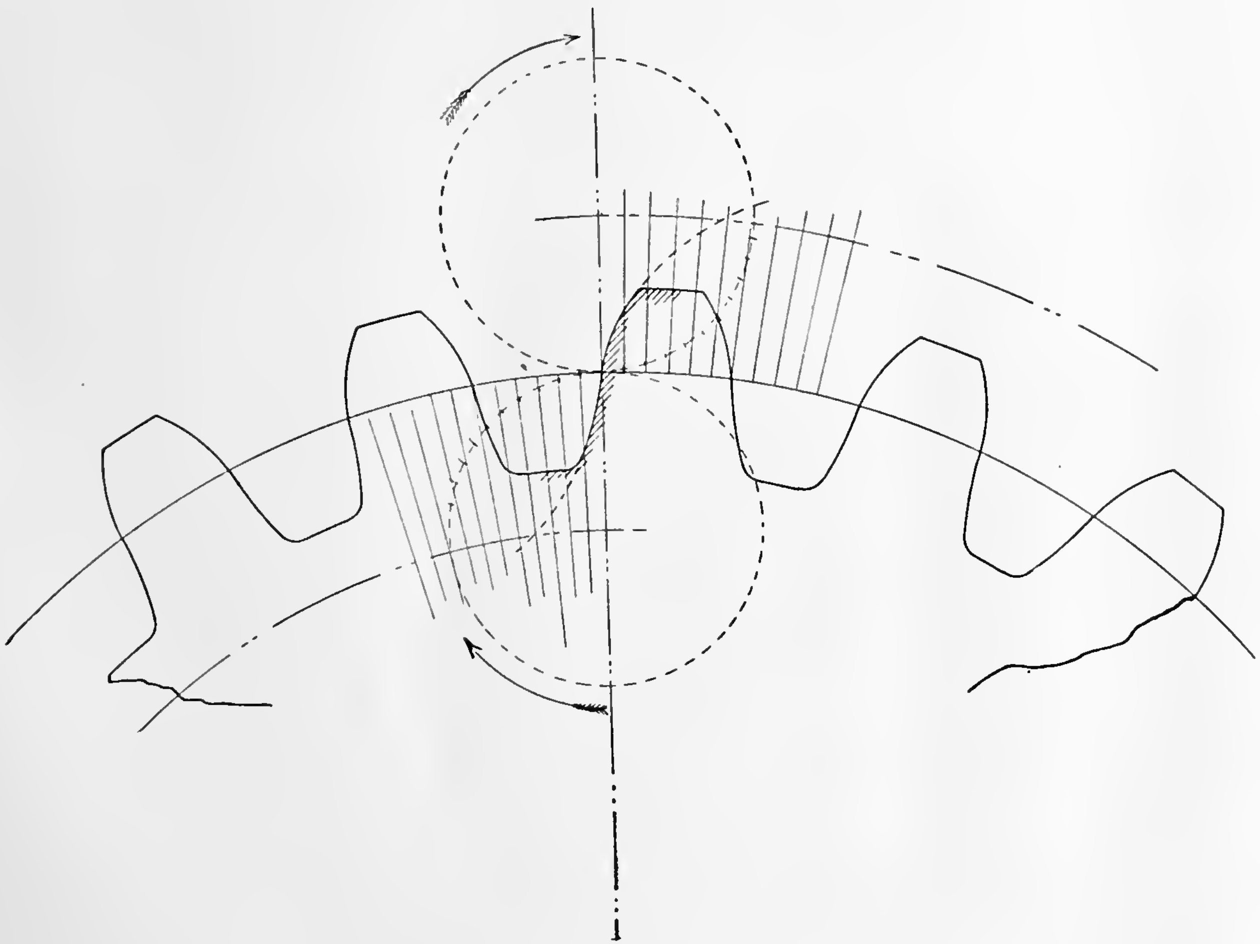


PLATE 22.

The Prolate Cycloid.—If the tracing point be *within* the circumference of the generating circle, the curve described by this point while the generating circle rolls on a straight line is called the *prolate* cycloid. This is the curve which is described by the centre of the crank pin of a locomotive when the driving wheel rolls upon the rails. The director is equal in length to the circumference of the generating circle, and the subdivisions are equal in number and length to those of the generating circle. The path of the *generating point*, if the wheel did not advance during its revolution, would be the small circle (Fig. 30), which is drawn inside the generating circle. It is subdivided to correspond with the subdivisions of the generating circle by radial lines drawn from the centre to the outer circumference. The arcs and chords by which the points in the prolate cycloid are obtained are taken from the smaller circle, and are marked off exactly as for the cycloid, all of which is clearly given in Fig. 30.

The Curtate Cycloid (Fig. 31) is a curve which is described by a tracing point which is *without* the generating circle.

The process of laying out this curve is clearly shown in Fig. 31, and is just the same as for the prolate cycloid (Fig. 30), except that the inner circle is the generating circle, while the outer one is the path of the tracing point if it did not advance during its revolution. In Fig. 30 another method of getting at the points in the curve is given. Instead of transferring the chords of the arcs by means of the compass, lines are drawn through the points in the circumference and parallel with the *director*. Where these lines intersect the vertical lines drawn from the dividing points in the director, points will be found through which to draw the curve. This method may be employed for the cycloid and the prolate cycloid. In the case of the epicycloid and the hypocycloid, these lines would be drawn from the same centre as the director.

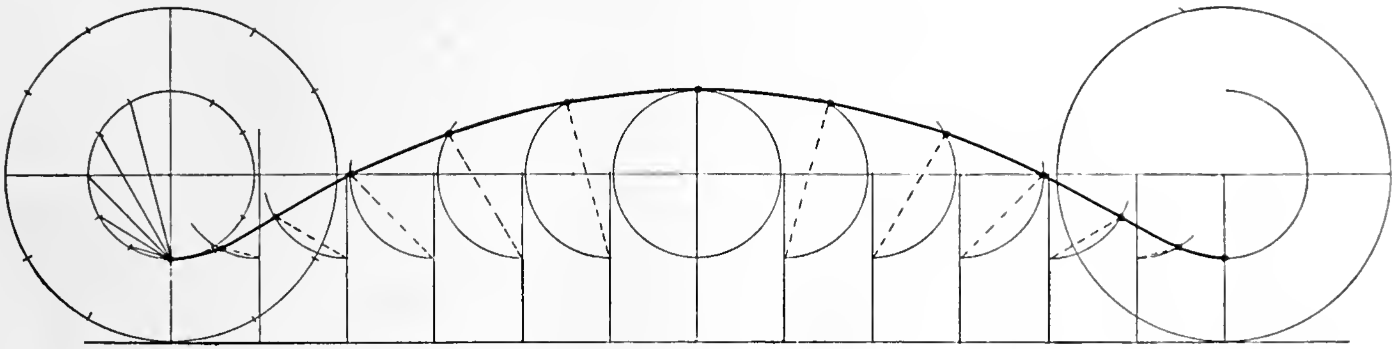


FIG. 30.

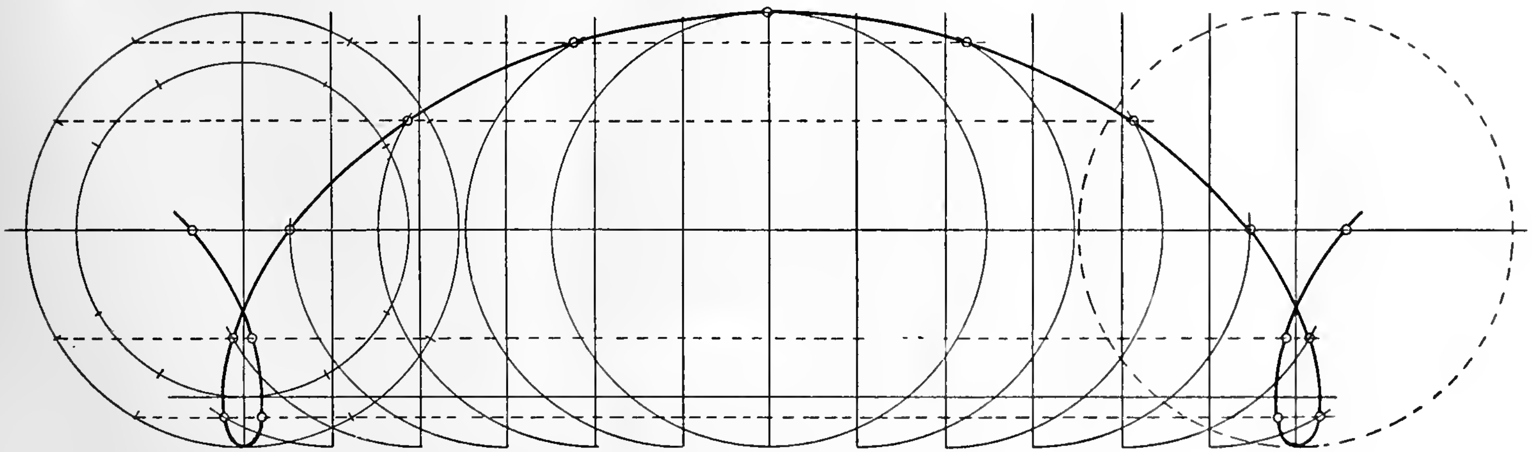


FIG. 31.

PLATE 23. THE HELIX.

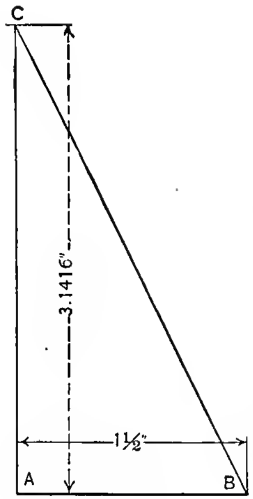


FIG. 32.

Cut from a piece of thin paper, the right-angled triangle, C A B (Fig. 32), having its base or side, A B, $1\frac{1}{2}$ inches long and the side, A C, 3.1416 inches long. If this triangle be wound around a cylinder one inch in diameter, with its side A B parallel with the axis G H of the cylinder (Fig. 33), the angle C will meet the angle A, and the hypothenuse will trace the line C D E F B, which line is called the *helix*. Or if the point C (Fig. 33) be moved at a uniform speed $1\frac{1}{2}$ inches in a straight line, the cylinder at the same time making one revolution at a uniform rate of speed, the result of the two movements would be a line which would correspond exactly with the line traced by the hypothenuse of the triangle. The distance A B which the point C moves during one revolution of the cylinder is called the *pitch*, or *lead*, of the helix, and corresponds with the pitch of the ordinary screw-thread of a bolt.

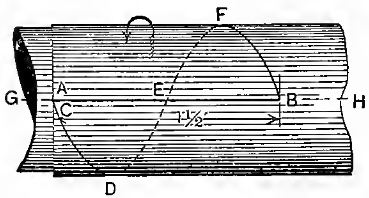


FIG. 33.

To draw a helix, the pitch and diameter being given:

Draw the centre line E F (Fig. 34), draw semi-circle C F D equal in diameter to the required helix, draw C D and project C and D indefinitely parallel with E F. Divide semi-circle into any number of equal points, as 1, 2, 3, 4, and project these points parallel with E F indefinitely. Lay off B D equal to the required lead and divide into twice as many equal parts as used for the semi-circle, as 1′, 2′, 3′, 4′, etc.; project these points upon 1, 2, 3, etc., produced as at *a-b-c*, etc.; these intersections give points through which the helix may be drawn. In Fig. 34 the pitch, or lead, is laid off on a line parallel with B D, but this is not necessary, as the subdivisions can be made upon either A C, B D or the centre line E F.

To draw a helical spring:

FIG. 35.—Draw the helix as in Fig. 34, which would be the centre line of the spring. On this centre line draw small circles equal in diameter to the rod from which the spring is made, and draw lines tangent to these circles, as shown. The helix in Fig. 35 is *finer* than in Fig. 34.

PLATE 23

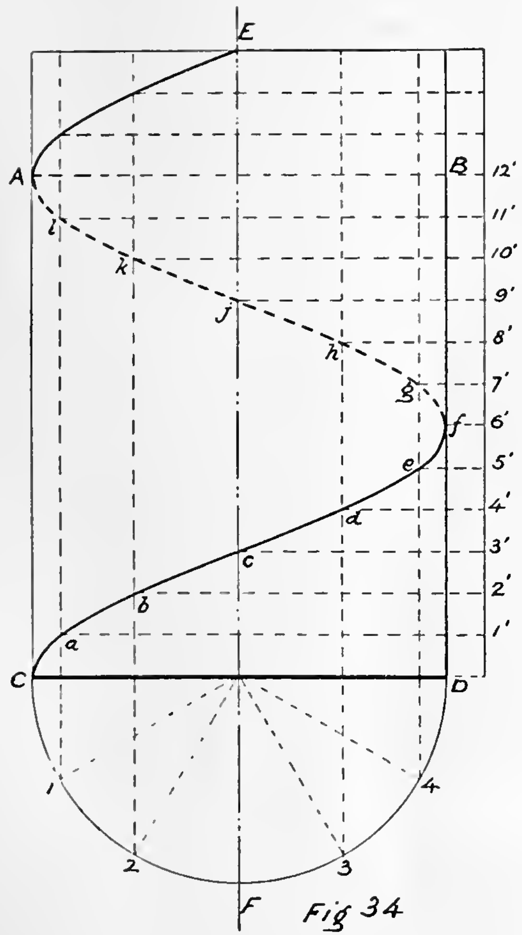


Fig 34

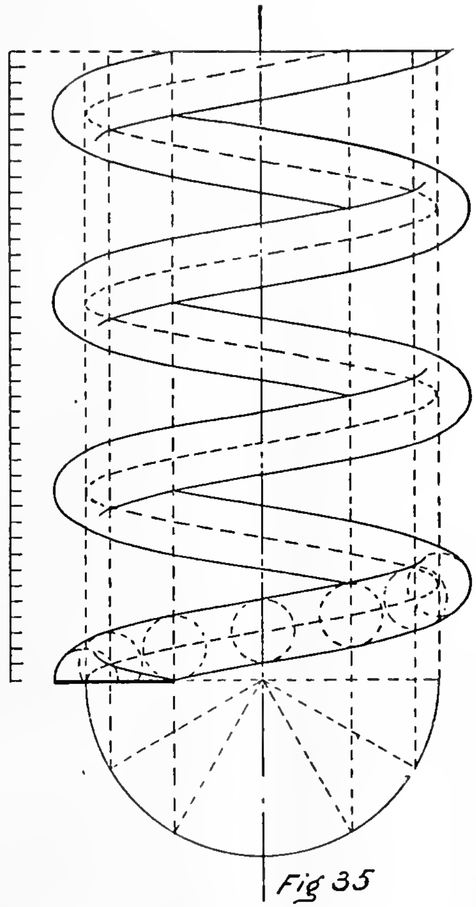


Fig 35

Plate 24. The Helix.

To draw a V-thread screw:

Draw centre line A B (Fig. 36), and on it draw semi-circle equal in diameter to the outside diameter of the screw. Subdivide and project the points, as in Fig. 32, lay off G H equal to pitch of thread, and subdivide as before. With 30° angle draw E K and J K. Take distance K L in compasses, and with this for radius and O for centre draw circle M N P, which will be equal to the diameter at the bottom of the thread. Project the points from G H upon the lines drawn from points in the outer diameter of the screw and complete E Q of the helix. Now take G H in the dividers and point off on the lines from the outside diameter as many threads as are required; having drawn lines of the helix through these points, with the 30° angle draw in the sides of the threads. In the same way project the points from the inner circle and draw in the curves of the helix representing the bottom of the thread.

Fig. 35.—*To draw a square-threaded screw:*

Draw circles representing the outside and inside diameters and draw the helix as A B, and on the lines projected from the circle which represents the diameter point off the thickness of the thread and the spaces between them, and through these points draw the curves of the helix, connecting the alternate curves by straight lines, as shown. Having completed the outer curves and the tops of the threads, draw the curves of lines representing the root of bottom of the thread. The square thread usually is made equal in depth to the face or width, and the space between the threads equal to the width. The thread may be considered as a square bar wound around a cylinder, the bar advancing as it is wound, so that the space between the coils will be equal to the width of the bar. The square thread is not always of this proportion, being sometimes shallower; also, the space may be either greater or less than the width of the thread, depending altogether upon the work to be done by it.

The V or common thread may be considered as a triangular bar wound around a cylinder, but the edges of the bar are in contact.

Both square and V threads are made either double or treble, etc., depending upon the speed of advance or lead required for each revolution.

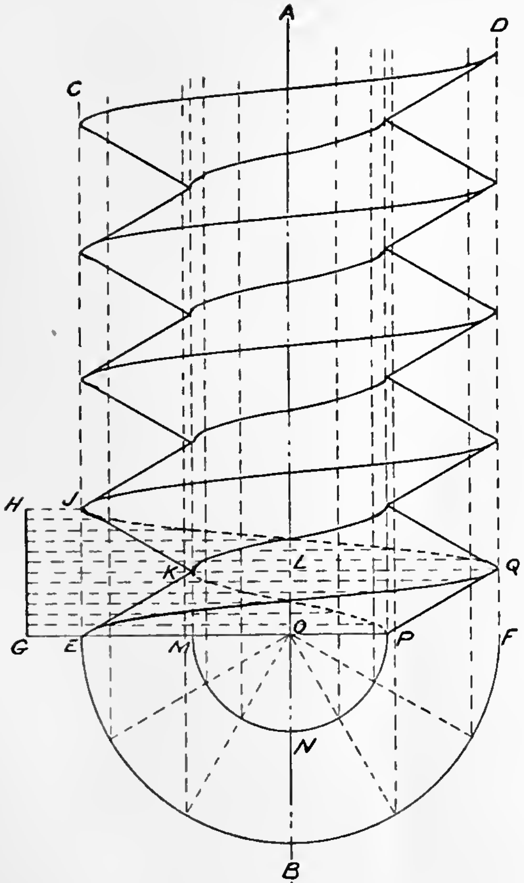


FIG 36.

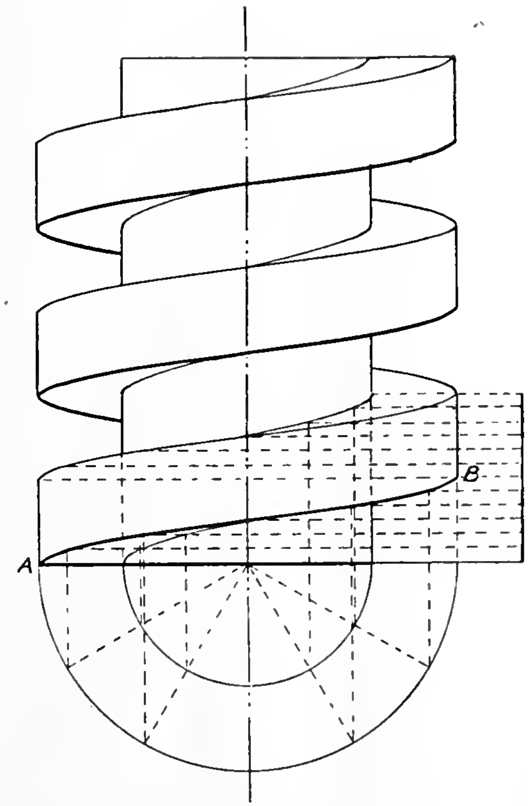


FIG 37.

CHAPTER VIII.

Intersections and Envelopes.

Plate 25. *Intersection of Cylinder with Annulus.*

Draw centre lines A B, C D, and E F. With O as centre draw outside of annulus H E B F and inside I J K L, also circle shown in dash and two dots representing centre of mass of annulus. Draw O G, and with Q its intersection with centre line of annulus as centre and Q G as radius draw circle equal in diam. to the cylinder. The centre of this circle may be placed at any point, depending upon the desired view.

Project Q indefinitely beyond C D and complete the outline of the cylinder M N P R; also complete the outline on side elevation of the annulus or centre line C D, as shown in the plate No. 19.

Now take points 1, 2, 3, 4, 5, 6, spaced at random, and with compasses from centre O transfer them to centre line E F, as 1′, 2′, 3′, etc. Project points 1′, 2′, 3′, etc., vertically across the side elevation of annulus, as 1‴, 2‴, 3‴, etc., and project these points of intersection across to 1″, 2″, 3″, etc. Now project points 1, 2, 3, etc., vertically upwards to intersect with 1″, 2″, 3″, etc. These intersections will be points in the curved line which defines the intersection of the annulus and cylinder.

PLATE 25

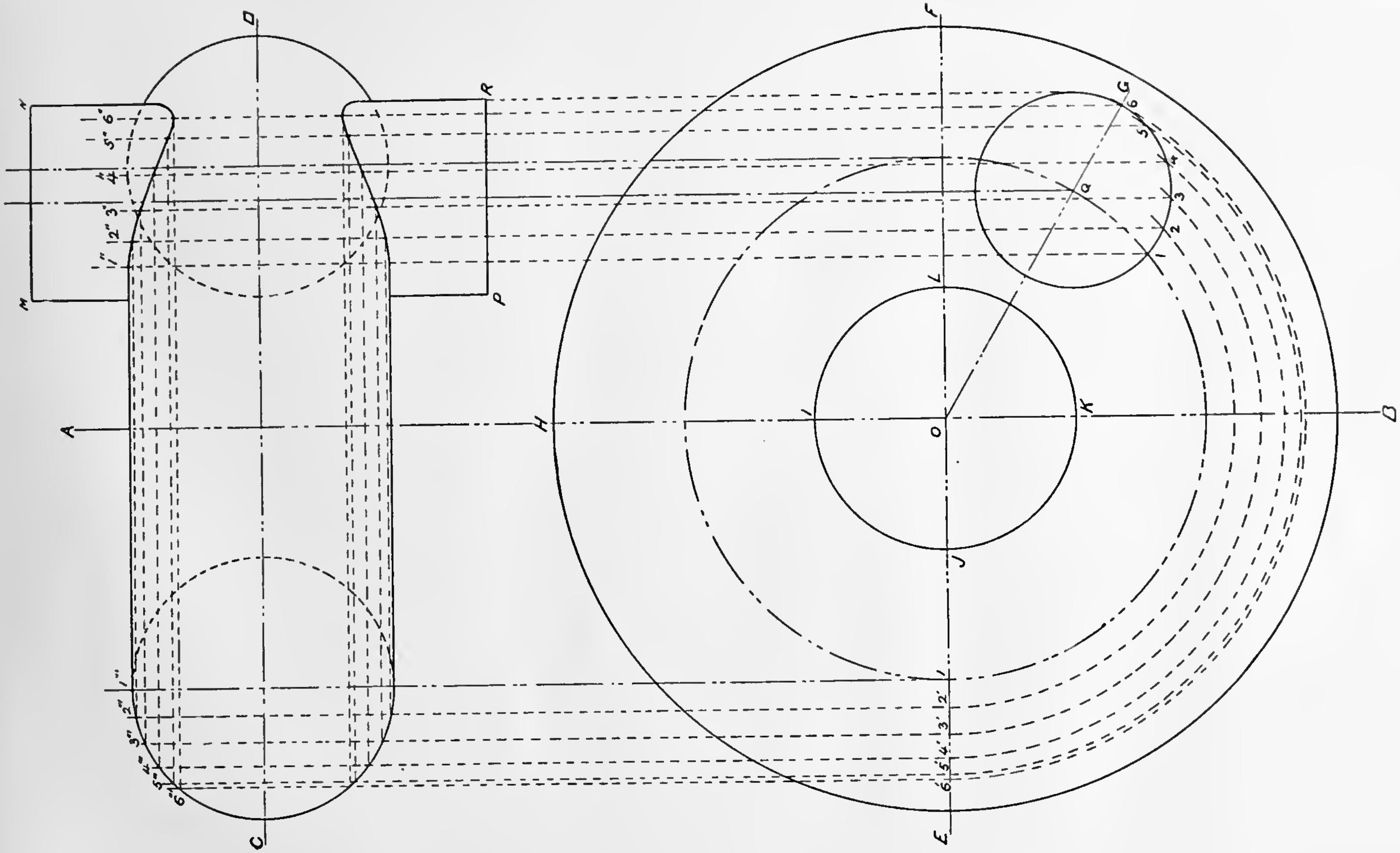


PLATE 26. *Intersection of Annulus and Hexagonal Prism.*

The method for ascertaining the line of intersection in this case is exactly the same as for the previous lesson (Plate 19), and having followed the several steps in that lesson, the student should have no difficulty whatever in doing Lesson 20.

It is advisable that the student do both 24 and 25 several times, varying the position of the centre Q.

PLATE 26

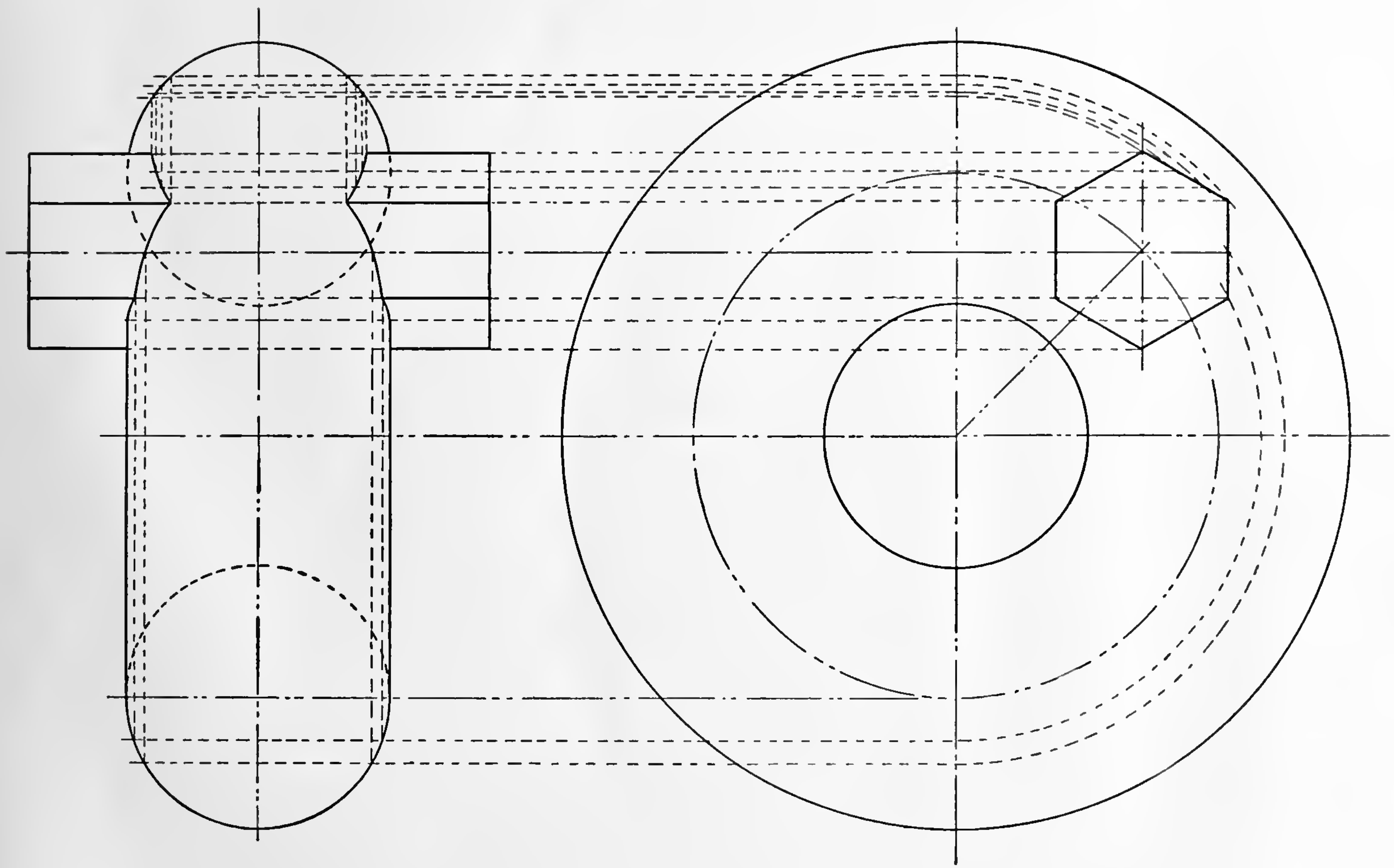


PLATE 27. *Intersection of Cone and Cylinder.*

Draw centre lines E F and G H. Complete outline of cylinder A B C D and draw semi-circle A E B.

Draw outline of cone G J K, being sure that the cone is so located with reference to the cylinder that its diameter at the height E F is less than that of the cylinder. Produce A B to N and M. Produce J K to L. On the base of cone draw semi-circle J H K. Project G to H and make O L equal to half the diameter of base of cone. Draw N L and take points *b* and *c* at random, and through them draw N *e b* 2‴ and N *f c* 1‴, project points *d, e, f* to *d′ e′ f′*, and *a, b, c* to *a′ b′ c′*. With O for centre and 1‴ and 2‴ and L for radii draw arcs 1‴, 1″ and 2‴, 2″ and L M, project 1″ across circle J H K to 1, 4, and 2″ to 2, 3 and M to H; project these points upon base of cone, as 1′, 2′, 3′, 4′, and from these points draw lines to vertex of cone. Where these lines intersect the lines drawn from *a, b, c* and *d, e, f* will be points in the curve defining the intersection. The plan of the intersection is found as follows: Draw a circle representing the cone in plan, on the centre line G H produce and draw upon it the plan of cylinder. Upon this circle project the points 1, 2, 3, 4, and from them draw diameters. Upon these diameters project the points of intersection *a′, b′, c′* and *d′, e′, f′*, and through these intersections draw the curves which complete the plan. These curves will form ellipses.

PLATE 27

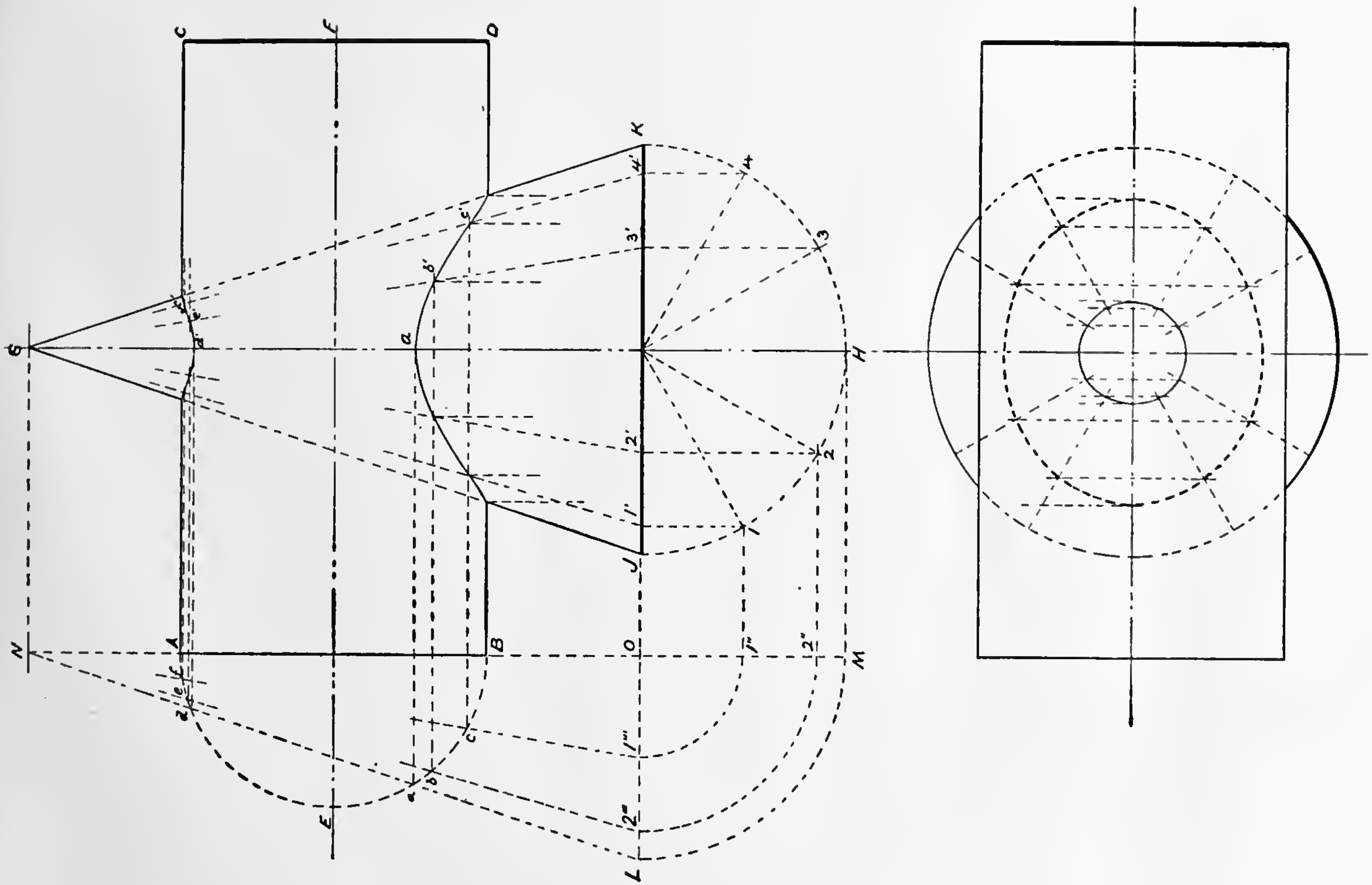


PLATE 28. *Intersection of Two Cones.*

Draw in side elevation the two cones, being sure that the piercing cone shall be less in diameter than the one pierced at the point where their centre lines or axes cross.

Produce the base C D indefinitely to N and M; also produce base F G indefinitely to L and K. Draw K M, touching the vertices A and E of the cones A C D and E F G. Draw semi-circles on the bases of the cones, as F H G and C J D. Draw K N tangent to F H G, and from point of tangency 4 draw a line to the base F G and parallel with axis; from point of intersection with base, draw a line to vertex E. Now take points 1, 2, 3 at random, and through them from vertex K draw lines to N C, cutting circle in 1′, 2′, 3′. With O for centre transfer these lines to O L and on to the vertex M. Cutting the semi-circle C J D in points 1″, 2″, 3″, 4″ and 1‴, 2‴, 3‴, 4‴, project these points upon the base C D, and from them draw lines to vertex A. Now project points 1, 2, 3 and 1′, 2′, 3′ upon base F G, and carry them on to vertex E. These lines will intersect those drawn from base C D in points which will be points in the curve of intersection. The plan of the intersections is drawn the same as that in Lesson 21.

PLATE 28

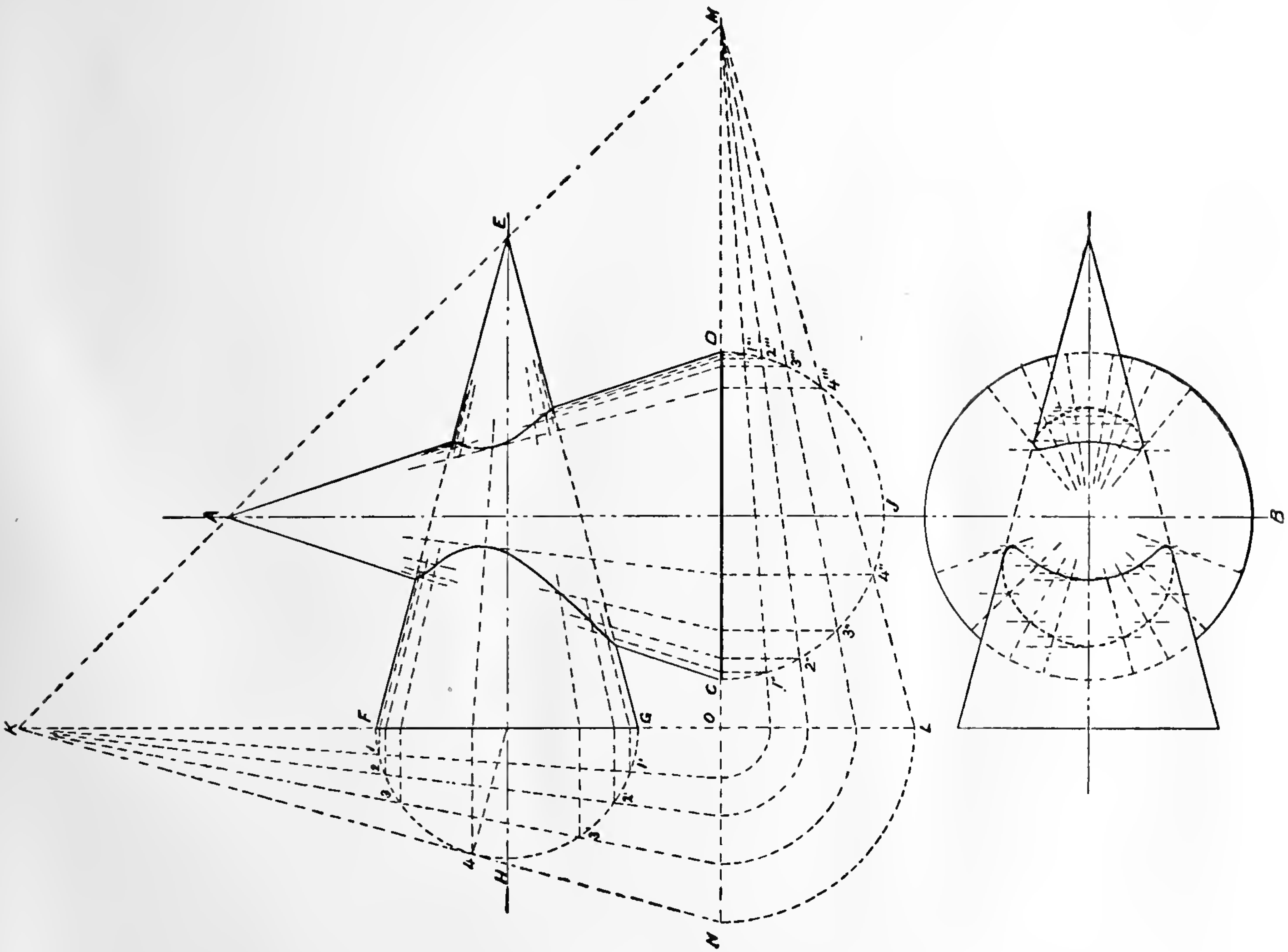


PLATE 29. *Intersection of Cone and Sphere.*

With O at intersection of the centre lines, draw plan of the sphere. Draw O F at any required angle with centre line, and at some point as centre draw circle representing plan of cone.

Project O and F indefinitely to A and C and parallel with each other. On centre line O A draw side elevation of sphere, and on F C complete side elevation of cone C D E. Produce the base D E of the cone indefinitely to some point E′. Make D′ E′ equal to radius of cone base, and draw D′ C′; project C to C′, and draw C′ E′. This will represent half of the cone in elevation. Through the centre *d* of the sphere draw 4′ *d* 4 and produce indefinitely to the left. Make J K equal to O F, and with K for centre and radius equal to radius of sphere, sweep arcs cutting C′ E′ at G″ H″. Project G″ H″ to G and H. Take any number of points on the sphere, as 1, 2, 3, etc., and through them draw parallel with diameter 4, 4′ the lines 1-1′, 2-2′, 3-3′, etc.

With *a* 1 as radius sweep arcs in the plan with O for centre, as 1-1; then with *a*′ 1′ as radius and F for centre sweep arcs cutting arcs 1-1, project these points of intersection upon line *a a*′ 1′ in the elevation. Proceed in the same way with *b* 2 and *b*′ 2′ and each of the others in succession, marking the points of intersection both in the plan and elevation until all the points in the curves are found. Now with F for centre and F′ G″ sweep arc intersecting O F at G′, project G′ to G. In the same way make F H′ equal to F″ H″, and project H′ to H. Through these points draw the curves which define the intersection both in elevation and plan.

PLATE 29

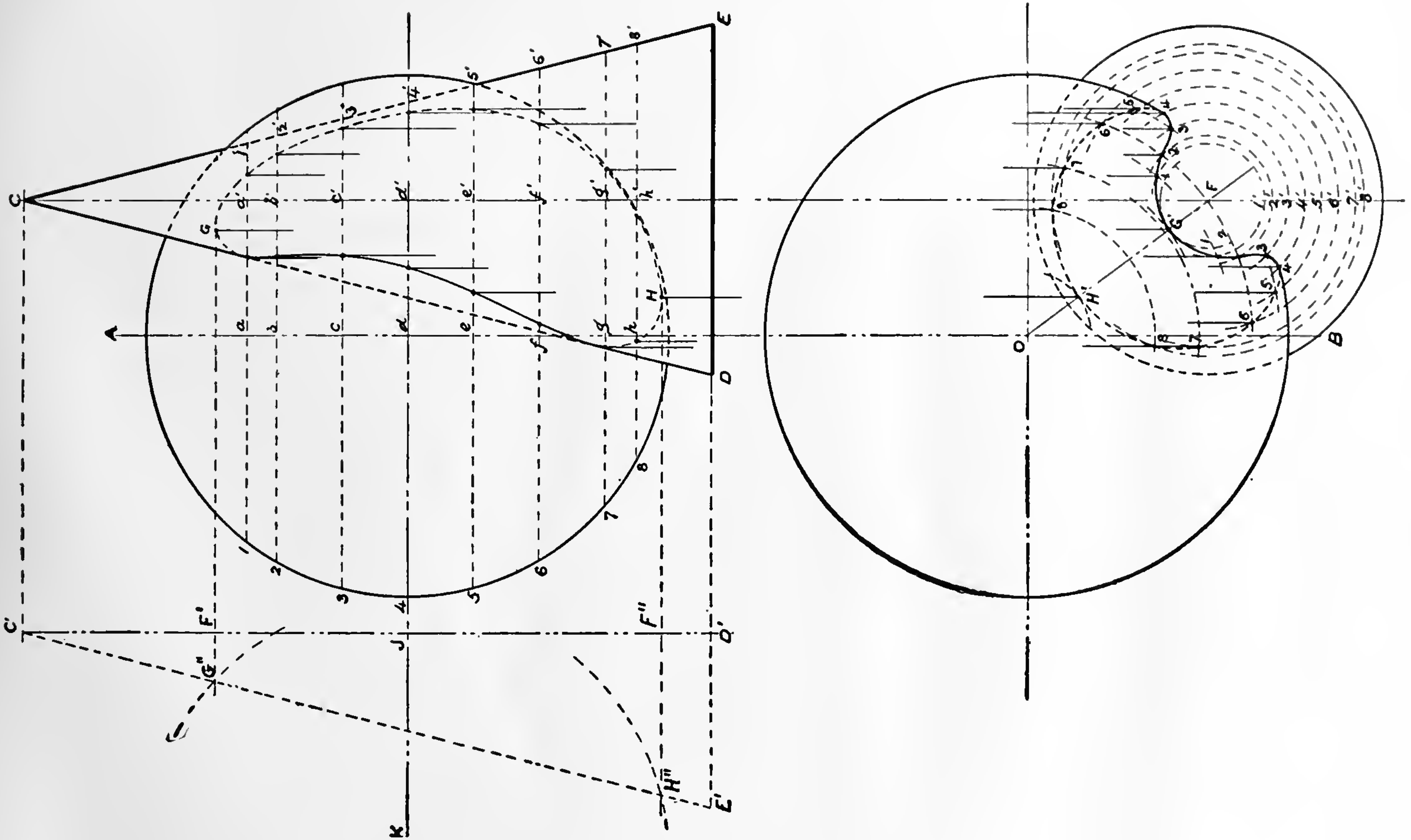


PLATE 30. *Intersection of Two Cylinders of Equal Diameter at Angle of 90°, and Development of Envelope.*

Draw centre lines A B and C D at right angles, and with their intersection as centre draw circle A C E equal in diameter to the required cylinders. Project points A, C, O and P, as indicated in Plate 24, and G H and J K, completing side elevation of cylinders, with the exception of the line of intersection. The two cylinders being of equal diameter, and placed at the angle of 90°, the line of intersection will be a straight line drawn from F to L. To demonstrate the correctness of this statement, divide the circle into any number of equal parts (twelve in this instance), and through these points draw lines parallel with the centre lines. These lines will intersect in points which will be points in the line of intersection of the two cylinders.

To lay out the flat sheets or envelopes which when rolled up into tubes would, when joined, form the right-angled elbow. Draw line M N and make it equal in length to the circumference of one of the cylinders. Divide into as many equal parts as was the circle A C E, and through these points, at 1, 2, 3, etc., draw lines perpendicular to M N. Take distance 1′, 2′, in compasses and step or mark it off on each side of point 6, as 6, 2″, 6-2‴. Next take 1′-3′ and step it off each side of point 6, as 6-3″, 6-3‴, and so on until all the points have been transferred to each side of point 6. Now transfer point 4‴ to M and N, 3‴ to 1 and 11, 2‴ to 2 and 10, 6 to 3 and 9, 2″ to 4 and 8, 3″ to 5 and 7. A curve drawn through these points will be the developed intersection of the cylinders.

NOTE.—When the cylinders are of equal diameter the line of intersection will be a straight line, no matter what may be the angle at which the cylinders meet.

PLATE 30

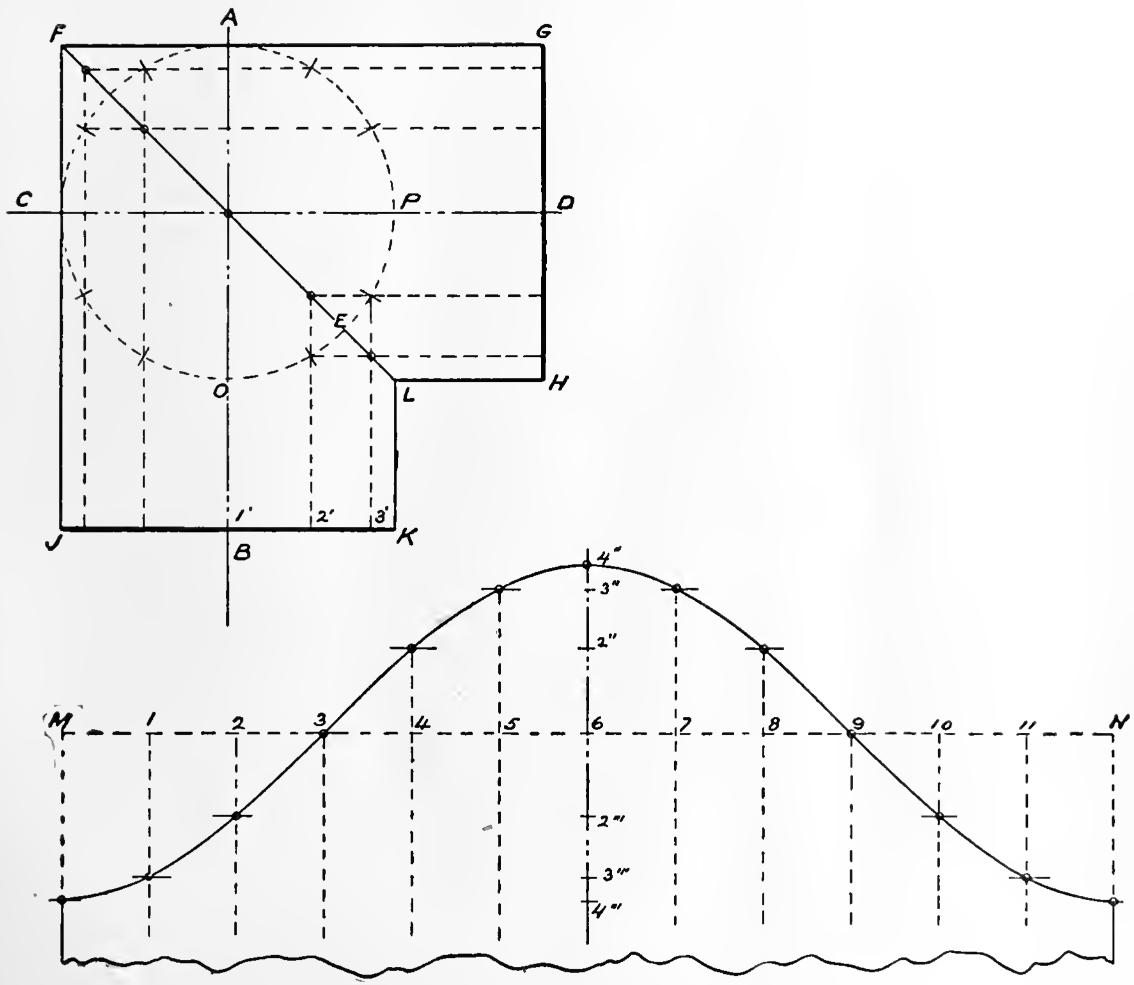


PLATE 31. *To Lay Out an Elbow of Several Sections and to Develop a Section.*

Draw the right angle A O, O E. With O for centre and O A equal to the outer radius of elbow draw arc A B C D E, and from same centre and radius O F, equal to inner radius of elbow, draw arc F G H J K.

Divide outer arc into as many equal parts as elbow is to have sections, and from centre O draw radial lines to the points of division, as B C D. Complete the straight sections A F N Q and E K L M if they are required. This will complete the side elevation.

To lay out one of the sections:

On L M with centre O′ draw semi-circle L R M and divide into equal parts, as 1, 2, 3, 4. Parallel with E L draw 1′-1, 2′-2, etc. With D and E for centres and radius greater than half of D E sweep intersecting arcs S, draw S O, parallel with D E draw link 1′-1″, 2′-2″, etc.

Draw *a b* and make it equal to circumference of pipe or elbow, or twice L R M, and divide it into twice as many equal parts as L R M, and draw lines at the points of division perpendicular to *a b*.

Make lines at *a* and *b* each equal to J K, at 1 and 11 each equal to 4′-4″, and so on, finally making 6 equal to D E. These should be taken from S O and laid off on each side of *a b*. Through the extremities of these lines curves are to be drawn, which will be the developed lines of intersection of the sections. If the several sections are cut out of the sheet and rolled up and joined together they will form the elbow. In these exercises no allowance is made for laps for joining. The additional material for this purpose is added to one side and one end of the developed section, according to requirements of construction.

PLATE 31

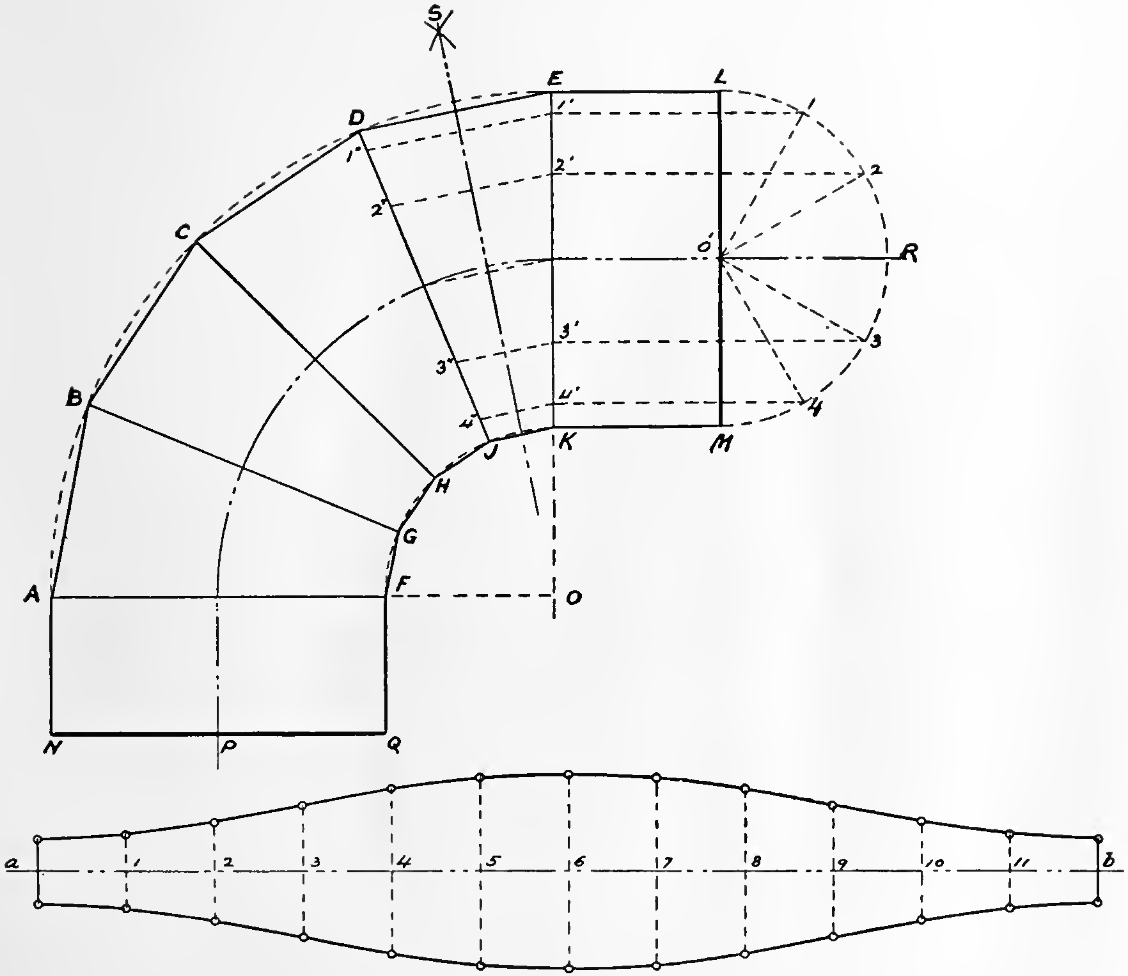


PLATE 32. *Intersection of a Small Cylinder with a Large Cylinder at Angle of 30°.*

Draw elevation and plan, as shown in Plate 26.

The drawing of the line of intersection is done exactly as in preceding lessons, and is clearly indicated in the plate. To develop the envelope of the small cylinder, draw *g h* and make it equal to the circumference of small cylinder and subdivide, as in previous lessons. Draw P R (see elevation) at right angles to axis of small cylinder. Transfer P 5′ to *g* and *h*, *e′* 4′ to J J′ and *t t′*, *d′* 3′ to *k k′* and *s s′*, and so on until all the points have been measured off. Through these points, *g j′ k′ l′ m′*, etc., draw the curve, which will be the developed line of intersection.

PLATE 32

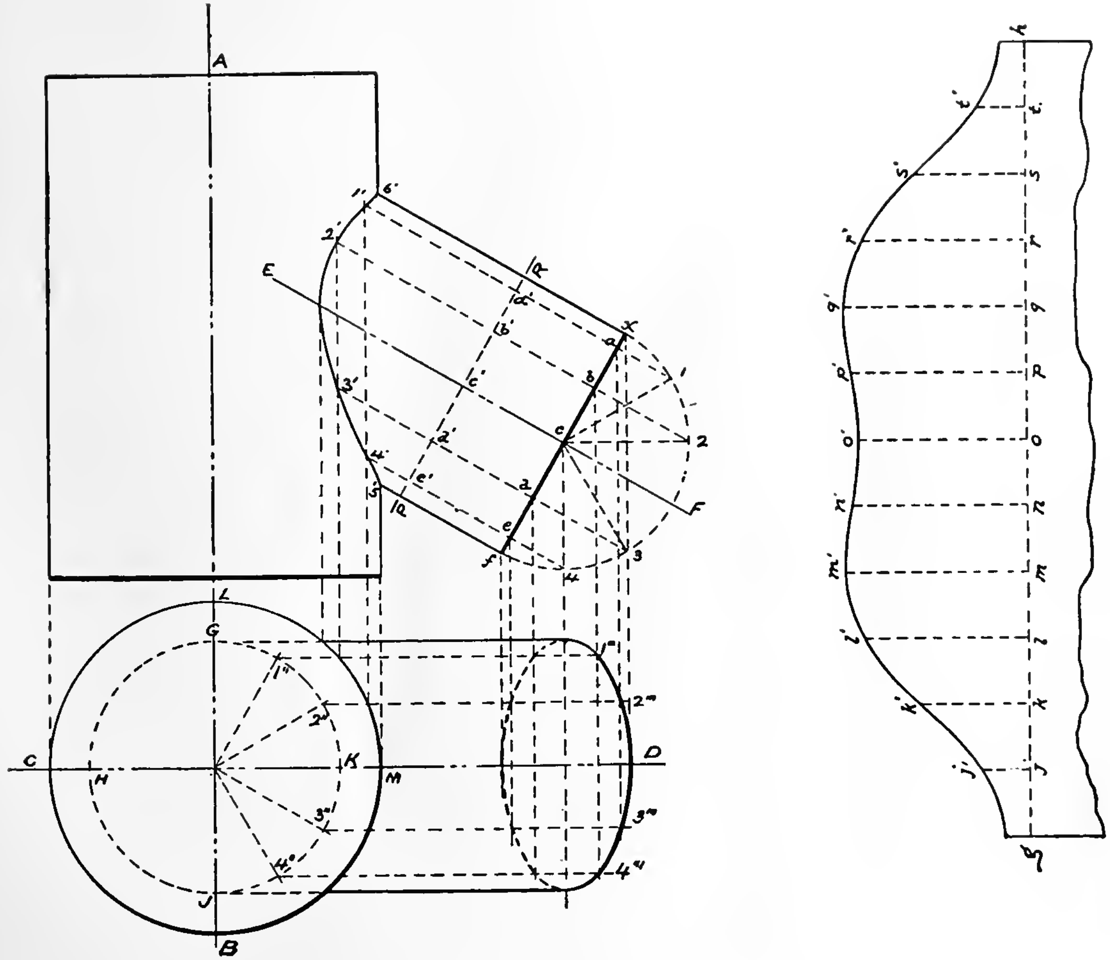


PLATE 33. *To Lay Out the Envelope of a Cone.*

FIG. 38. Draw cone A B C. With vertex A as centre and A C as radius draw arc A C. Make A C equal to circumference of base B C, and draw A D.

To lay out the envelope of a hexagonal pyramid:

FIG. 39. Draw semi-circle on base B C and divide into three equal parts, B 1, 1-2, 2 C. Draw 1-1′, 2-2′, and make A 3′ equal to height of pyramid. Draw A B, A 1′, A 2′, A C, completing side elevation of pyramid. With A for centre and radius A C draw indefinite arc, and on it step off C D, D E, E F, etc., each equal to 1-2. Draw A D, A E, A F, etc., to complete the envelope.

PLATE 33

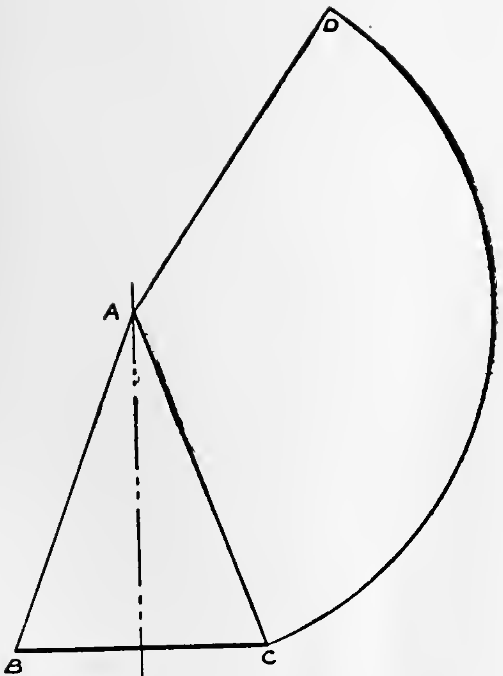


FIG 38

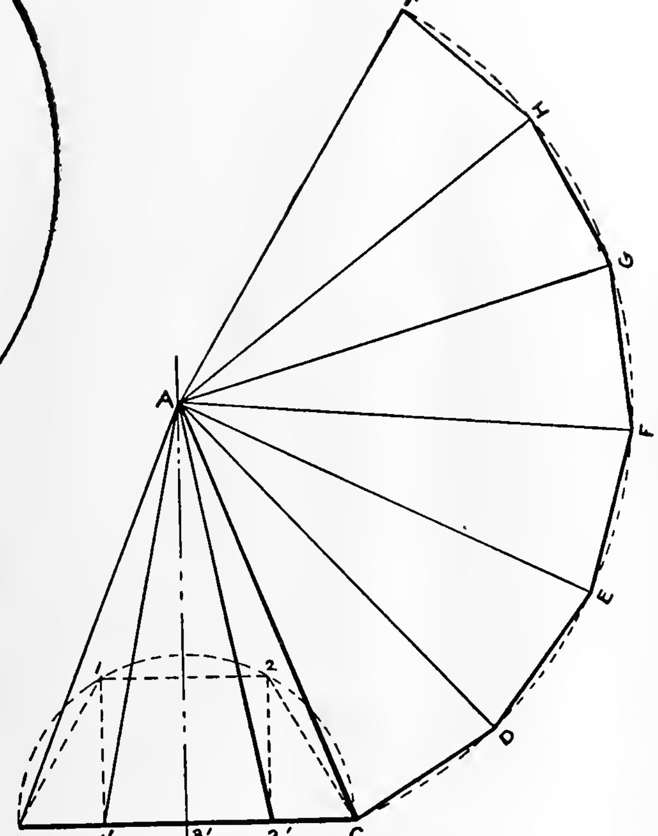


FIG 39

PLATE 34. *To Draw a Hemispherical Dome and to Develop in the Flat Sheet the Sections.*

Let C A D be the side elevation of the dome and E B F the plan.

Divide the arc A C into any number of equal parts and draw lines through the points of division and parallel with the base C D, as 5′-14′, 6′-15′, etc.

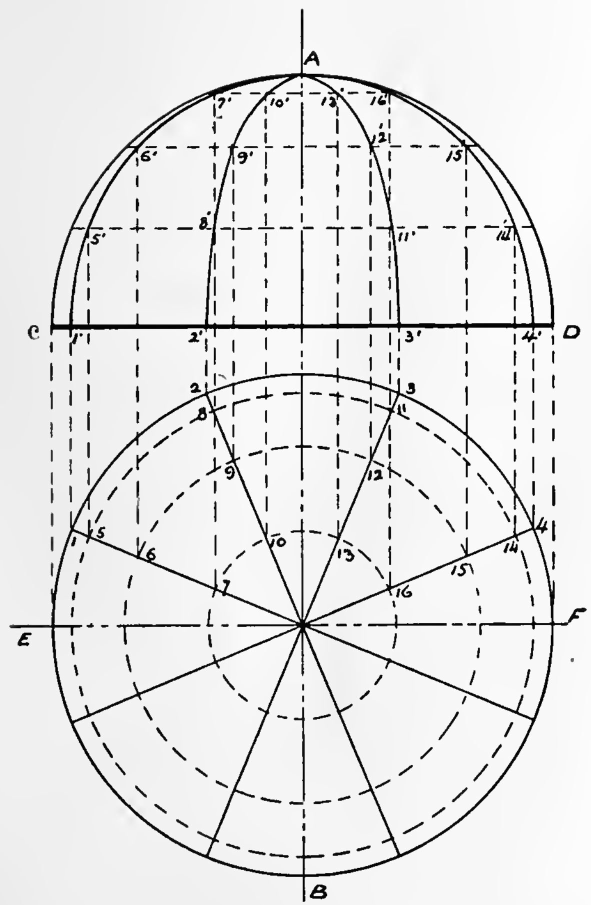
Divide the circumference in the plan into as many equal parts as there are to be sections in the dome, and draw diameters as at 1, 2, 3, etc., and draw also in the plans circles equal in diameter to the sphere at 5′-14′, 6′-15′, etc. Where these circles intersect the diameters are points, as 1, 5, 6, etc., which are to be projected upon the lines in the elevation, as 1′, 5′, 6′, etc. These points, 1′, 2′, 3′, 4′ and 5′, 8′, 11′, 14′, etc., are points through which curves are to be drawn representing the sections of the dome in elevation.

To lay out one of the sections:

Draw J K, making it equal to the arc A C, and divide it into the same number of equal parts as was the arc A C, and through the points of division draw *a b, c d, e f,* etc. Make *a b* equal to the arc 2, 3, *c d* equal to the arc 8, 11, and so on until all the lines are measured off, and through the extremities *a, c, e,* etc., draw curves to complete the figure, which will be the desired section of the dome.

Another method: Make J K equal to the arc A C, and through K draw *a b* at right angles to J K, making *a b* equal to the arc 2, 3, and on it with K for centre draw semi-circle *a j b,* whose diameter is equal to the length of arc 2, 3. Divide this semi-circle into as many equal parts as was the arc A C, and through the points of division draw lines parallel with *a b,* cutting the semi-circle in points *a, c′, e′,* etc., and project these points upon the lines *c d, e f, g h.* Through the points *c e g* J and *d f h* J draw curves.

PLATE 34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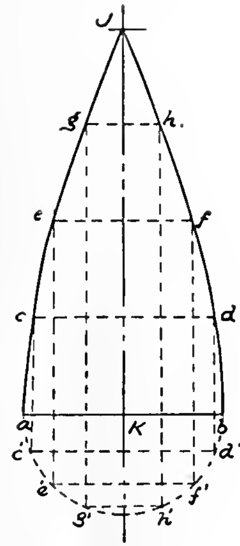
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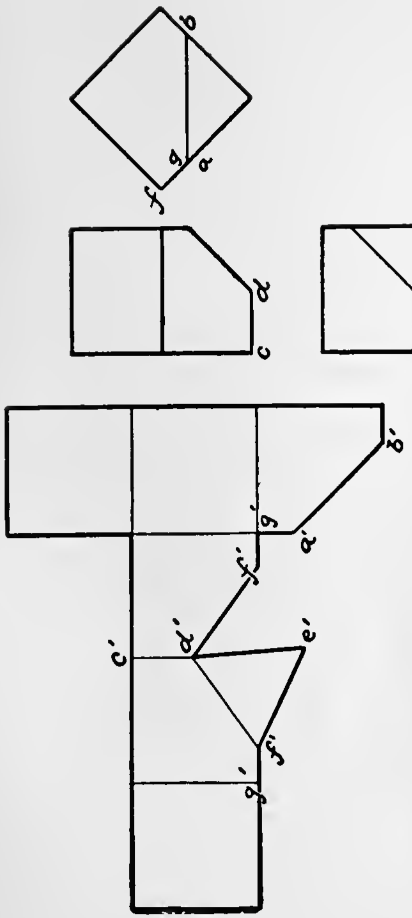
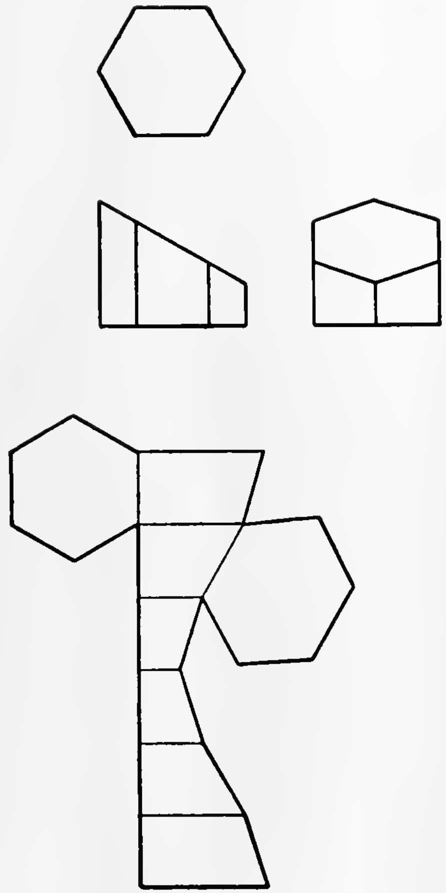
PLATE 35. *To Develop the Surface of a Square Prism with One of Its Corners Cut by a Plane at* 45°.

Begin by laying out adjacent rectangles to represent the sides 1-2-3-4, adjoining a square representing the bottom and another the top. In the plan is shown the cutting plane *a b* in the envelope. Make *a'-b'* equal to *a b*. Make *c'-d'* equal to *c d*, and *f'-g'* equal to *f g*. Connect *a'-b'*, *c'-d'* and *f'-g'*. Make *d'-e'* equal to *d'-f'*, and *f'-e'* equal to *a'-b'*.

To develop a hexagonal prism which is cut by a plane at an angle with its axis, follow the same method as given for the square prism, taking note that the hexagon to make the oblique face is elongated more or less, depending upon the angle of the face.

PLATE 35





CHAPTER IX.

SECTIONS, ISOMETRICAL PROJECTION AND SHOP DRAWINGS.

PLATE 36.—A cube standing upon a corner, its bottom face at an angle of 45° with the horizontal, and cut by a vertical plane. To lay out the cube and develop the section:

FIG. 40.—Draw A B with 45° angle, and at right angles to it draw B D and A F, making A B equal to the diagonal of the square side of the cube, and from its middle point E draw E F perpendicular to A B. Draw B D and A C parallel with E F. With E for centre and radius E B draw arc B G. As the figure is a cube, E B would be the radius of the circumscribing circle, and the diagonal B G would equal the length of a side of the cube. Therefore with B as centre and B G as radius draw the arc G D, then B D will equal the length of a side of the cube. Draw D F C parallel with A B to complete the side elevation, and draw the perpendicular O P for the cutting plane. Draw M N perpendicular, and upon it project the corners of points in the side elevation, and make K L and H J equal to A B, and complete the front elevation of the cube. Project the points in which O P cuts the side elevation upon the front elevation, and connect these points to complete the section, as shown by the shaded portion of the figure.

FIG. 41.—Sections of an annulus.

The side elevation shows half of the annulus, and the lines A B and C D are the cutting planes. The section at A B is clearly shown, and the student should be able to draw this section without any explanation. The same is to be said with reference to the section C D. Therefore the only particular explanation will be as to the method of determining the width of the section at E F.

From centre O draw O L perpendicular to C D, and with L its intersection with the centre line of the annulus for centre and L 2 for radius draw the arc 1, 2, 3. E F is the point 4 projected, and 1, 4, 3 would be the width of the section at E F.

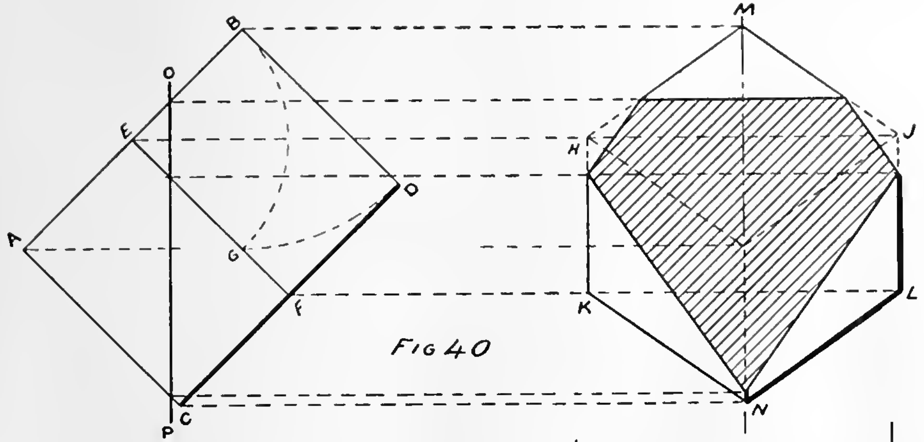


Fig 40

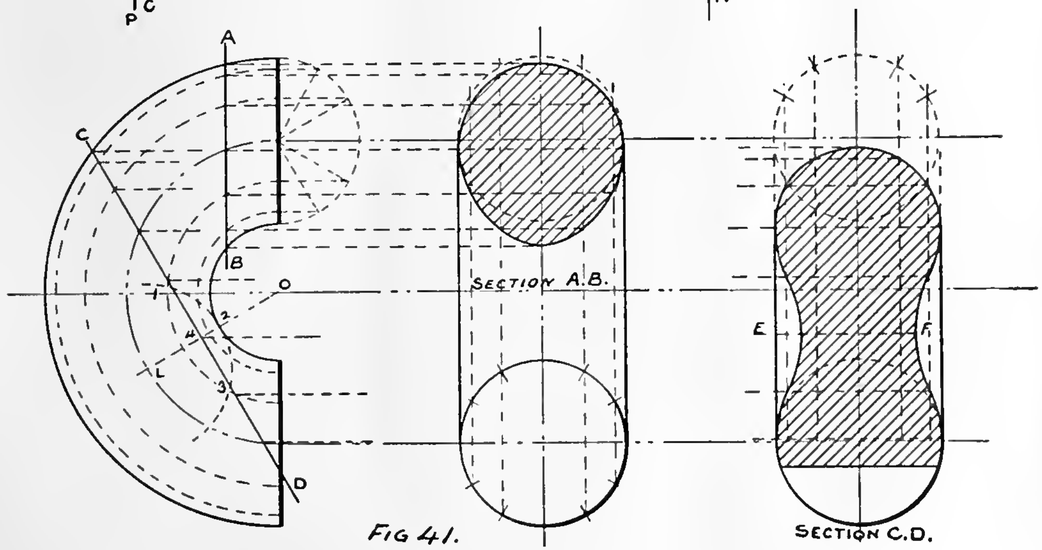


Fig 41.

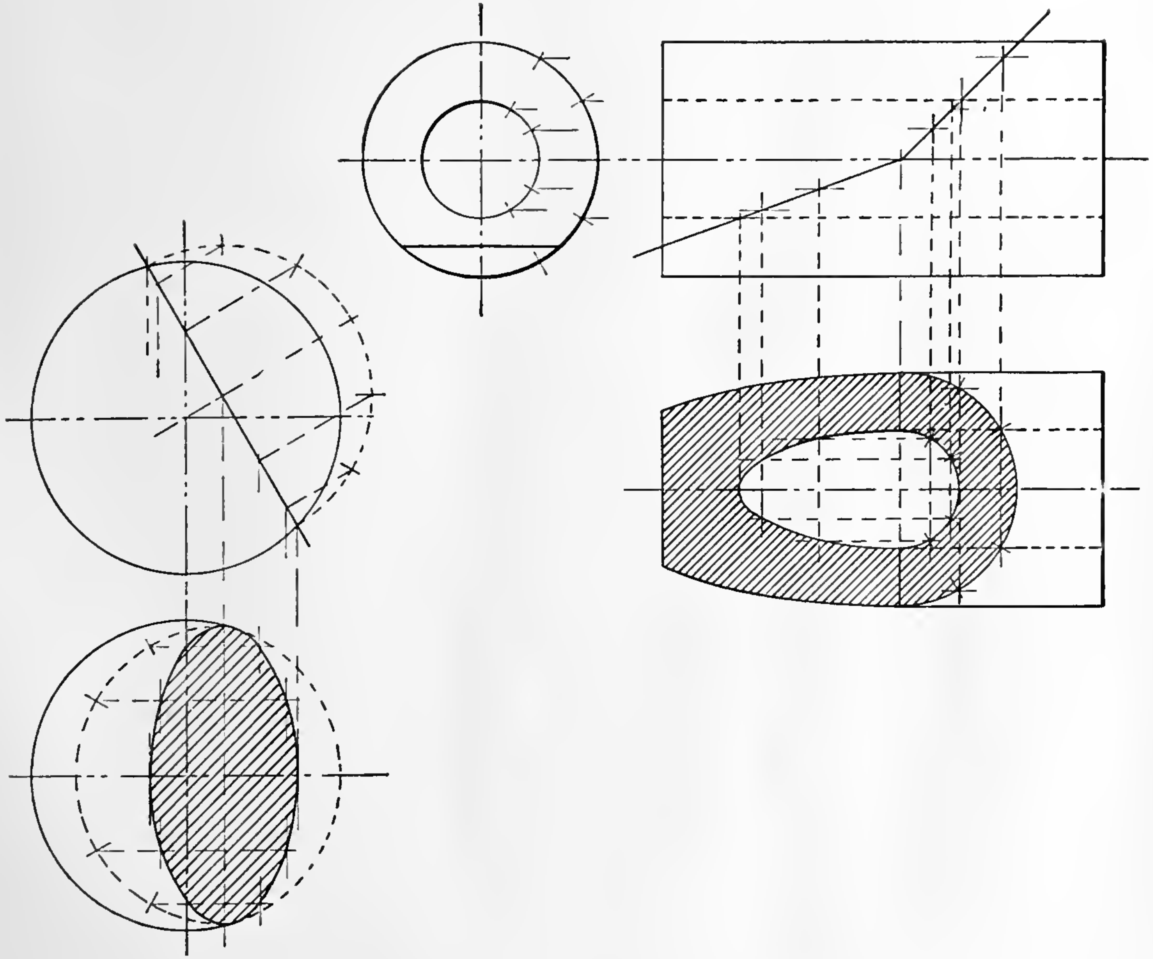
PLATE 37.—A sphere cut by a plane at an angle to its vertical axis. In the side elevation a straight line drawn to the required angle will represent the plane.

The section in plan will take the form of an ellipse, and the method of developing this ellipse is clearly indicated. The elevation drawn perpendicular to the cutting plane would be a circle with diameter equal to the long diameter of the ellipse or the length of the chord which represents the cutting plane.

A cylinder cut by two planes at different angles to the axis, said planes meeting at the centre of the cylinder. The end elevation shows the cutting plane, also the points which are to be projected upon the lines or planes in the side elevation, and to be projected from the side elevation onto the plan.

The plan shows points which are to be projected upon the points from the side elevation. The intersections of the projections from these points will give points in the curves to complete the plan. A cylinder cut at an angle of 45° to its axis, when viewed in the plan, will show in the developed section a circle.

PLATE 37



Isometrical Projection.

Plate 38.—Objects drawn in isometrical show three of their faces in one view, all of which can be scaled or measured.

It is a species of perspective, differing from linear perspective in that the lines are parallel instead of being drawn to meet in a "vanishing" point.

Horizontal lines are drawn at an angle of 30° to the horizontal, which is equivalent to tipping the object upon one of its corners, if it is a rectangle or a solid, such as a rectangular prism, thus giving what might be called a "bird's-eye view." The principle of isometrical projection is shown in Fig. 1, in which a rectangular prism is drawn in isometrical. The dimensions are, length $1\frac{1}{2}''$, breadth $\frac{1}{2}''$, height or thickness $\frac{1}{2}''$. By applying the scale to the figure it will be seen that all of these dimensions can be scaled off. The dotted regular hexagon is placed upon the figure to show that the lines are all drawn to the angles of 30° and 90° to the horizontal, so that the T square and the 30°-60°-90° triangle are the principal tools required when working in isometrical. In Fig. 2 is shown a timber lying upon its side, with another timber having the same breadth and thickness standing upon one of its ends upon it.

In Fig. 3 is shown a cube in isometrical, and standing upon the cube is a square pyramid, the base of the pyramid being smaller than the face of the cube. From this figure it will be seen that a regular hexagon gives the outline of the cube in isometrical. The dimensions are, for the cube, each face a $\frac{3}{4}''$ square, base of pyramid a $\frac{1}{2}''$ square, height of pyramid $1\frac{1}{4}''$. In drawing this figure, first draw a circle $1\frac{1}{2}''$ diameter, and with 30° angle draw the four sides of the hexagon and the two radii, and with the 90° angle draw the vertical sides and the vertical radius. This will complete the cube. Draw two diagonals on the upper face of the cube. Where they intersect will be the centre of the face, and from this centre measure the height of the pyramid. Lay out the base of pyramid by measuring the length of a side upon the side of the top face of the cube, as indicated by dotted lines. Draw lines parallel with the sides of the face of the cube, and where they intersect will be the corners of the base of the pyramid. From these corners draw lines to the vertex to complete the pyramid.

Fig. 4 shows a simple truss. First draw the four outside members of the form and draw the diagonals shown in dotted lines. These will be the centre lines of the diagonal braces. At the intersection of these centre lines draw a small circle whose diameter is equal to the face of the braces, and parallel with these centre lines and tangent to the circles draw the lines showing the thickness of the timber. Where the face line of the

PLATE 38

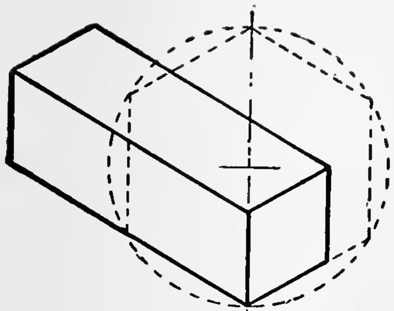


FIG. 1.

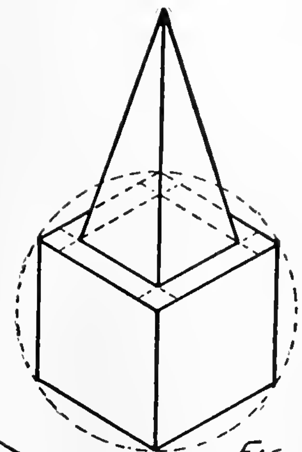


FIG. 3.

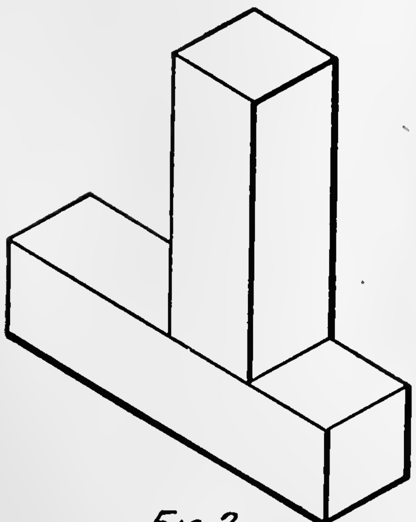


FIG. 2.

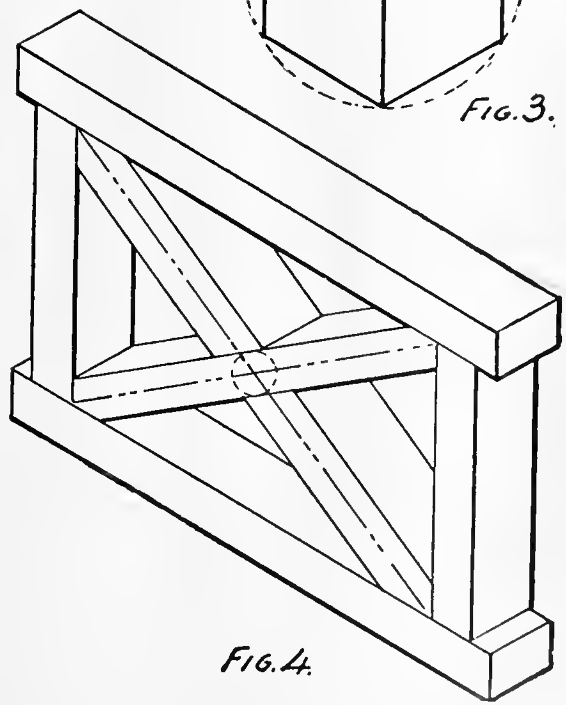


FIG. 4.

diagonal intersects the vertical, draw a line across the face of the vertical, and where it intersects the other edge of the vertical will be the point which measures the width of the diagonal. From this point draw a line parallel with the face lines of the diagonal to define the top face. At the intersection of the diagonal draw a line across the top face of the diagonal, and where it intersects the back edge of the diagonal will be the point defining the width of the other brace. Through this point draw a line parallel with the front face to complete the second diagonal.

In Fig. 1, Plate 39, is shown a frame made up of square timber. At each corner of the frame is a vertical timber smaller than that in the frame, the top ends of which are formed into tongues. The length and width of the frame would be measured along the lines A and B, the height or thickness of the timber on C, the breadth on D, while the distance the verticals are set back from the edge of the frame is measured off from the corner at E and F. Lines drawn from E and F parallel with A and B will intersect at the point from which the near corner of the vertical is to be drawn, while the two faces of the upright are measured from this near corner. In drawing this figure the pupil will work to the following dimensions, and use scale 1″ = 1 foot:

Length of base (A), 8′-0″; width of base (B), 6′-0″.

Thickness of timber (C), 6″; width of timber (D), 6″.

Vertical timbers set back from edge (E and F), 1″.

Width and thickness of verticals, 4″.

Height of verticals, 6′-0″.

Tension in middle of timber, $1\frac{1}{2}$″ thick, 3″ long.

In Fig. 2 is shown a box open at both ends, each face of which is a square. In the centre of the two front faces is a square hole. In the rear faces are also square holes, but these are not in the centre of the faces. Draw to the following dimensions:

Faces of square sides of box, 2″ square.

Thickness of walls, $\frac{1}{4}$″.

Openings in sides, 1″ square.

Place openings in the centre of the two front or rear faces. In the rear faces the openings are $\frac{1}{4}$″ below the top and $\frac{1}{2}$″ from the inside corner. Omit the shading.

In Fig. 3 is shown a circle in isometrical.

Two methods of drawing the circle are given. First method: Lay out the rhombus with major or long axis F G equal to diameter of the circle, bisect and draw perpendicular to it the minor or short axis. With 30° angle draw F B, G B, F A and G A. These lines will intersect at A and B, thus cutting off the correct length of the short axis. With centre O draw circles equal in diameter to F G and A B. Divide these circles and proceed as in lesson on Page 64, Plate 13, Fig. 17.

Second method: Project A and B to either side. With C for centre, F G for radius, sweep an arc cut-

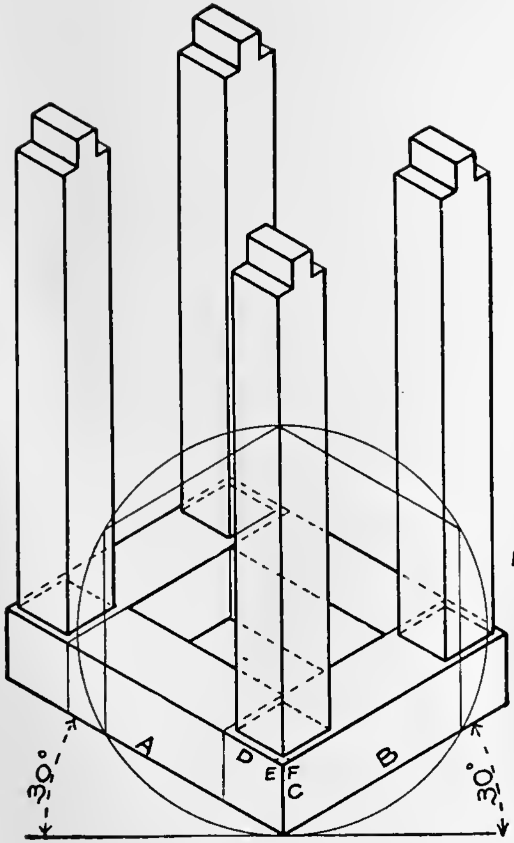


Fig 1.

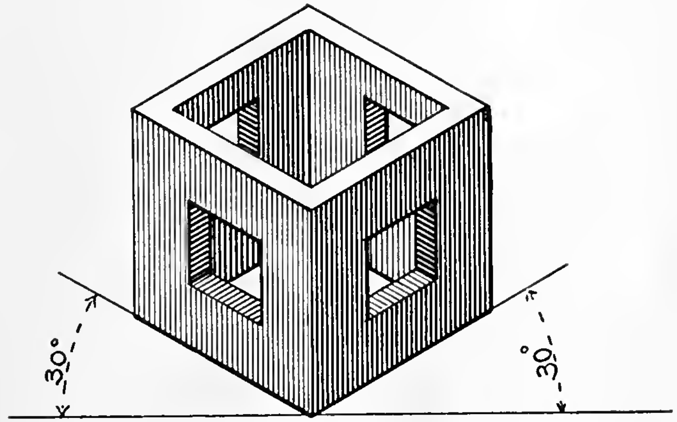


Fig 2

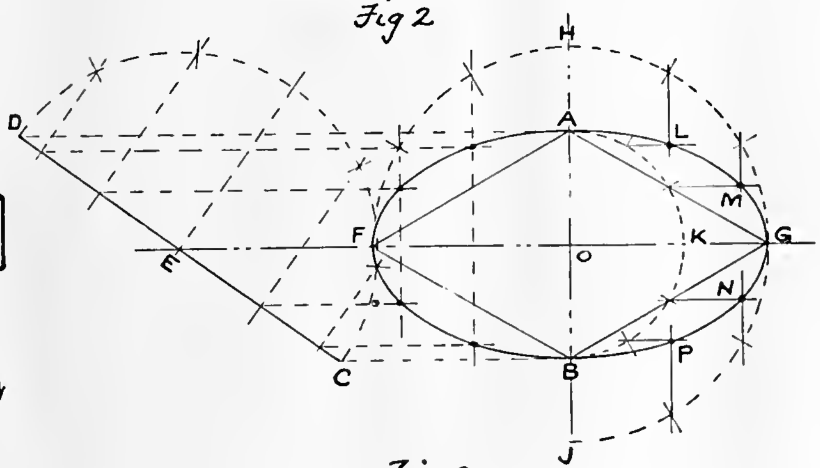


Fig 3.

ting A produced in D, draw C D and bisect in E and erect perpendicular. With E for centre and E C for radius draw semi-circle and subdivide, and project the points of subdivision perpendicularly upon D C. With O for centre and radius O G draw semi-circle and subdivide, and proceed as in lesson on Page 52, Plate 7.

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

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

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

Plate 41. Symbolical Shading.

At one time the draughtsman represented the various materials by means of colors applied to the drawing with a brush. With the advent of the "blue printing" process it became necessary to abandon this method, owing to the fact that the colors would not print. Now colors are not used even for lines, and it is necessary to employ other means to convey to the workman the information in regard to the several metals or other materials to be employed. The line work shown on Plate 39 is now *standard,* and is employed by all workshops of any importance, and indeed by most of the smaller ones as well. When the shadings are not used the draughtsman must carefully mark each piece with the name of the material, and even when the symbolical shadings are used they can only be employed for parts in section, therefore the name must be marked on full figures. This will be noted in the plates on shop drawing.

PLATE 41

Symbolical Shading.

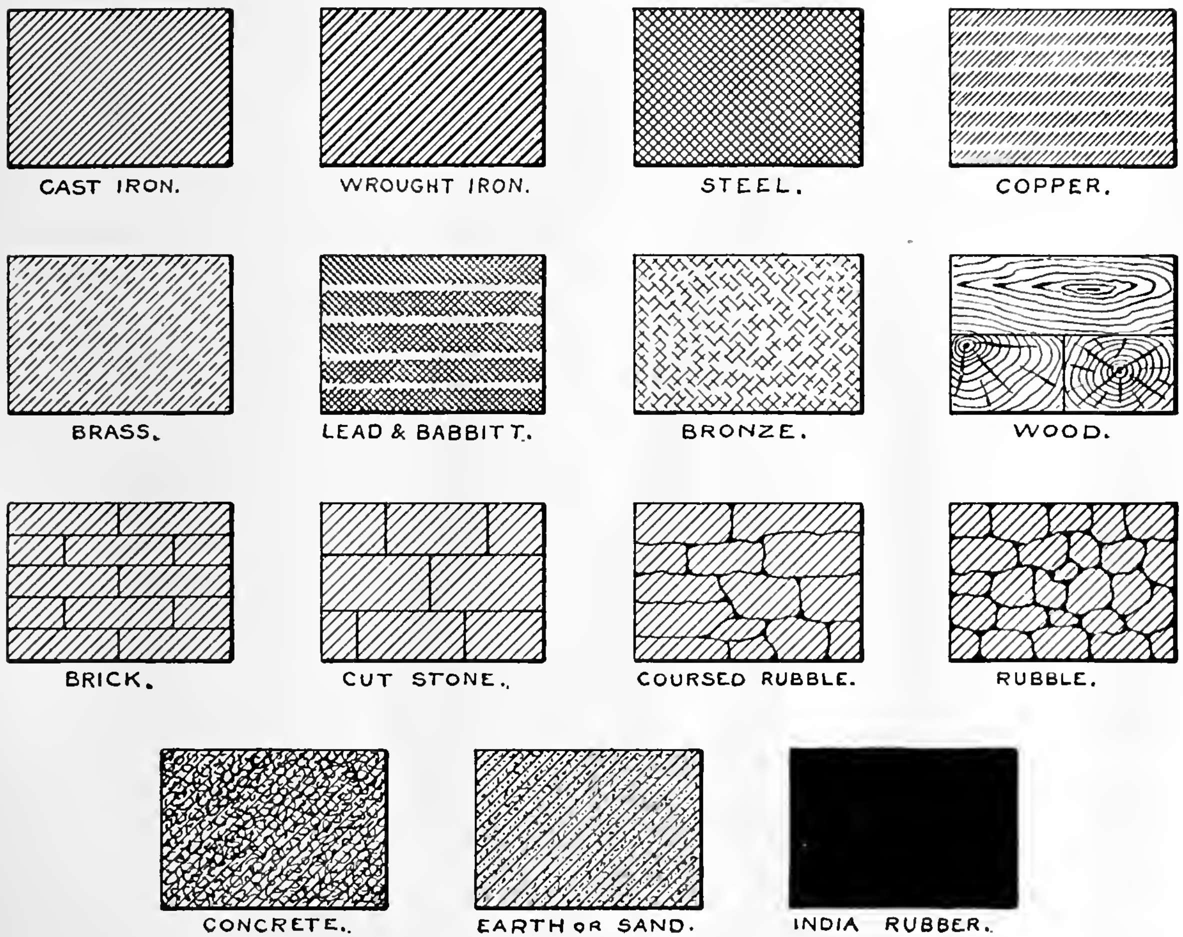


PLATE 42

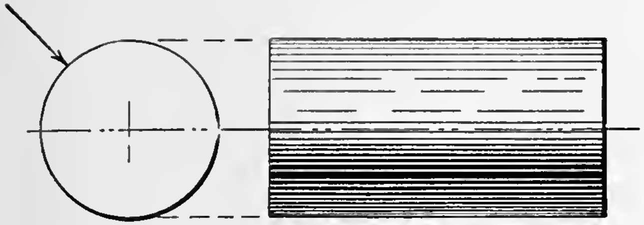


Fig. 1.

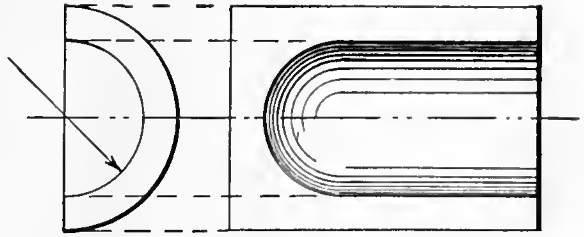


Fig. 2.

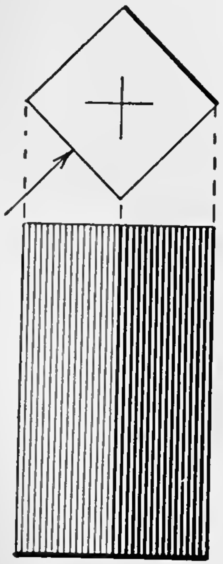


Fig. 3.

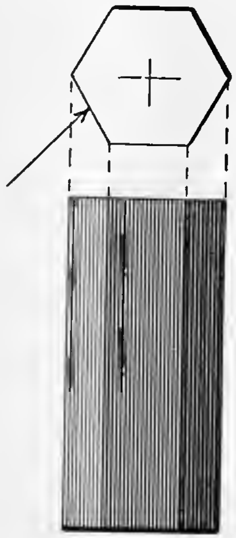


Fig. 4.

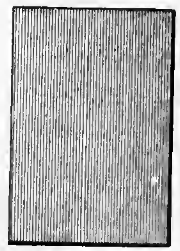


Fig. 5.

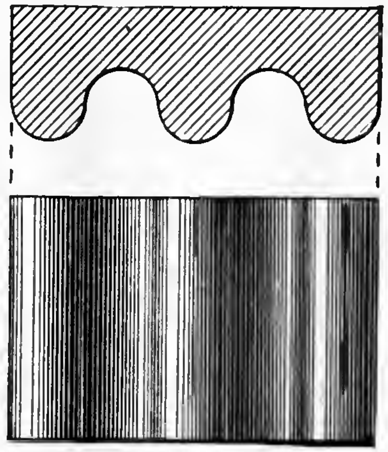


Fig. 6.

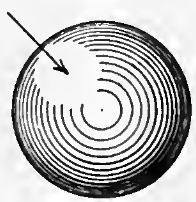


Fig. 7.

LINE SHADING.

Conventional Screw Threads.

Screw threads are of many forms, those in most common use being shown on Plate 43.

The United States, or Franklin Institute standard: The angle of the sides is 60°. The depth is $\frac{3}{4}$ of the pitch, and the top and bottom are flattened an amount equal to one-eighth of the pitch. In the large workshops of the United States this thread is standard, and it is used exclusively in all Government shops.

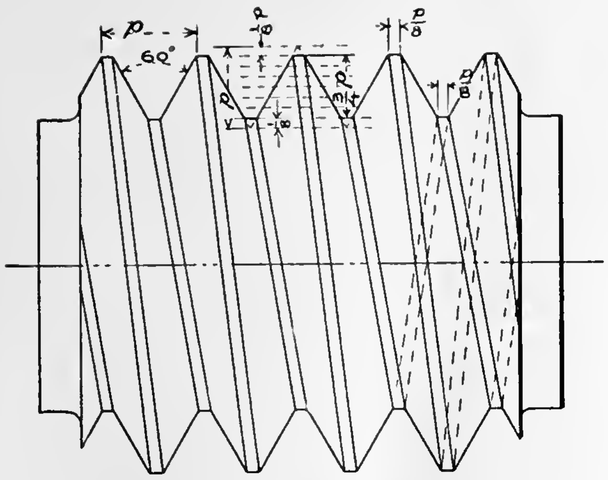
Common, or V thread: Before the adoption of the United States standard thread this was the commonly used thread, and is still largely employed. The angle of the sides is 60°.

The square thread is employed in machine tools and for many special purposes. It is especially valuable when a quick pitch is required, combined with great strength and comparatively large diameter at the bottom. That is, it is not as deep as either the U. S. or V threads would be with the same pitch. The proportions vary greatly, depending upon the service. The usual proportions, however, are as its name implies—square—the depth being equal to the width, which in turn is equal to half the pitch.

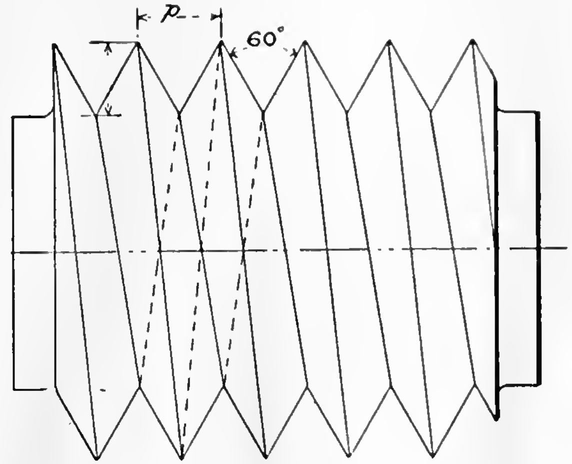
The 15° thread is a modification of the square thread. Its sides have the angle of 15°, its depth is equal to half the pitch, and its width at one-half its depth is half the pitch. Therefore to lay out this thread draw a pitch line half-way between the top and bottom of the thread, and on this line mark off the threads and spaces each equal to half the pitch. Through these points draw the sides of the thread at the angle of 15°. The sides will give the width of the thread at the top and bottom. This thread has all the advantages of the square thread, with the added advantage of greater strength and slightly greater wearing surface for the same pitch.

Any of these threads can be made right or left hand, double or treble, etc.

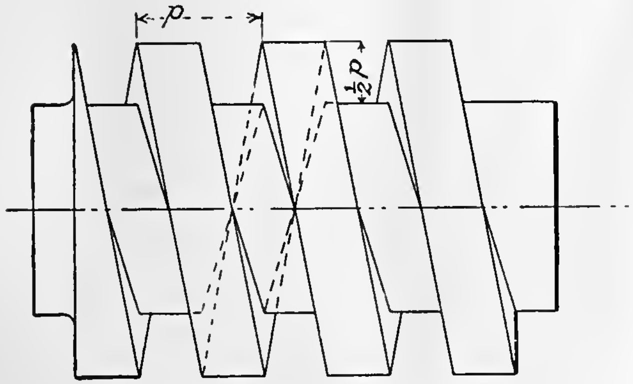
The figures in this plate show the method usually employed in the draughting room in drawing large screws, straight lines being employed to show the threads, instead of the developed curves of the helix. This is done to economize in time. There are many occasions for drawing the true curves, therefore the draughtsman must be familiar with the method.



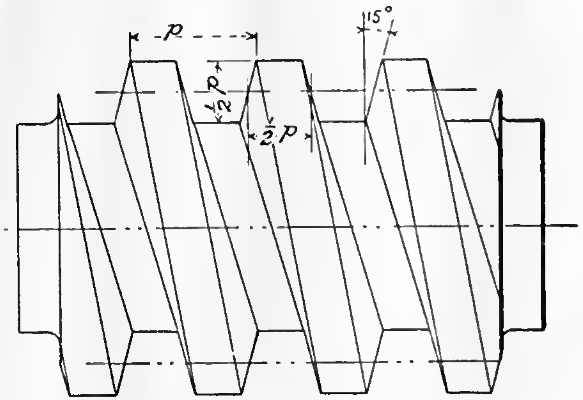
U.S. STANDARD THREAD.



COMMON OR "V" THREAD



SQUARE THREAD



15° THREAD.

CONVENTIONAL SCREW THREADS.

Bolts and Nuts.

On Plate 44 are shown a standard hexagon nut in Fig. 1, a cap screw (Fig. 2), and a set screw (Fig. 3).

To draw the standard nut or bolt head, take from the table on Page 128 the short diameter and draw a circle whose diameter is equal to the dimension given. Then with the 30°-60° triangle and T square draw the sides of the nut tangent to this circle. The circle will represent the *chamfer* of the nut or bolt head. Concentric with this circle draw in dotted line another circle equal in diameter to the bolt, and inside of this another circle equal to the diameter at the bottom of the thread. These two inner circles apply only to the nut.

To draw the side elevation showing the short diameter, project 1′-2′-3′ either to the right or left, draw 1-2-3 and parallel with it 4-5-6 spaced equal to the diameter of the bolt or the distance given in the table. With compass in 1-2 and 3 and radius 1-2 sweep intersecting arcs. With these intersections for centres and same radius draw the arcs 1-2 and 2-3. For the nut, project circles representing the thread.

To draw elevation showing the long diameter, project the points 2′-3′-4′-5″ downward, and draw bottom and top of nut or bolt head as before. With radius equal to 3′-4″ and centre on centre line of nut draw arc tangent to the top. Prolong this arc indefinitely across the other faces of the nut. Bisect 2′-3′ and 4′-5′ in *a* and *b*, project *a* and *b* to *a′*-*b′*. These will be the centres of the small arcs which define the chamfer. If for nut, project the circles representing the thread.

In Fig. 2 is shown a standard *cap screw*. These are *finished* tap bolts, having the heads smaller than the standard bolt heads. The top of the head is spherical in finish, and its height is equal to the diameter of the bolt.

Dimensions of standard cap screw heads are given in the table on bolt heads and nuts.

In Fig. 3 is shown a *set screw*. These are generally made with square heads, the short diameter of which is equal to the diameter of the bolt, the height of the head being of the same dimension. Under the head the bolt or body is reduced to the same diameter as the bottom of the thread. This is done to enable the thread to be cut all the way over the body. At the point there are several styles of finish, all of which are indicated, viz.: The cup, flat and point sizes of standard set screw heads are given in the table, but if drawn with the short diameter and height equal to the diameter of the body of the screw they will be correct.

The method of drawing the bolt head or nut as given above is correct for *finished* nuts and heads, but it is rarely followed in the draughting room because of the

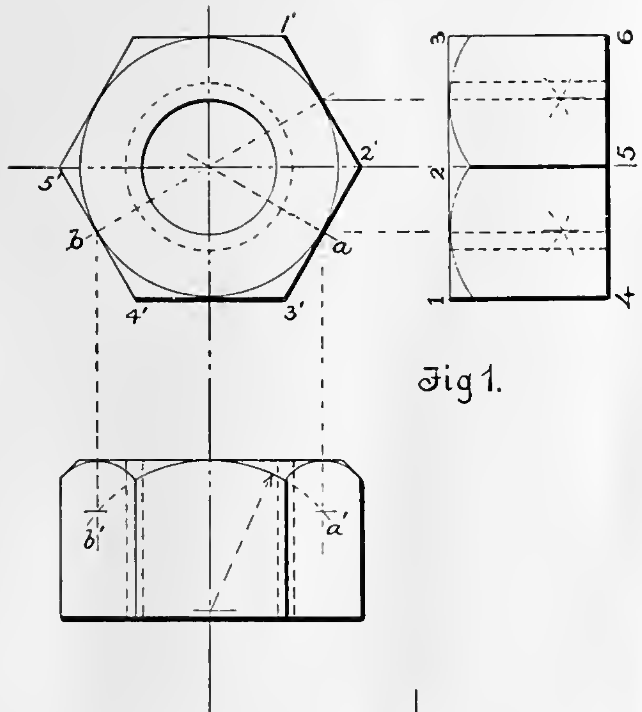


Fig 1.

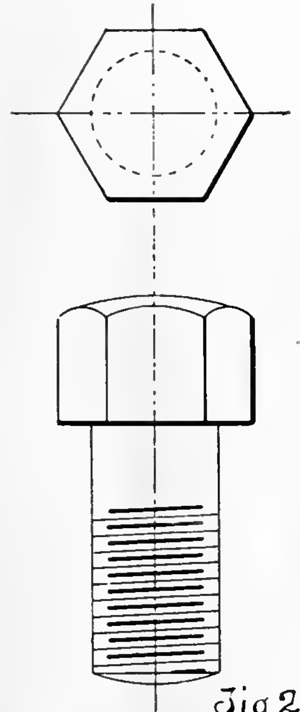


Fig 2.

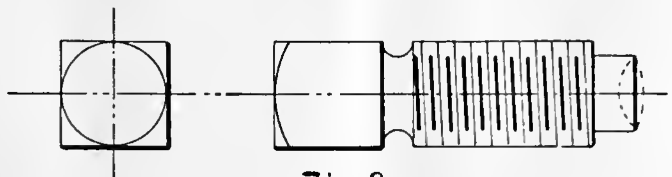


Fig 3

STANDARD NUTS AND BOLTS.

time consumed in a needless detail. The rule usually followed is to make the long diameter equal to twice the diameter of the bolt, and the height equal to the diameter of the bolt. The arcs showing the chamfer are drawn in by the eye, and the draughtsman soon becomes expert at this. This makes the nut or bolt head larger in diameter than it is, in fact, and insures *clearance*. There are cases when it is necessary to draw to actual size, notably when clearances are small, and the student should be familiar with the method of doing it.

TABLE VI.

U. S. Standard Nuts, Bolt Heads and Threads.

Diameter of Bolt.	No. Threads Per Inch.	Diameter at Bottom of Thread.	Short Diameter Nut or Head.	Thickness Rough Bolt Head.	Short Diameter Cap Screw.	Short Diameter Set Screw.
¼	20	.185	½	¼	7/16	¼
5/16	18	.240	19/32	19/64	½	5/16
⅜	16	.294	11/16	11/32	9/16	⅜
7/16	14	.344	25/32	25/64	⅝	7/16
½	13	.400	⅞	7/16	¾	½
9/16	12	.454	31/32	31/64	13/16	9/16
⅝	11	.507	1 1/16	17/32	⅞	⅝
¾	10	.620	1¼	⅝	1	¾
⅞	9	.731	1 7/16	23/32	1⅛	⅞
1	8	.837	1⅝	13/16	1¼	1
1⅛	7	.940	1 13/16	29/64	1⅜	1⅛
1¼	7	1.065	2	1	1½	1¼
1⅜	6	1.160	2 3/16	1 3/32		
1½	6	1.284	2⅜	1 3/16		
1⅝	5½	1.389	2 9/16	1 9/32		
1¾	5	1.490	2¾	1⅜		
1⅞	5	1.615	2 15/16	1 15/32		
2	4½	1.712	3⅛	1 9/16		
2¼	4½	1.962	3½	1¾		
2½	4	2.175	3⅞	1 15/16		
2¾	4	2.425	4¼	2⅛		
3	3½	2.628	4⅝	2 5/16		
3¼	3½	2.878	5	2½		
3½	3¼	3.100	5⅜	2 11/16		
3¾	3	3.317	5¾	2⅞		
4	3	3.566	6⅛	3 1/16		
4¼	2⅞	3.798	6½	3¼		
4½	2¾	4.027	6⅞	3 7/16		
4¾	2⅝	4.255	7¼	3⅝		
5	2½	4.480	7⅝	3 13/16		
5¼	2½	4.730	8	4		
5½	2⅜	4.953	8⅜	4 3/16		
5¾	2⅜	5.203	8¾	4⅜		
6	2¼	5.423	9⅛	4 9/16		

Long diam. hexagon nut or bolt head = short diam. × 1.155.

Long diam. square nut or bolt head = short diam. × 1.414.

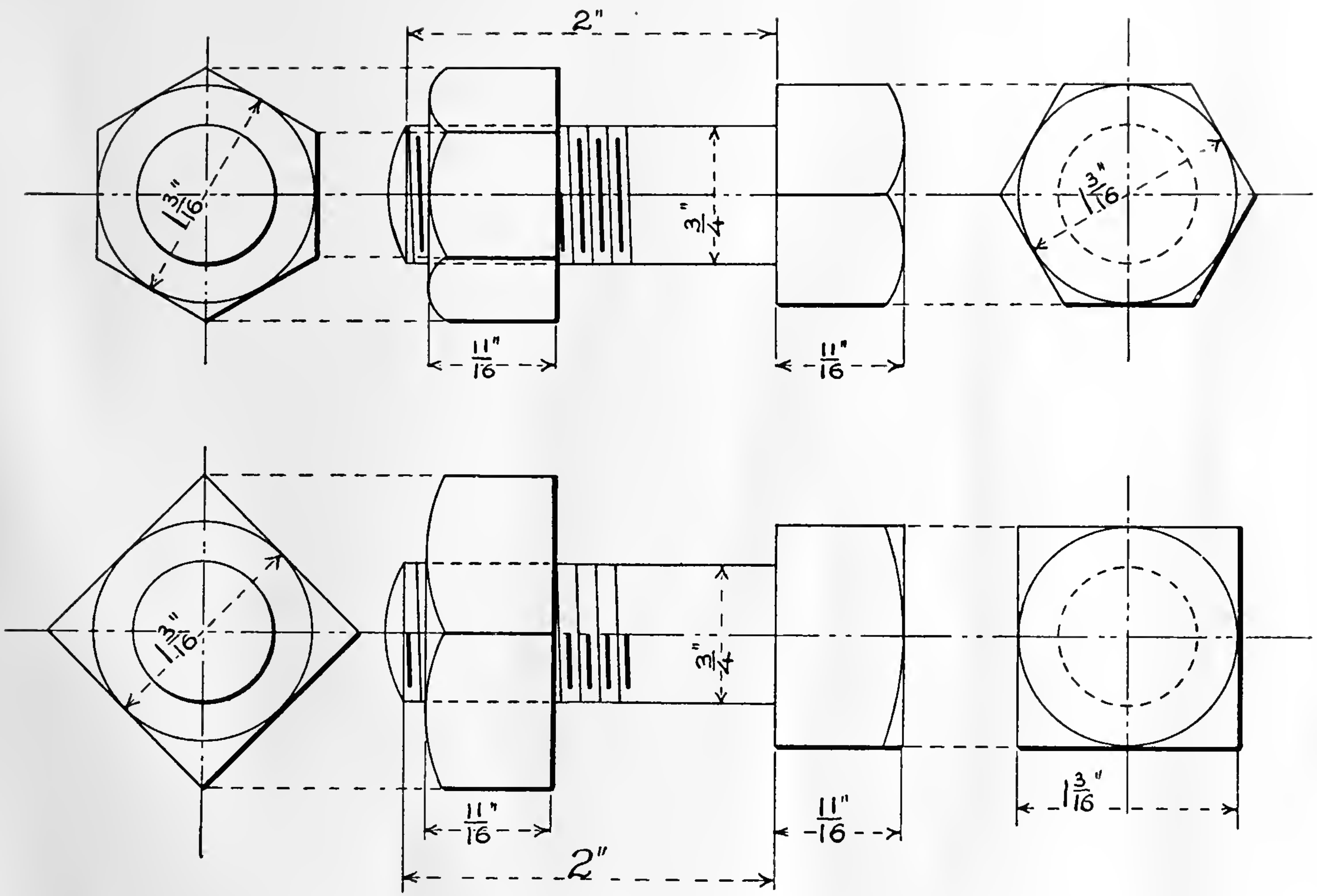
Thickness of bolt heads given in table is for *rough* heads.

Thickness of finished heads and nuts is equal to diam. of bolt. Other dimensions given in table are finished sizes.

Short diam. of rough nut or bolt heads = 1½ × diam. of bolt + ⅛ inch.

In Plate 45 are given examples of conventional bolts and nuts, hexagon head and nut and square head and nut. When bolts of small size, and of any size to small scale, are drawn, the threads are represented as shown in the drawings, usually as in the upper one. The lines representing the top of the thread are fine, and extend at an angle entirely across the bolt, while those indicating the bottom of the thread are half-way between the tops of the thread, are heavy, and stop short of the sides. If left-hand thread is wanted it is so marked; also if a special thread, double thread, triple thread or other departure from standard. No special instructions imply that the bolt is *standard*.

PLATE 45

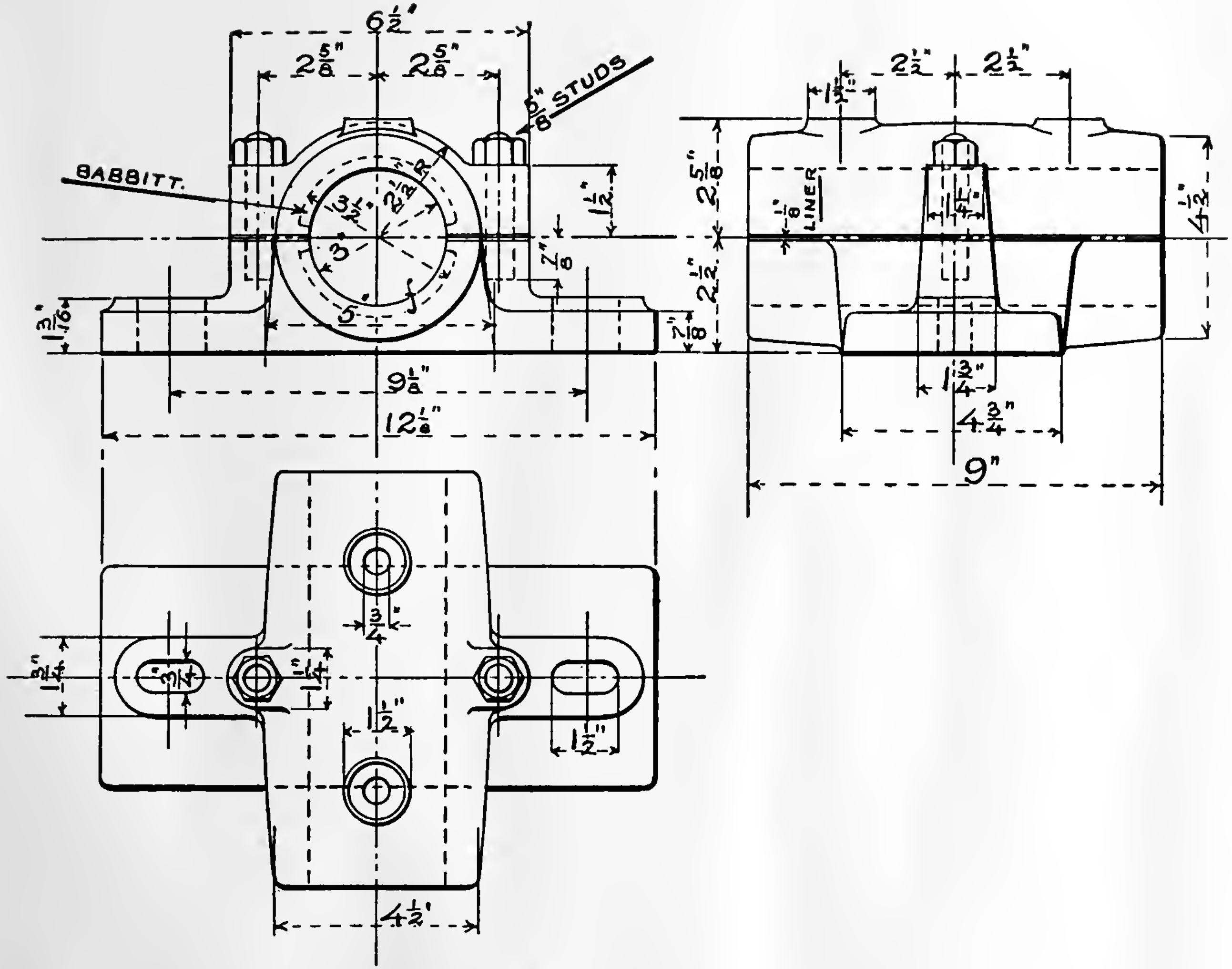


CONVENTIONAL BOLTS AND NUTS.

Shop Drawings.

Plate 46 shows a common form of pillow block, or bearing, for supporting shafting. It is shown in front and side elevations, and plan and all necessary dimensions for making a drawing or pattern and for finishing are given. The student should practice upon this, making drawing to scale of $\frac{1}{2}$ size, or 6″ = 1 foot.

PLATE 46



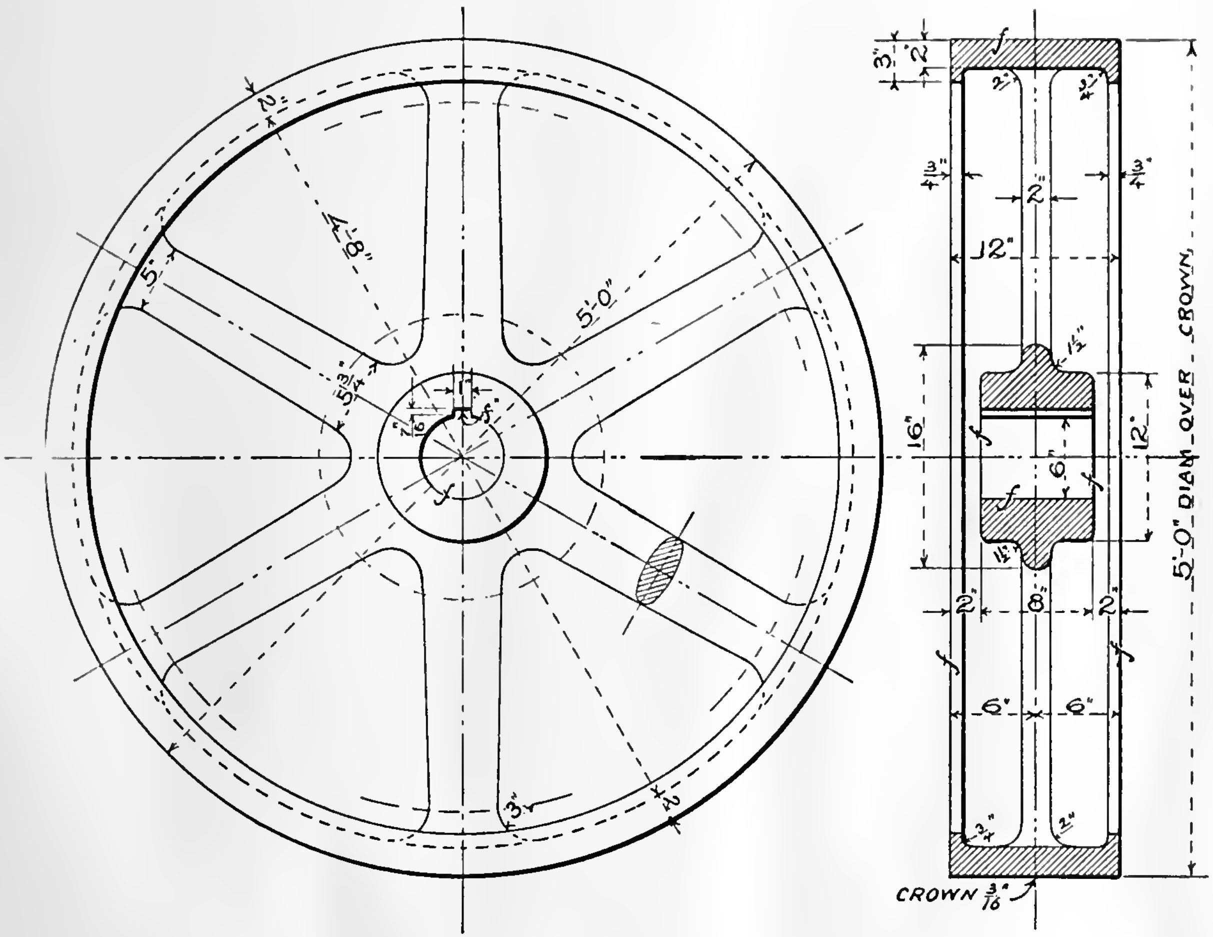
PILLOW BLOCK.

Plate 47 shows a flywheel with broad face, usually called a "band flywheel."

The side elevation and section give all information required by pattern maker and machinist in making the wheel, and the student should proceed as follows in making the drawing: Draw first the horizontal and vertical centre lines for both views and then the circles for face or outer circumference, thickness of rim—dotted—and the inside flange, the bore of the hub and the outside of hub. There being six arms, draw centre lines of these arms. As the fillet or curve joining the arms to the rim is to be 3″ radius, sweep arcs across the centre lines of the arms 3″ from the dotted line. For thickness of rim on these arcs measure the width of the arm 5″ or $2\frac{1}{2}$″ each side of the centre line. Next lay off the thickness of the arm at the hub $5\frac{3}{4}$″, and the diameter 16″ across the fillet connecting the arms at the hub. Draw in the sides of the arms, and with radius 3″ and centre on the arcs at the rim draw in the fillets tangent to the sides of the arms and the rim. Now find a radius by trial which will give an arc tangent to two arms and the circle for fillet at the hub. Through the centre of this arc draw a circle concentric with the hub. On this circle will be found the centres for the arcs connecting the arms.

The section shown is not a true section, in that the arm is not in section, but this method is usually employed, as it saves making many views. Scale off each side of the centre line the width of face, thickness of arm, length of hub and thickness of flanges, and draw the several lines parallel with the vertical centre line. Project the various diameters from the side elevation and draw in the fillets and keyway.

The section of an arm can be drawn upon one of the arms, as shown, or it can be drawn elsewhere outside of the wheel to a large scale. The letter "*f*" shows where the wheel is to be *machined*. That is, the hub is to be bored and faced on both ends, and the outside is to be turned on the outside and "crowned," also is to be faced on both edges or sides. The directions "crowned" $\frac{3}{16}$″, means that the rim is to be turned on the outside $\frac{3}{16}$″ higher in the middle than at the edges, the object of this crowning being to cause the band or belt to run fairly on the wheel.



BAND FLY WHEEL.

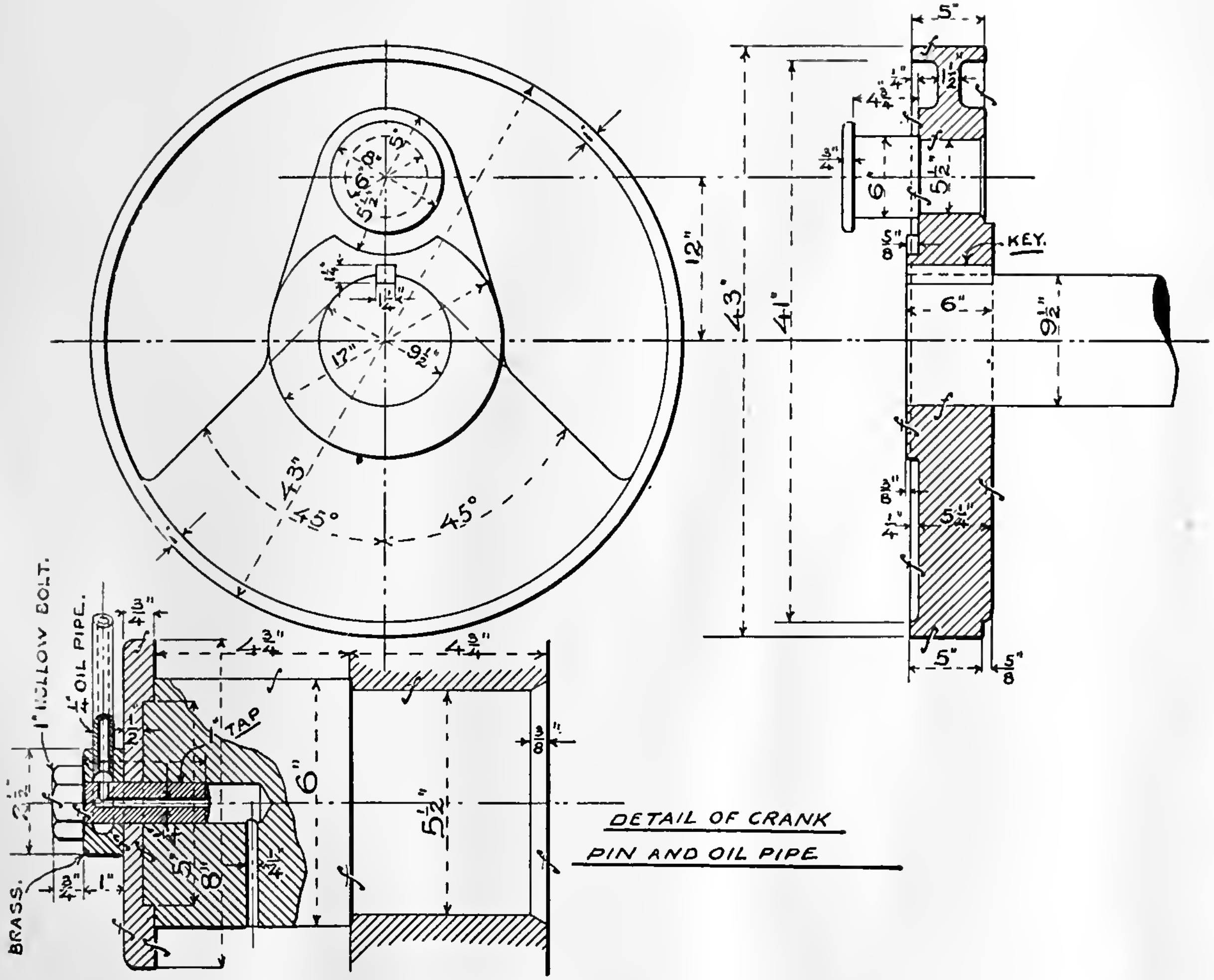
Plate 48 shows what is known as a "disc" crank for a steam engine, with crank pin and part of shaft.

Draw first the vertical centre line and then the horizontal line for centre line of shaft, and parallel with it, and 12″ apart, another centre line for the crank pin. On the centre line of the shaft draw the outside diam. of the crank, 43″ or radius $21\frac{1}{2}$″, and inside of rim 41″ diam. or $20\frac{1}{2}$″ radius; then diam. of hub 17″ and shaft $9\frac{1}{2}$″. Follow this by finishing the crank in eye 5″ radius and draw tangents for the crank; then put in circles showing crank pin collar and crank pin, the latter dotted, as it is behind the collar. With radius $5\frac{1}{2}$″ sweep the arc showing where the projecting hub is cut away to level of crank face to clear for crank pin boxes and draw in the key. The counterbalance is drawn from the rim to the hub 45° each side of the vertical centre line, and the lines of the counterbalance continued would be tangent to the shaft, as shown by dotted lines. The section shows the rim 5″ wide and the thickness through the hub 6″, the hub projecting $\frac{5}{8}$″ beyond the rim at the back and $\frac{3}{8}$″ beyond the rim on the front. The web or plate is $1\frac{1}{2}$″ thick, central with the rim, while the counterbalance is sunk $\frac{1}{4}$″ below the rim at the front, and projects $\frac{5}{8}$″ at the back. The finishes are indicated by the letter *f*.

The crank pin is shown in detail, drawn to a larger scale, and is partly in section. This section shows the cap to be a separate piece turned out to fit the projection on the end of the crank pin, and that it is held in place by a hollow bolt with a thick brass washer, having an oil groove turned inside which communicates with a pipe which is screwed into it. This pipe extends to the centre of the shaft, terminating in a hollow ball through which the oil is fed to the pipe, the oil being thrown by centrifugal force through the pipe and hollow bolt and out of the oil hole which is bored from the side of the crank pin opposite the centre of the shaft.

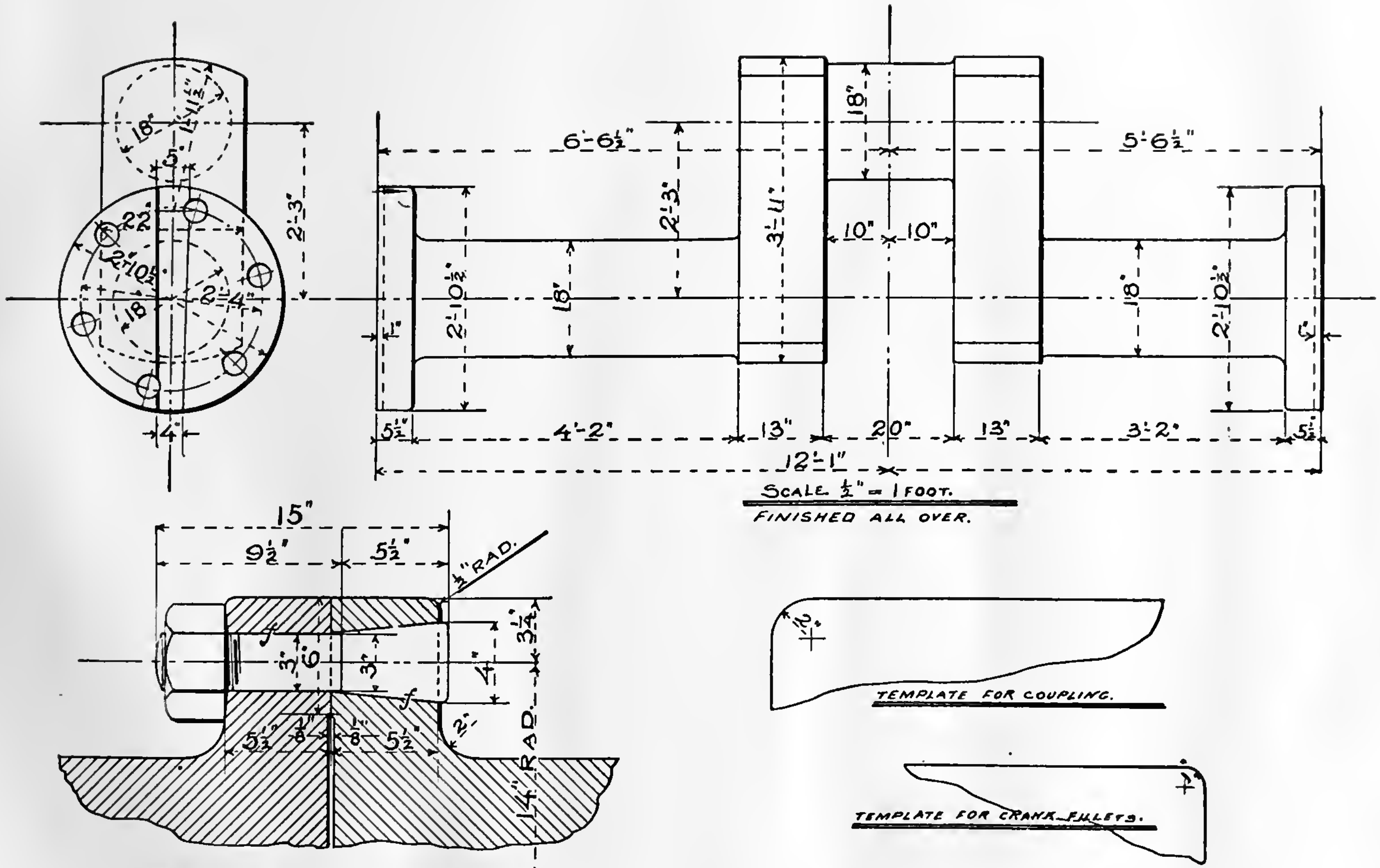
Make this drawing to scales 3″ and 6″ = 1 foot.

PLATE 48



DISC CRANK AND CRANK PIN.

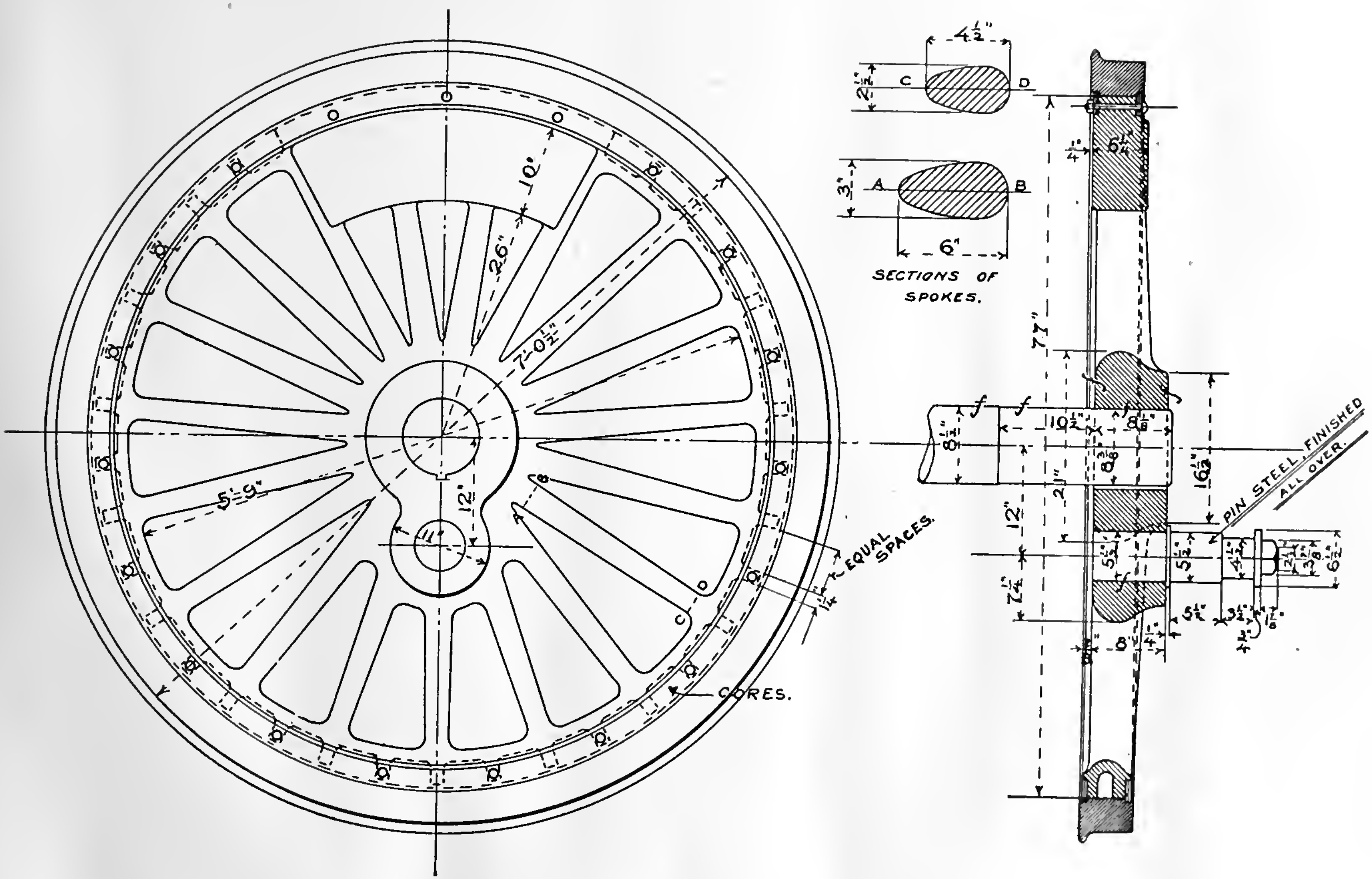
Plate 49 shows a solid crank shaft such as is used in the modern marine engine and in many vertical and horizontal land engines. Full dimensions and directions for the shop are given. Also for the draughting room. Make a drawing to larger scale than the plate, say 1″ for the shaft and 3″ for the coupling; also make detail of complete coupling or flange instead of half, as in the plate.



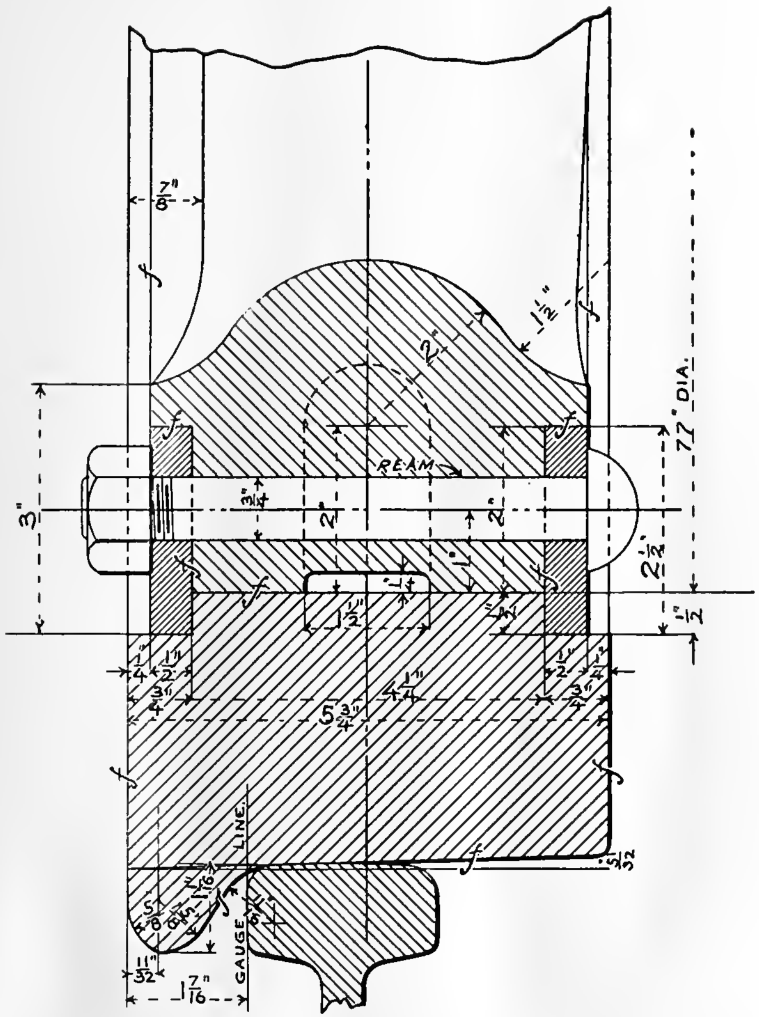
CRANK SHAFT FOR MARINE ENGINE

Plate 50 shows driving wheel of a locomotive in front elevation and sections. Also sections giving the shape of the spokes at hub and rim. Directions for drawing the front elevation of the wheel, as well as the section, the same as given for Plate 45, while the details of the rim and tire are given on Plate 51. Make drawing to larger scale for elevation and section, say 1" to the foot, while detail of the rim and tire may be drawn to scale of 3" = 1 foot. Note directions for finish, and be sure to give all necessary information on drawings.

PLATE 50



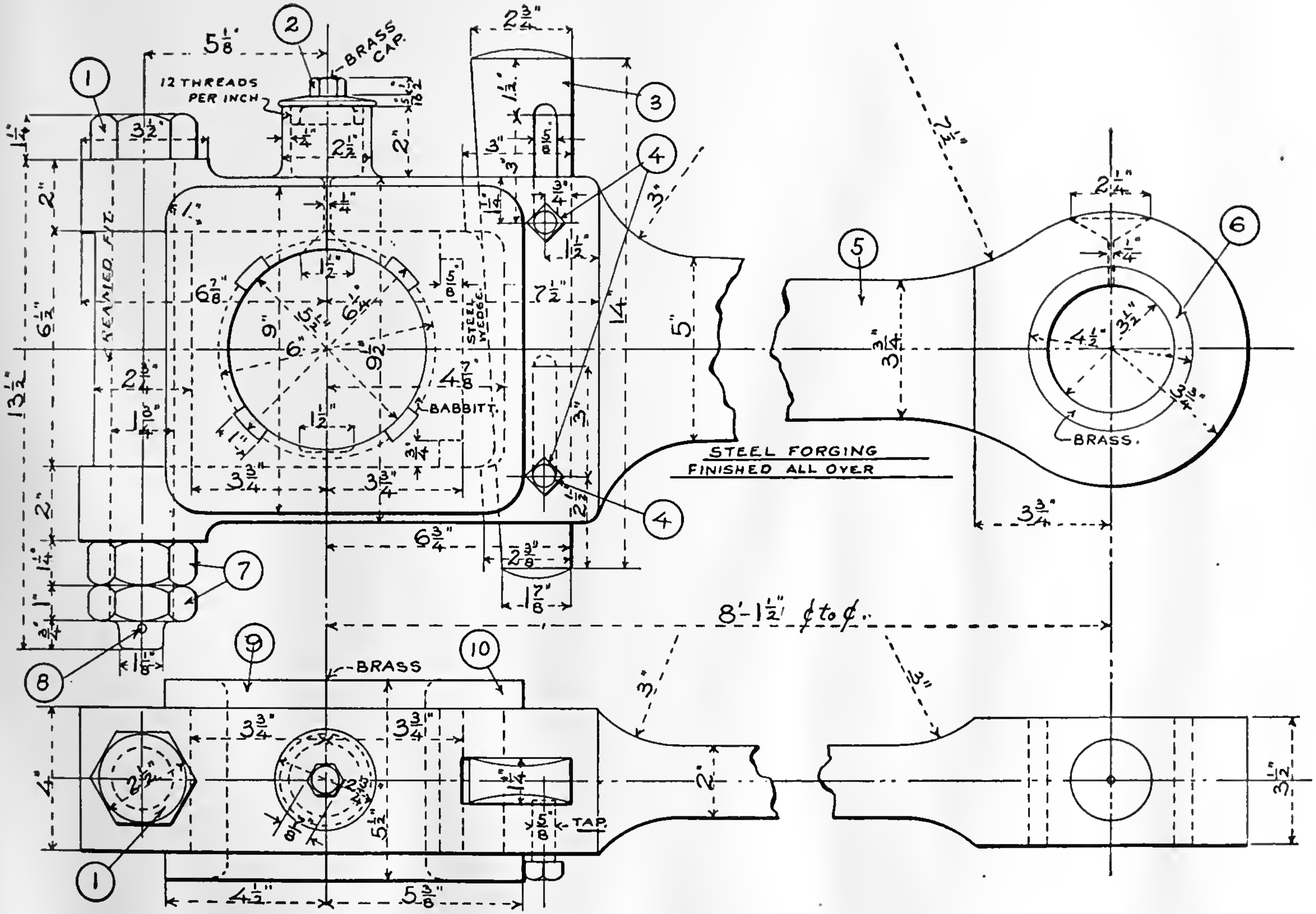
LOCOMOTIVE DRIVING WHEEL.



SECTION OF RIM AND TIRE LOCOMOTIVE DRIVING WHEEL.

PLATE 52.—A locomotive connecting rod. It will be noted that the ends only are shown, the body of the rod being "broken" away. Enough of the body is shown to indicate that it is tapered in width from 5″ at the large end to $3\frac{3}{4}$″ at the small end, while the dimension 8′-$1\frac{1}{2}$″ from centre to centre (usually abbreviated on drawing § to §) gives the necessary instructions to the smith for making the forging. The general directions "steel forging, finished all over," shows that the smith is to allow for this finish by providing additional metal for this finish, and the machinist understands that he is to machine and polish to every dimension. There being no *sections* to this drawing, none being necessary, the symbolical lines are not employed to indicate the several metals employed, therefore the names of these metals are marked on the pieces or parts. The boxes at the large end for the crank pin are of brass, lined in the bore with "babbitt" metal, which is retained in place by the "dovetails," while the small or "wrist pin" end is fitted with a brass liner or bushing, which is forced into place.

Draw this to several scales, say $1\frac{1}{2}$″, 3″ and 6″ to the foot.

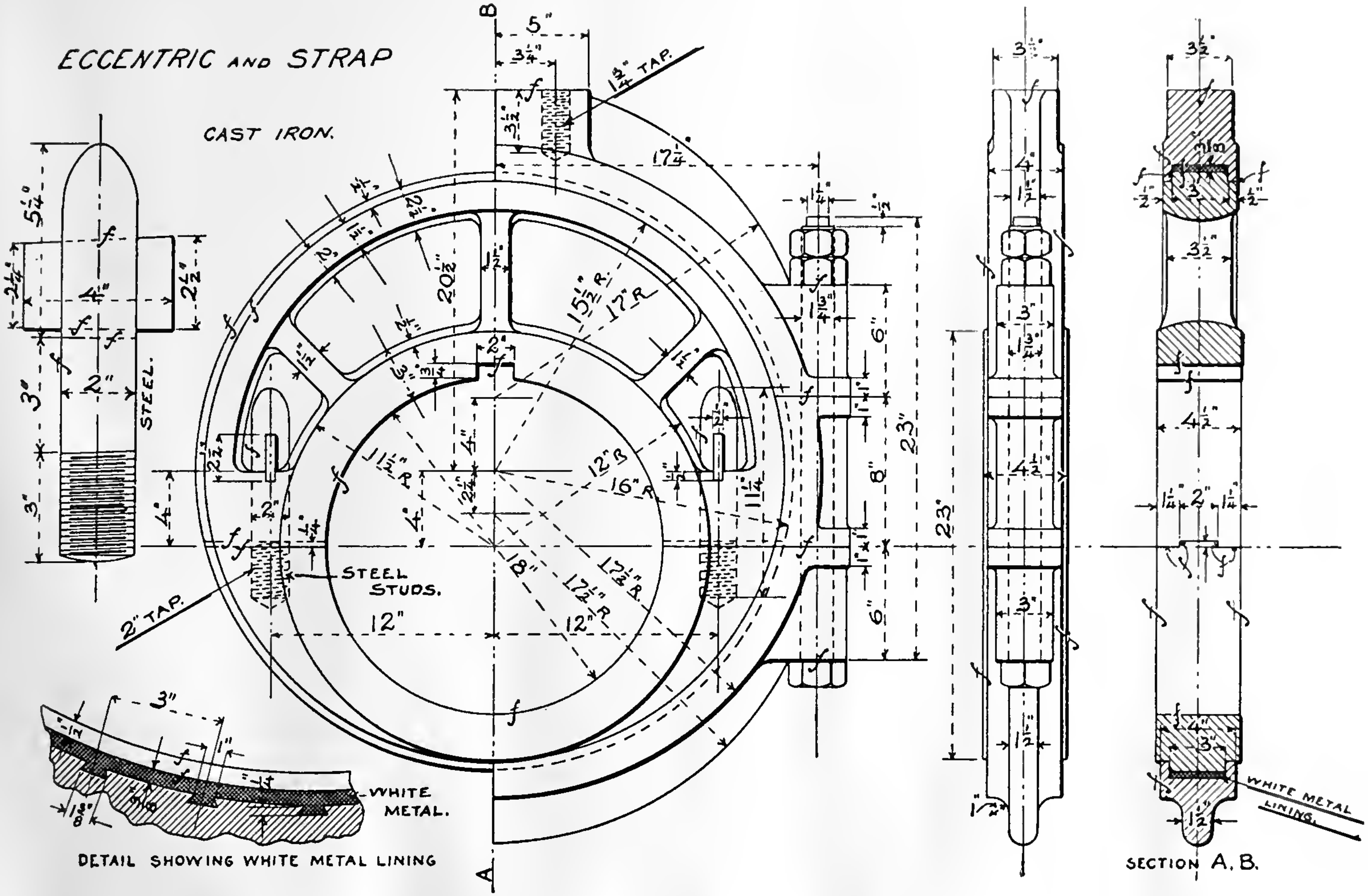


LOCOMOTIVE CONNECTING ROD.

PLATE 53.—Eccentric and strap for a marine engine. Only half of the strap is shown. Draw the eccentric and strap separate, making drawing of complete strap the other half of which is the same as the half shown.

The eccentric is made in two parts, which are fitted with a tongue joint, the parts being held together by studs and keys. The eccentric has a "throw" of 4″, which will impart a travel of 8″ to the valve of the engine. First lay out the main centre lines—that is, those passing through the bore of the eccentric, and 4″ from the centre of the bore and on the vertical centre line lay off the centre from which the outside and inside of rim are drawn to the radii given. Complete the details of the eccentric, both front elevation and section. The strap is in four pieces, the top and bottom straps and the two fillers. It is also lined with white metal or babbitt, which is held in place by the dovetails.

Draw to scale of 3″ = 1 foot for eccentric and strap, and 6″ = 1 foot for details.


ECCENTRIC AND STRAP
CAST IRON.
STEEL.
STEEL STUDS.
2" TAP.
1¾" TAP.
WHITE METAL.
WHITE METAL LINING.
DETAIL SHOWING WHITE METAL LINING
SECTION A. B.

Exercises for Review.

1 Draw plan of cube 2″ on each face, standing at angle 30° and 60″. Make front and side elevations.

2 A rectangular prism $1\frac{1}{2}$″ high, $1\frac{1}{2}$″ wide, 3″ long. An end elevation would show the prism resting upon one long edge, the sides at angles of 30° and 60° to the horizontal. Make plan and side elevation. Also oblique projection to show full view of one side.

3 A cone with base 2″ diameter, 3″ high, pierces another cone having base $2\frac{1}{2}$″ diameter, $3\frac{1}{2}$″ high. The axis of the first cone is vertical, that of the pierced cone is at the angle of 60° with the axis of the first cone. Develop the lines of intersection.

4 A hexagonal pyramid whose inscribed circle at the base is 2″, and whose axis is 3″, pierces a cone whose base is $2\frac{1}{2}$″ and height 3″. The axes are at right angles, or 90° to each other. Develop the line of intersection.

5 A ring 3″ inside diameter, 7″ outside diameter, and whose section is a regular hexagon, is pierced by a cylinder $1\frac{1}{2}$″ diameter. The axis of the cylinder is vertical to the plane of the ring, and is $4\frac{1}{4}$″ from the centre of the ring. A line connecting the centres of the ring and cylinder in plan is 30° to the horizontal centre line of the ring. Develop the lines of intersection.

6 A cone having base 2″ diameter, axis 3″ high, is revolved at a uniform velocity at the same time a point is moved along the side of the cone at the uniform velocity of 1″ for each revolution of the cone. Develop the path of the point on the cone and make plan of the line traced.

7 A hexagonal pyramid whose base is a regular hexagon circumscribed about a 2″ circle, and whose height or length of axis is 3″, is to be treated the same as was the cone in No. 6 above.

8 An octagonal prism whose base is a regular octagon inscribed in a circle $1\frac{1}{2}$″ diameter, and whose height on its axis is 2″, cut by a plane at the angle of 45°, the plane cutting the axis at its measured length of 2″, thus making one face longer than the opposite face. Draw plan, front and side elevations, and find length of long and short sides. Also develop the envelope.

9 Draw in front and side elevation and plan a cross whose shaft is 6″ square and 4′ high, standing upon a base 6″ thick and 2′ square. The arms are 6″ square and 1′ long each, and are 1′ below the top of shaft.

10 Draw No. 9 in isometrical.

11 Draw in isometrical a flight of six steps, whose dimensions are as follows: Length 6′, width of tread 12″, height of riser 8″. Each step is of one plank $1\frac{1}{2}$″ thick, and is supported on three strings of 2″ plank, those at the ends being set back 2″ from the ends of the steps. The third string is in the middle of the steps.

12 Draw in isometrical a truncated cone. Diameter of base 3″, diameter of top $1\frac{1}{2}$″, height 2″.

13 Draw a screw U. S. standard thread, 4″ outside diameter, 3 threads per inch, 3″ long, and make a section of a nut to correspond with it. Develop the curves of the helix.

14 Draw a square thread screw 4″ outside diameter, 1″ pitch, left-hand thread, developing the true curves. Make section of nut to fit.

NOTE.—In the section of a nut the thread is apparently the opposite hand to the thread of the screw. This is because in the elevation of the bolt the portion of the thread in view is in front, whereas the nut being in section, the *front* portion is removed, leaving the rear in view.

For further practice the pupil is advised to sketch odd pieces of machinery, or any objects that may be convenient, making careful measurements and marking them on the sketches, and afterward making drawings from these sketches. By so doing he will gain valuable experience. Besides acquiring the habit of observing, he will also learn how to measure, what to take and what not to take, as well as how to represent the objects on his drawings.

A VERTICAL ENGINE, WITH DETAILS OF PARTS.

In designing a piece of machinery, made up of a number of parts, the draughtsman first lays out a skeleton drawing, on which he maps out the movements, both as to extent, direction, and the relation the movements bear to each other. After this is done he can take up the details—that is, the drawing of each separate part.

Take as an example the vertical engine. The centre line of the shaft is first drawn, care being taken to so locate it that room will be left for the bed plate below it, and then the vertical centre lines for front and side elevations are drawn in. The next step will be to draw the centre line of the crank pin, which in the front or rear elevation would be a circle which projected upon the side elevation, or as in this case, section, would be two straight lines parallel with the centre line of the shaft, and showing the upper and lower positions of the crank pin corresponding to the extremes of travel of the piston.

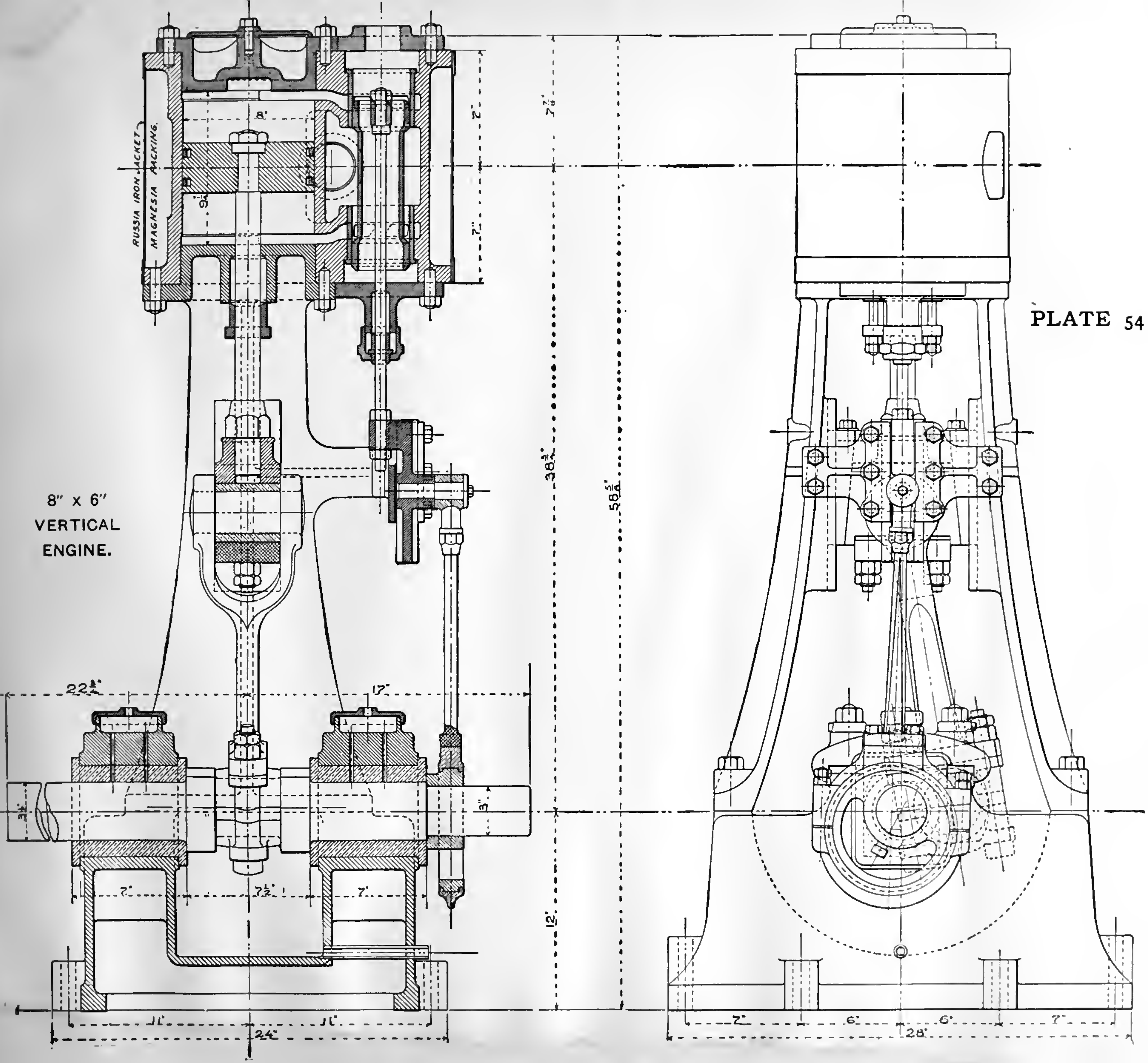
From the upper centre line, or top centre, the length of the connecting rod is measured upon the centre line which locates the "wrist pin," and from this the length of the crosshead, clearance between the crosshead and stuffing box, then the space or distance to the inside face of cylinder bottom. The next step is to lay out the clearance between cylinder bottom and the piston, thickness of piston, clearance between piston and top cylinder head, with the stroke of piston added. This gives the necessary inside length of the cylinder, and the cylinder is then drawn in, with the heads, walls and valve chest. At this point the position of the centre line of the valve stem is determined with reference to the centre line of the cylinder. The main dimensions and form of the bed plate and framing, together with the location and sizes of shaft bearings, guards, etc., are determined and drawn in for reference in detailing. Finally the guide for the valve stem is located and outlined as to form, and the position of the eccentric on the main shaft located. The draughtsman now takes up the matter of detailing, and his first step in this direction is to design the cylinder, with its steam and exhaust ports, the valve chest, valve, cylinder heads, and all the parts that go to make up the cylinder complete.

This is usually followed by the bed plates and frames on "housings," after which come the other details, until all the parts are drawn completely, and dimensions and full instructions for the shop embodied therein. In making the details, those parts that are to be made of cast iron or cast steel are grouped or kept together, and forgings are kept separate from them, the reason for this being that the pattern maker who makes the patterns from which the moulder produces the castings has nothing whatever to do with the smith's work, which is confined to the forgings, nor has the smith any business with the castings. The brass parts are kept, as far as possible, in a group or class, but the drawings for them go to the pattern maker.

Having completed all the details, the draughtsman takes his skeleton drawing in hand again and puts all the details into this drawing, thus assembling the parts and making the "general" drawing, or "assembly" drawing. In working out the details it may be necessary to alter the dimensions from those allotted to some of the parts, and it will therefore be necessary to alter the general drawing to correspond. As each drawing or sheet of drawings is completed it is checked at every point by another draughtsman, who places his initials upon it.

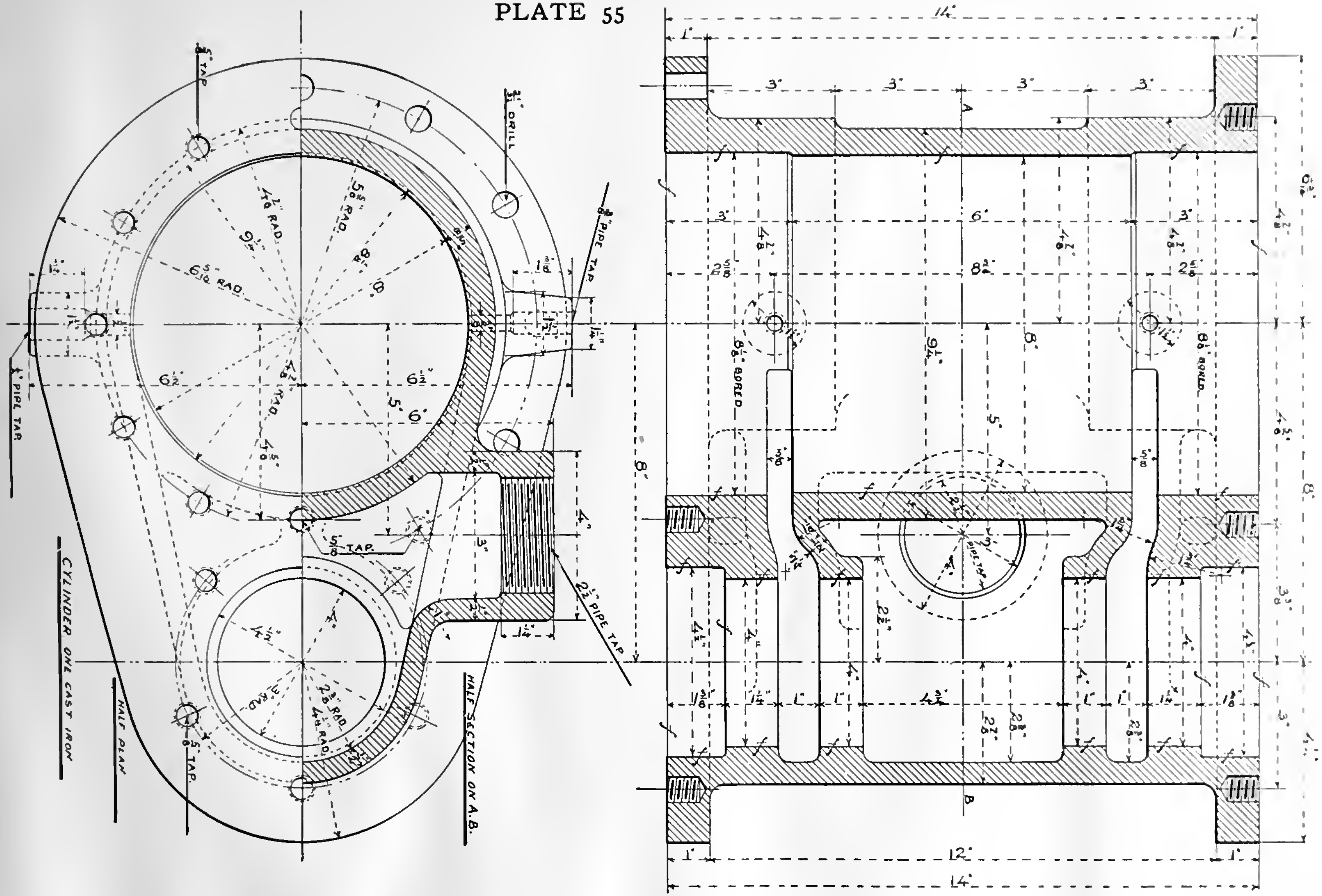
In making a set of drawings of the engine, which are included among the "shop" drawings, the pupil is expected to work as described above. Further, he should work entirely by the dimensions given, and not to transfer from the plates, by scale or otherwise, as his work will not come out right, the plates having been photographed off scale.

PLATE 54



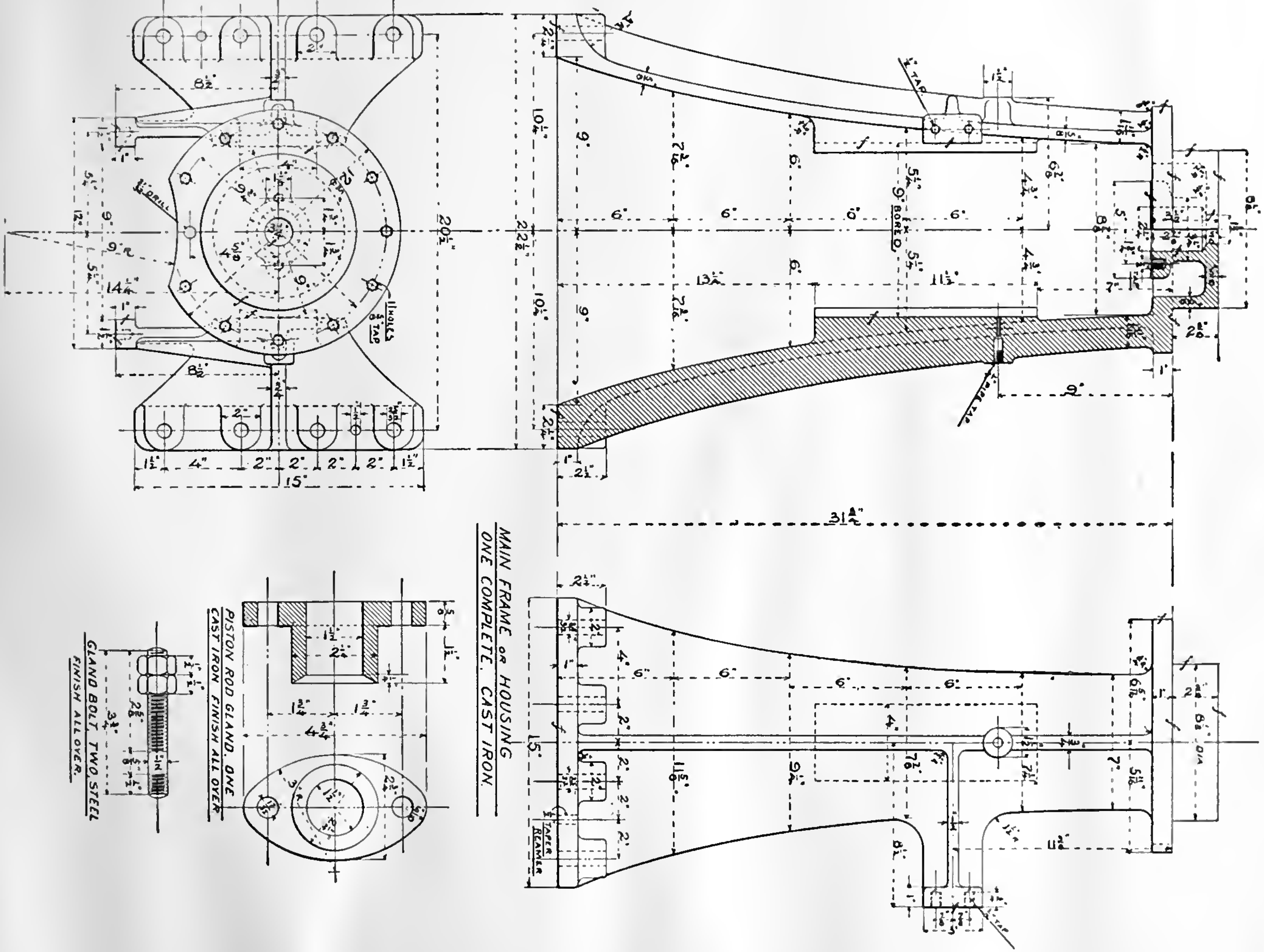
8" x 6"
VERTICAL
ENGINE.

PLATE 55

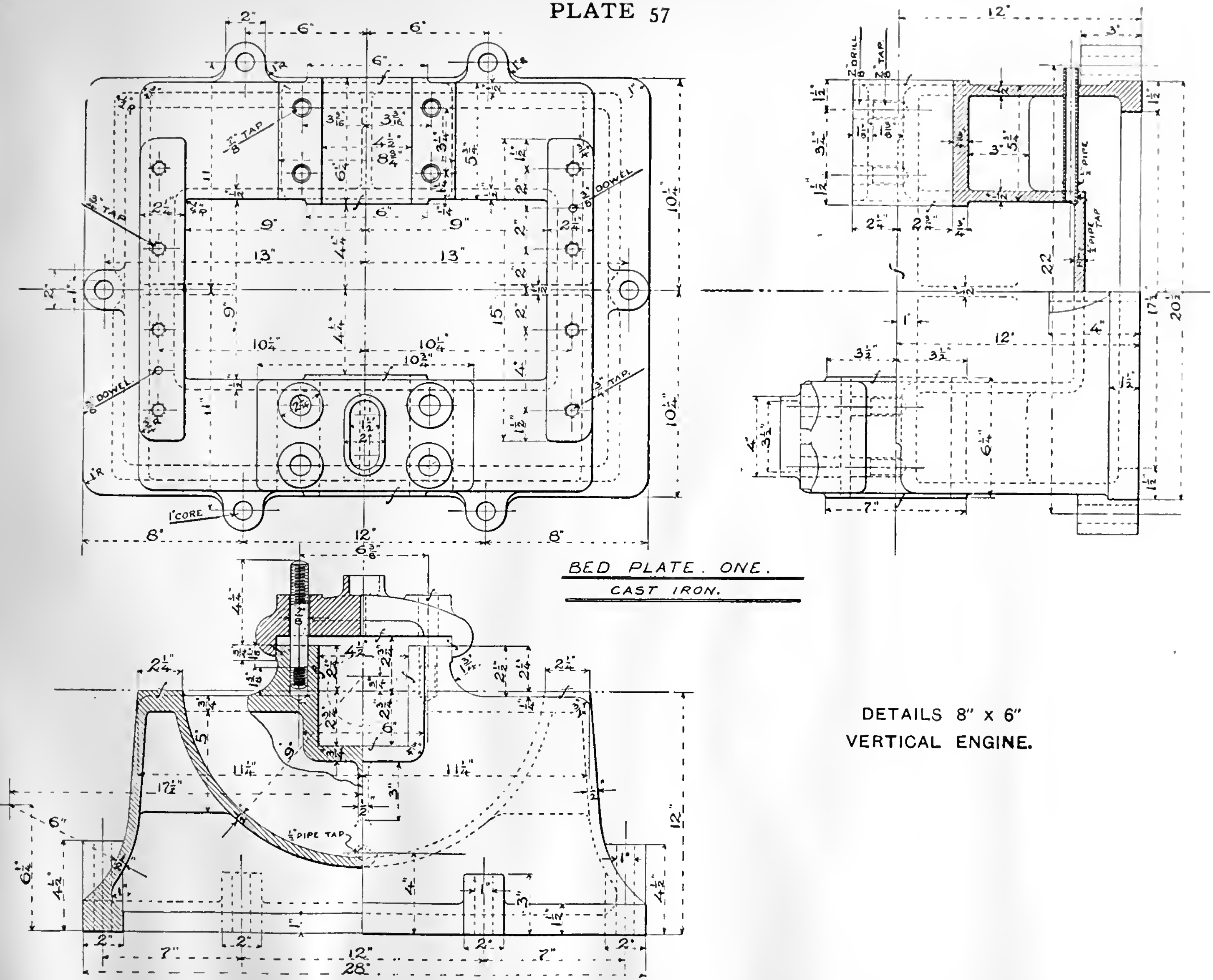


DETAILS 8" x 6" VERTICAL ENGINE.

PLATE 56



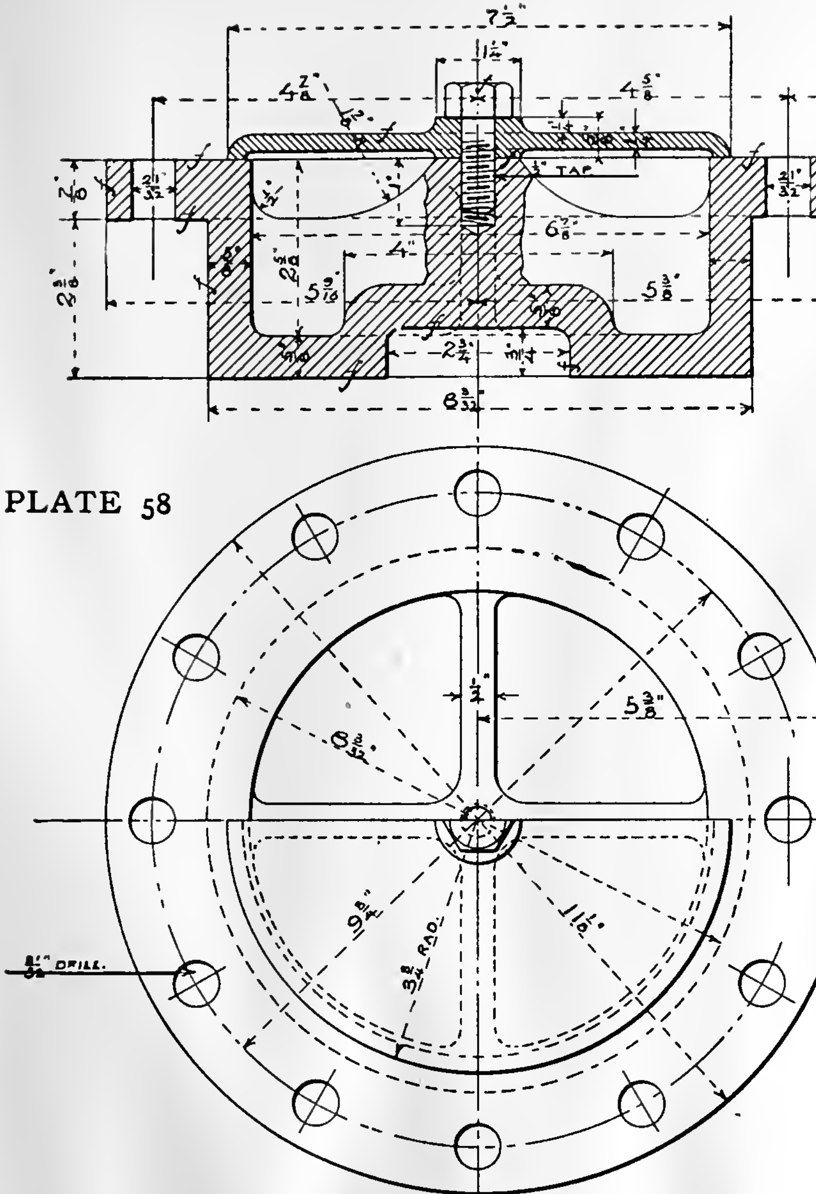
DETAILS 8" x 6" VERTICAL ENGINE.



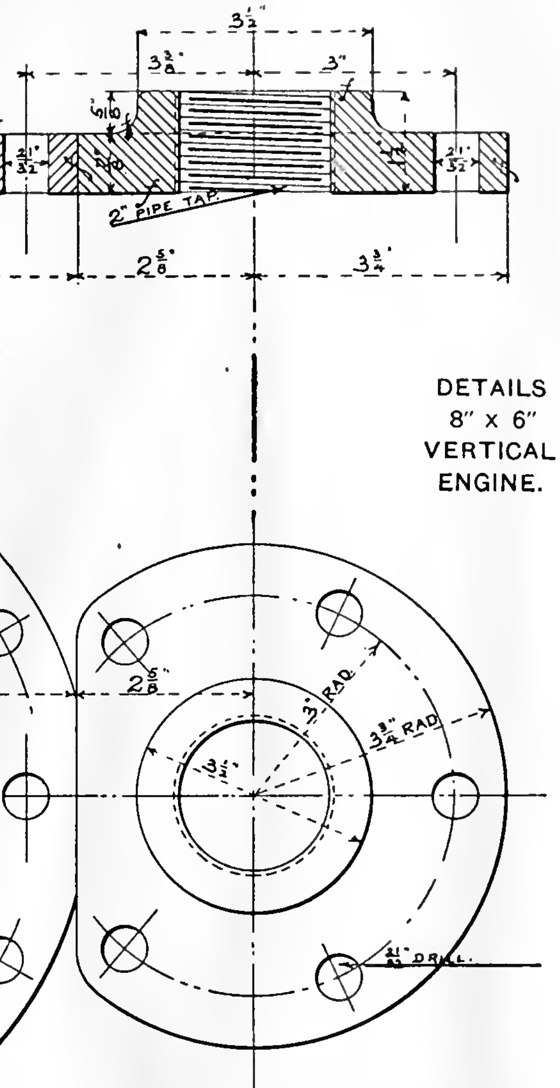
DETAILS 8" x 6"
VERTICAL ENGINE.

PLATE 58

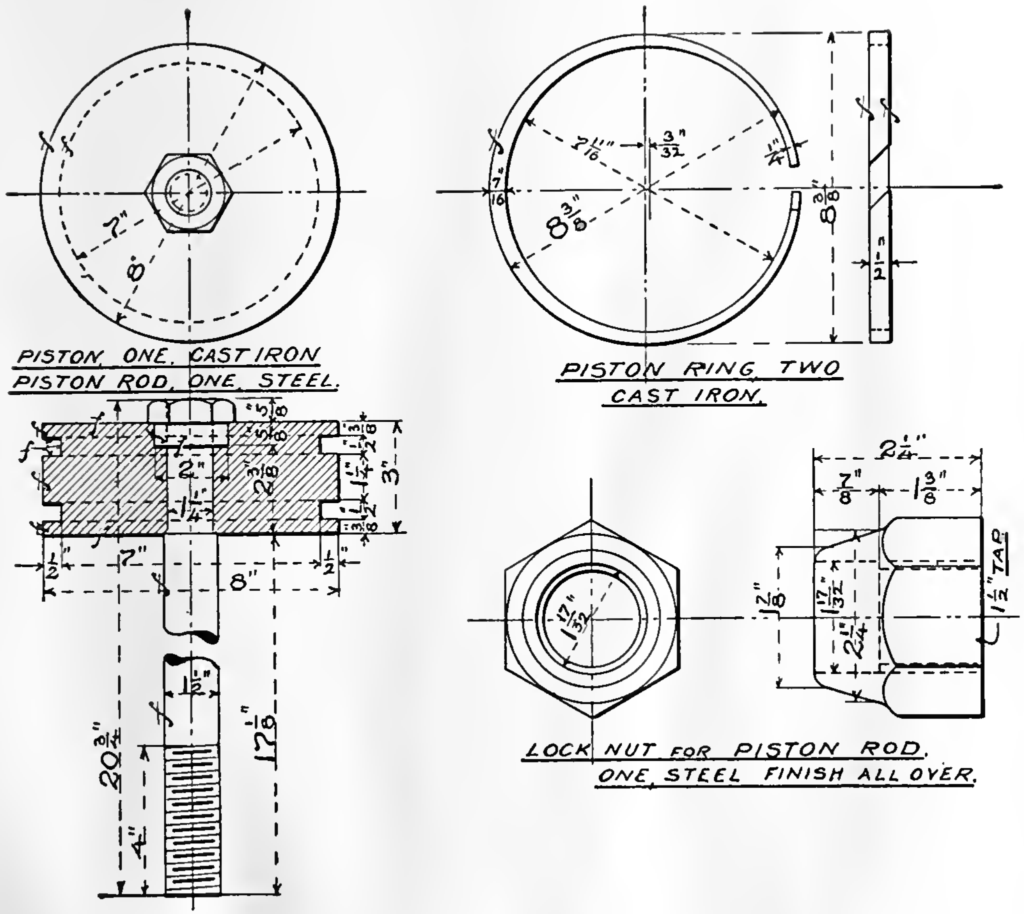
DETAILS
8" x 6"
VERTICAL
ENGINE.



CYLINDER HEAD. ONE- CAST IRON.

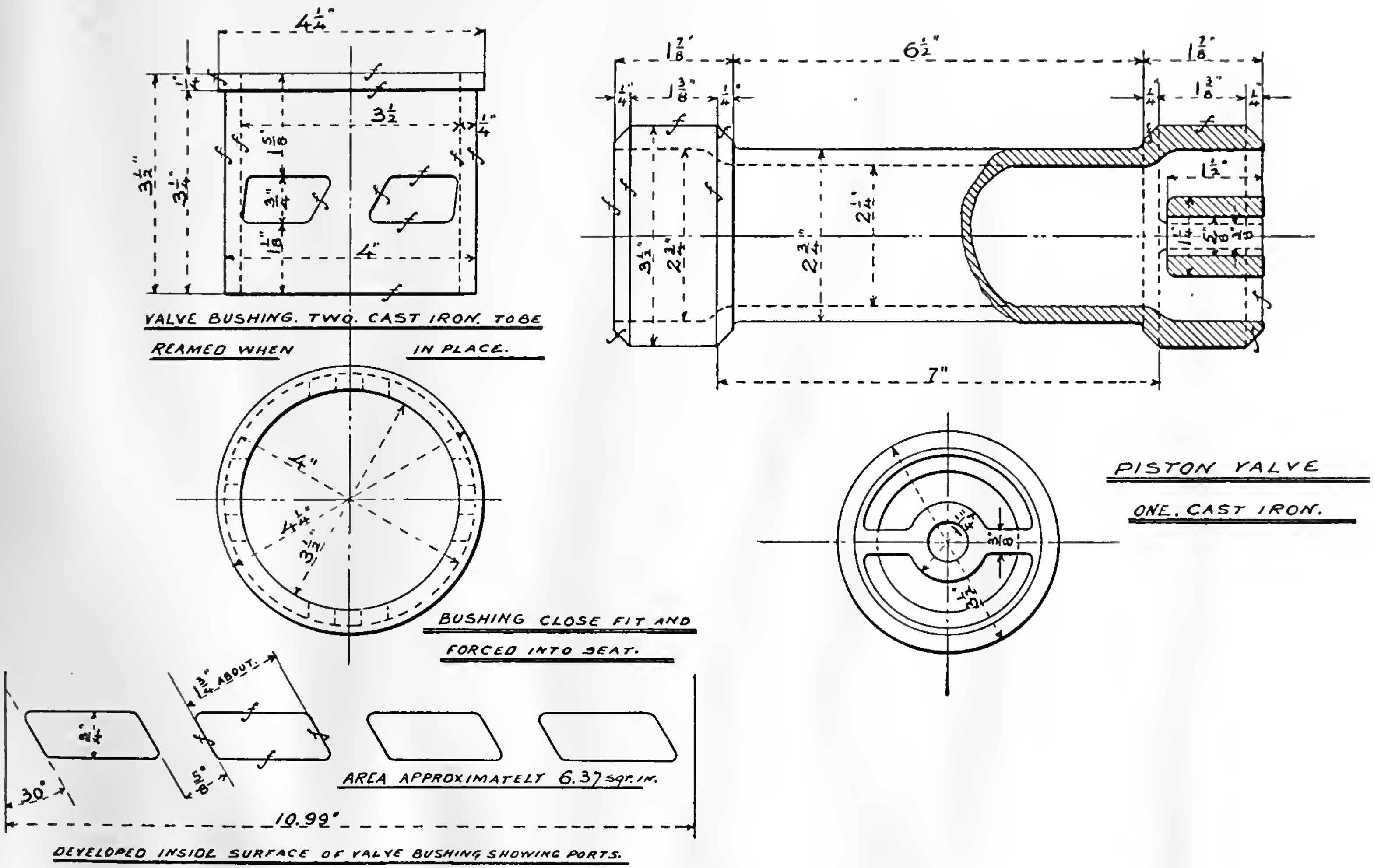


VALVE CHEST COVER. TOP END-
ONE CAST IRON.



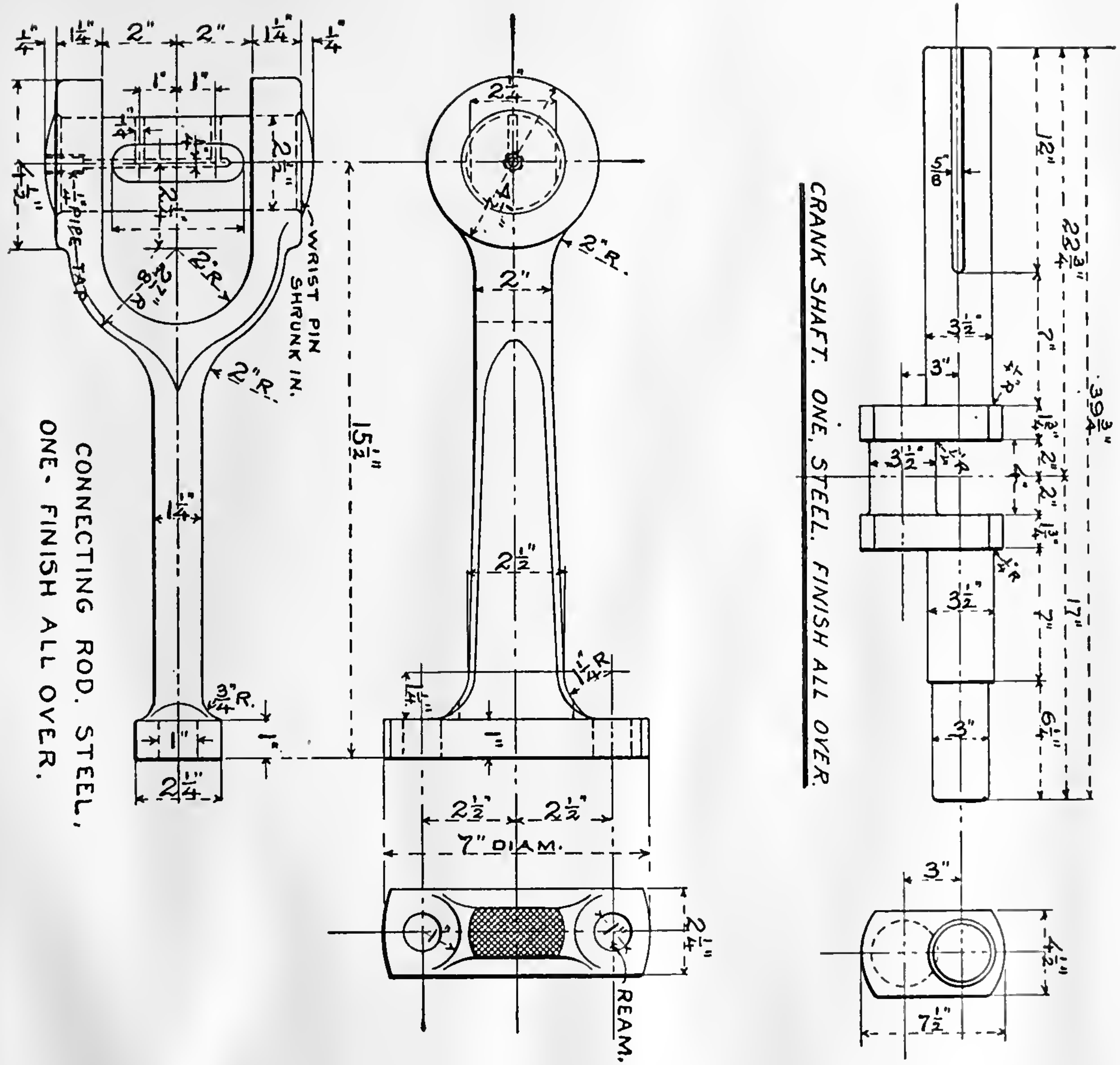
DETAILS 8″ x 6″ VERTICAL ENGINE.

PLATE 60



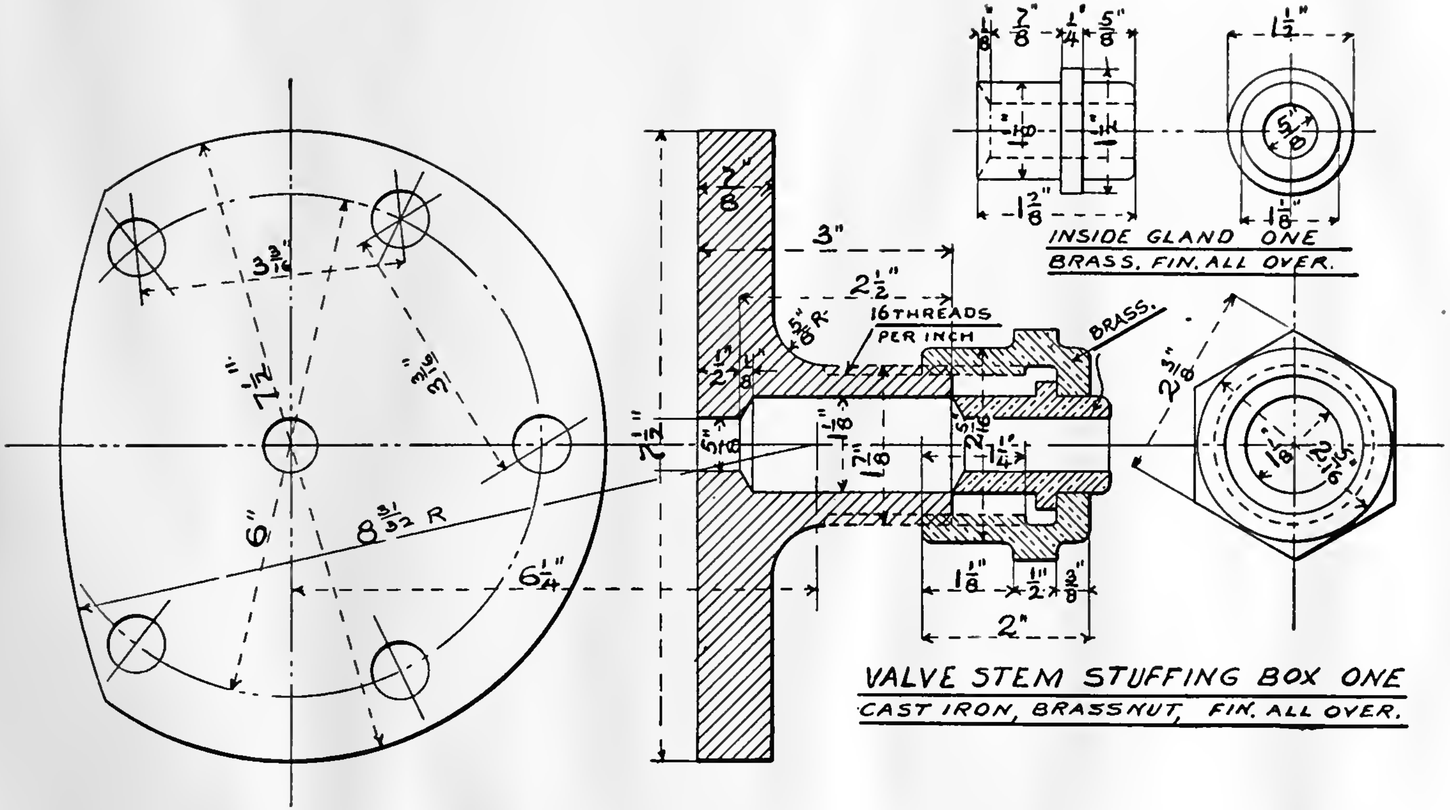
DETAILS 8" x 6" VERTICAL ENGINE.

PLATE 61

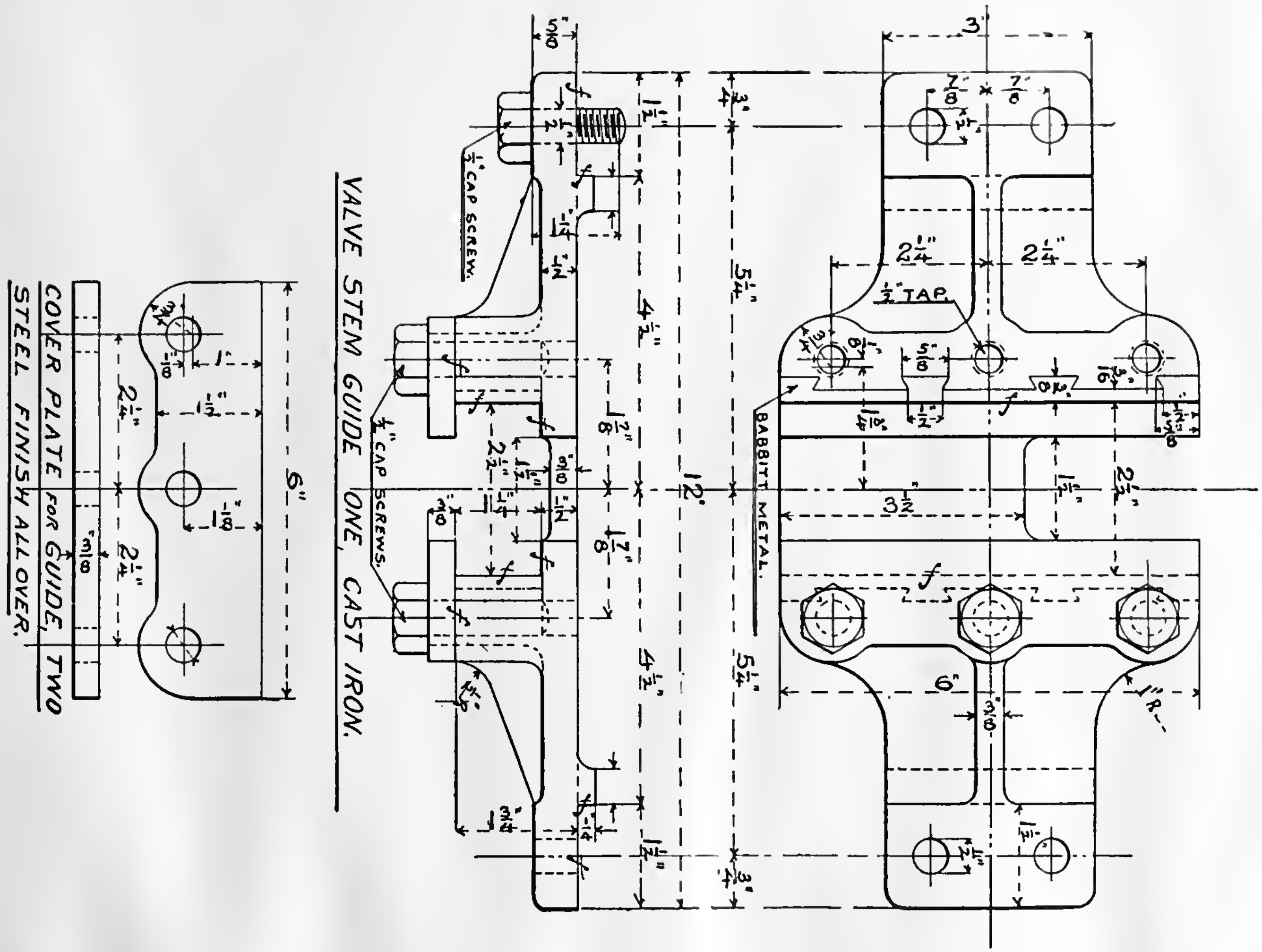


CONNECTING ROD. STEEL, ONE- FINISH ALL OVER.

DETAILS 8" x 6" VERTICAL ENGINE.

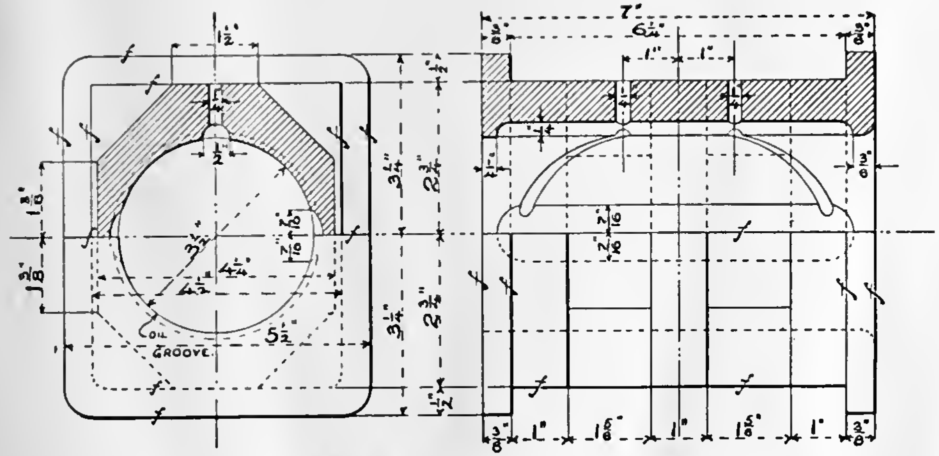


DETAILS 8″ x 6″ VERTICAL ENGINE.

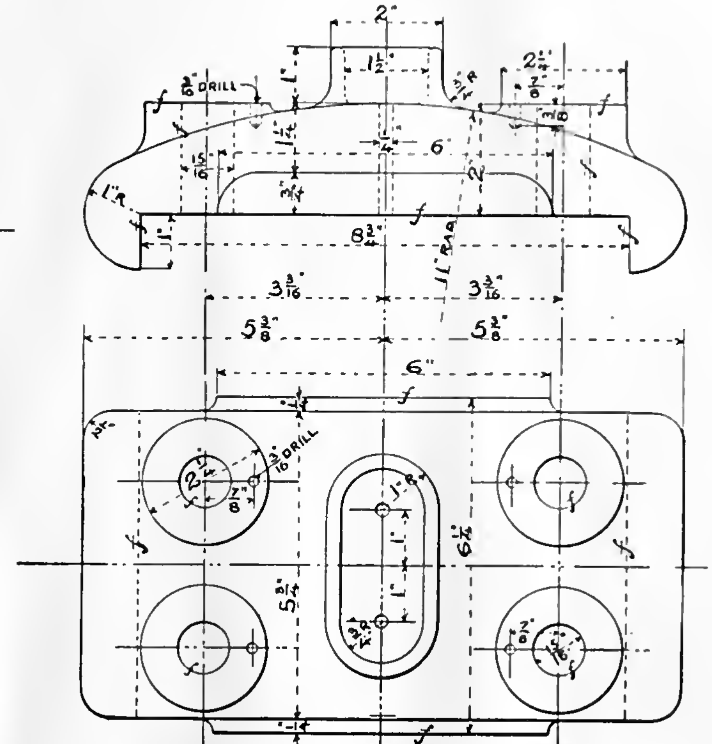


DETAILS 8" x 6" VERTICAL ENGINE.

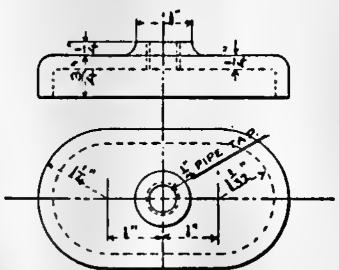
PLATE 64



BOXES FOR MAIN BEARINGS. TWO. BRASS.

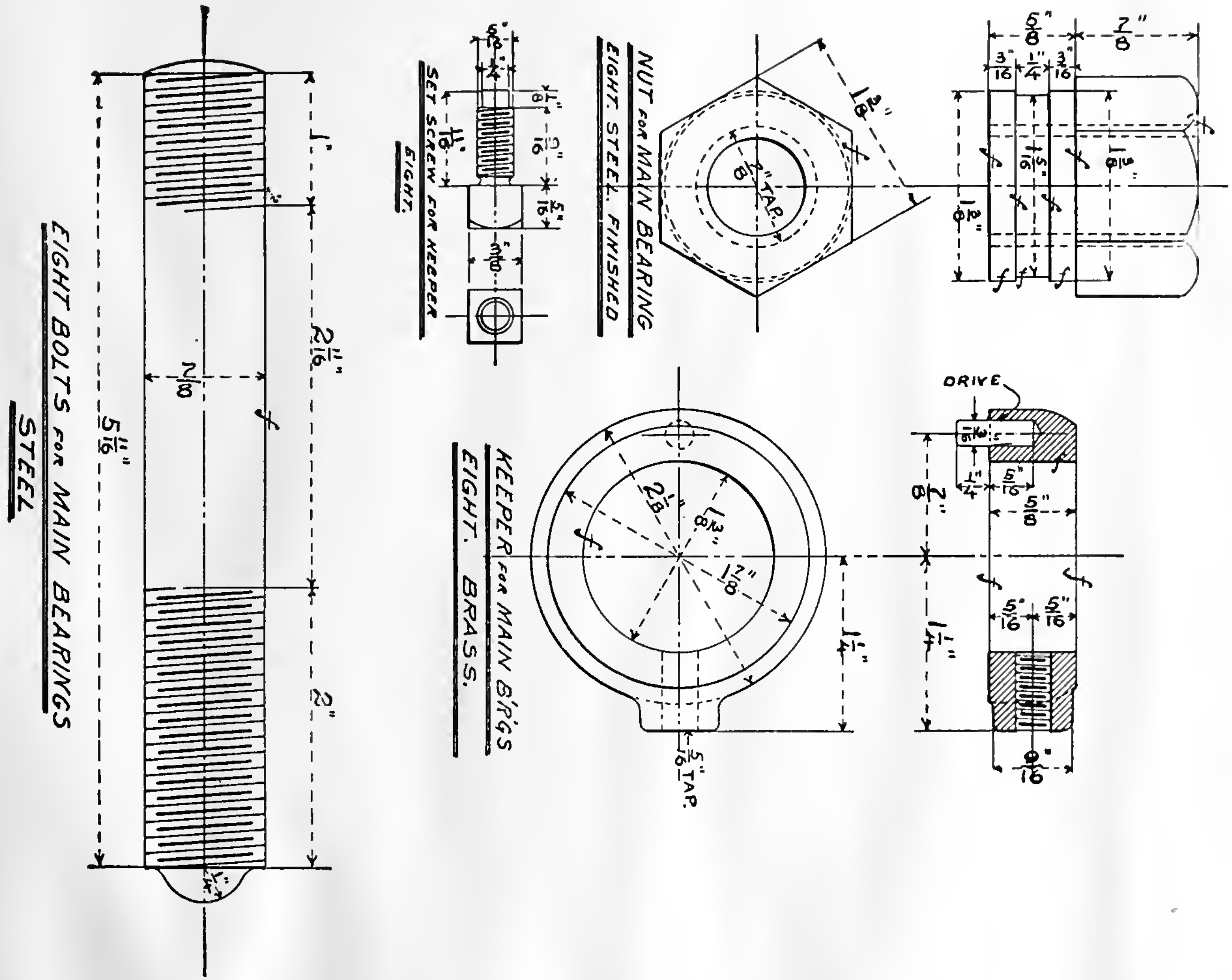


MAIN BEARING CAP. TWO. STEEL.



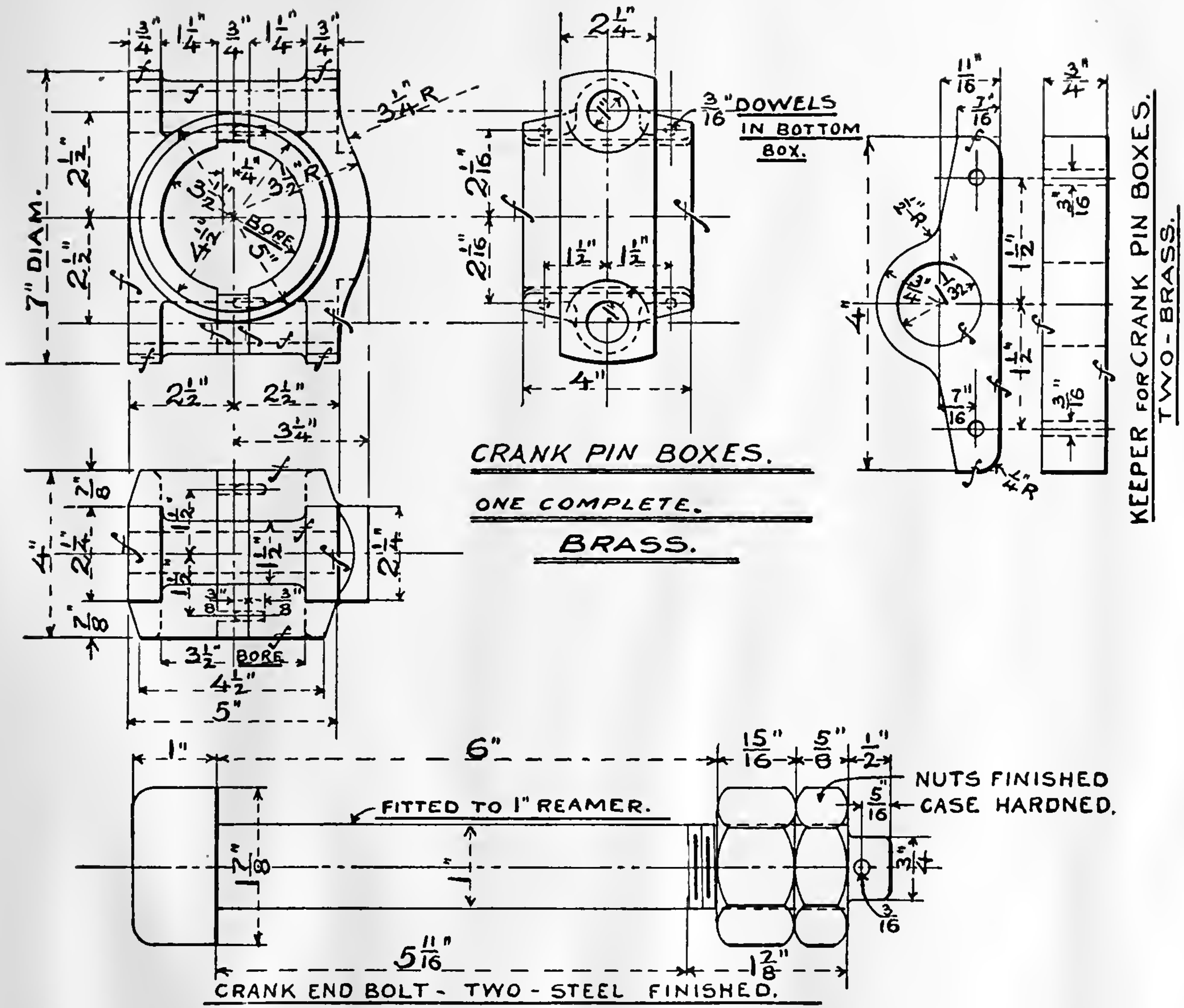
OIL CUP COVER.
TWO. CAST IRON.

DETAILS 8″ x 6″ VERTICAL ENGINE.

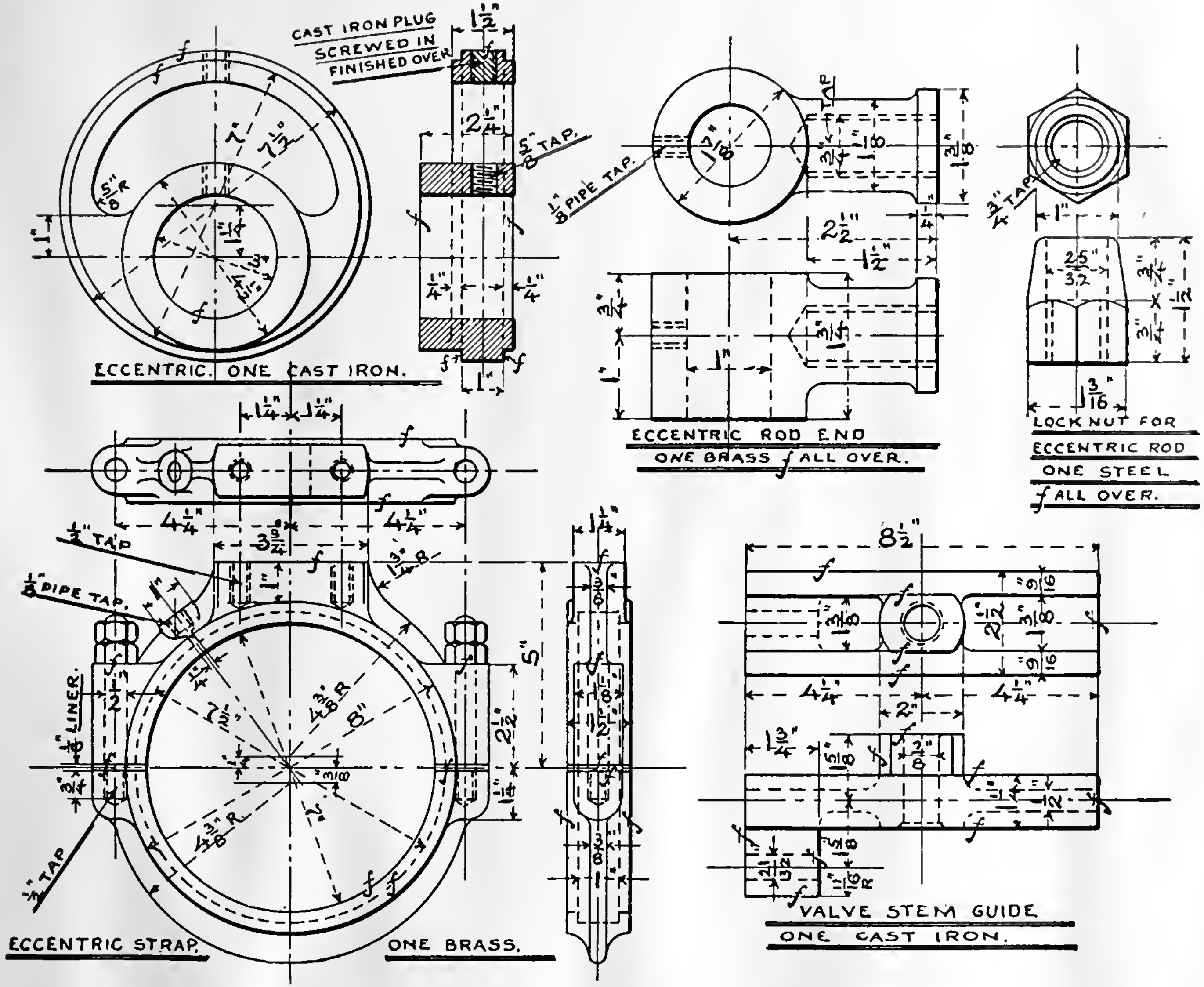


DETAILS 8" x 6" VERTICAL ENGINE.

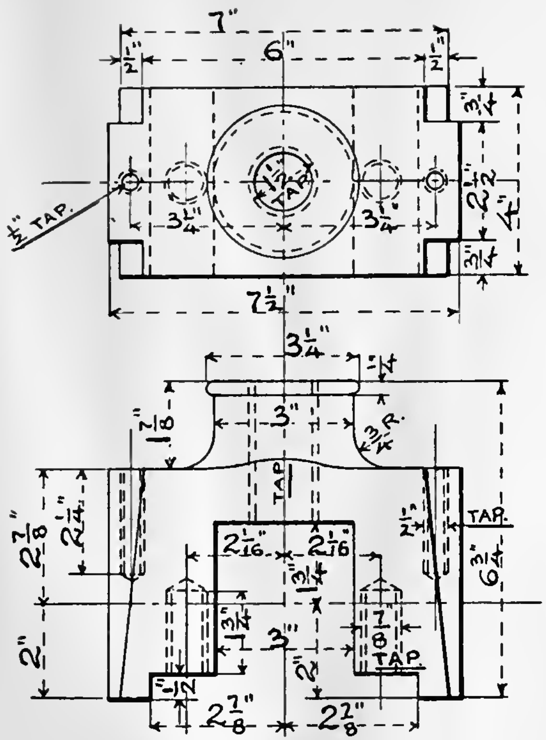
PLATE 66



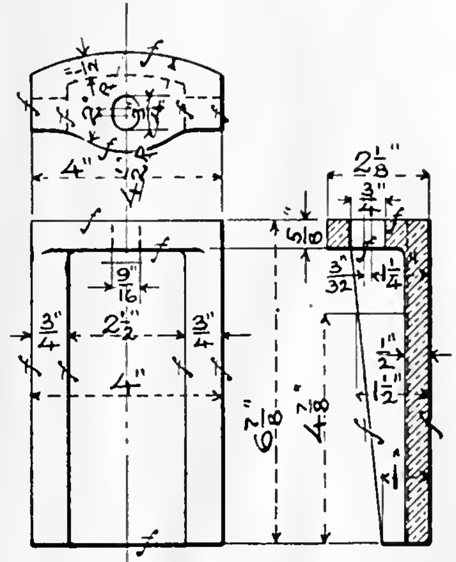
DETAILS 8″ x 6″ VERTICAL ENGINE.



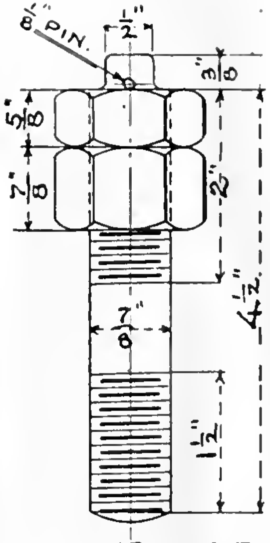
DETAILS 8″ x 6″ VERTICAL ENGINE.



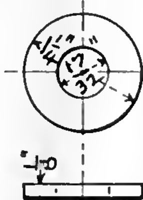
CROSS HEAD, ONE CAST IRON.
FINISHED ALL OVER.



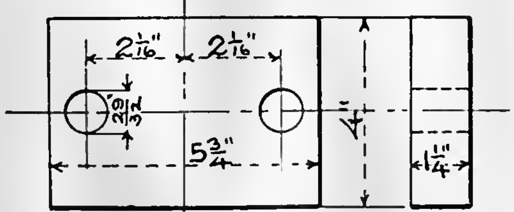
CROSS HEAD GIB, BRASS
TWO *f* WHERE SHOWN.



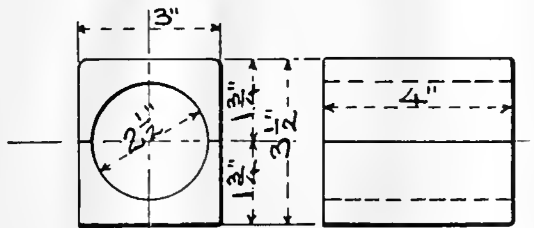
KEEPER STUD TWO
STEEL, FINISHED



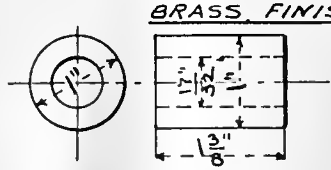
WASHER FOR
GIB BOLT TWO,
STEEL, FINISHED



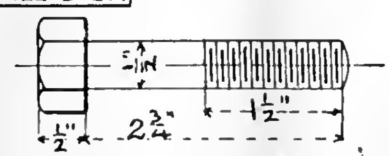
CROSS HEAD KEEPER, STEEL,
ONE, FINISHED ALL OVER.



WRIST PIN BOXES, ONE PAIR
BRASS, FINISH ALL OVER.

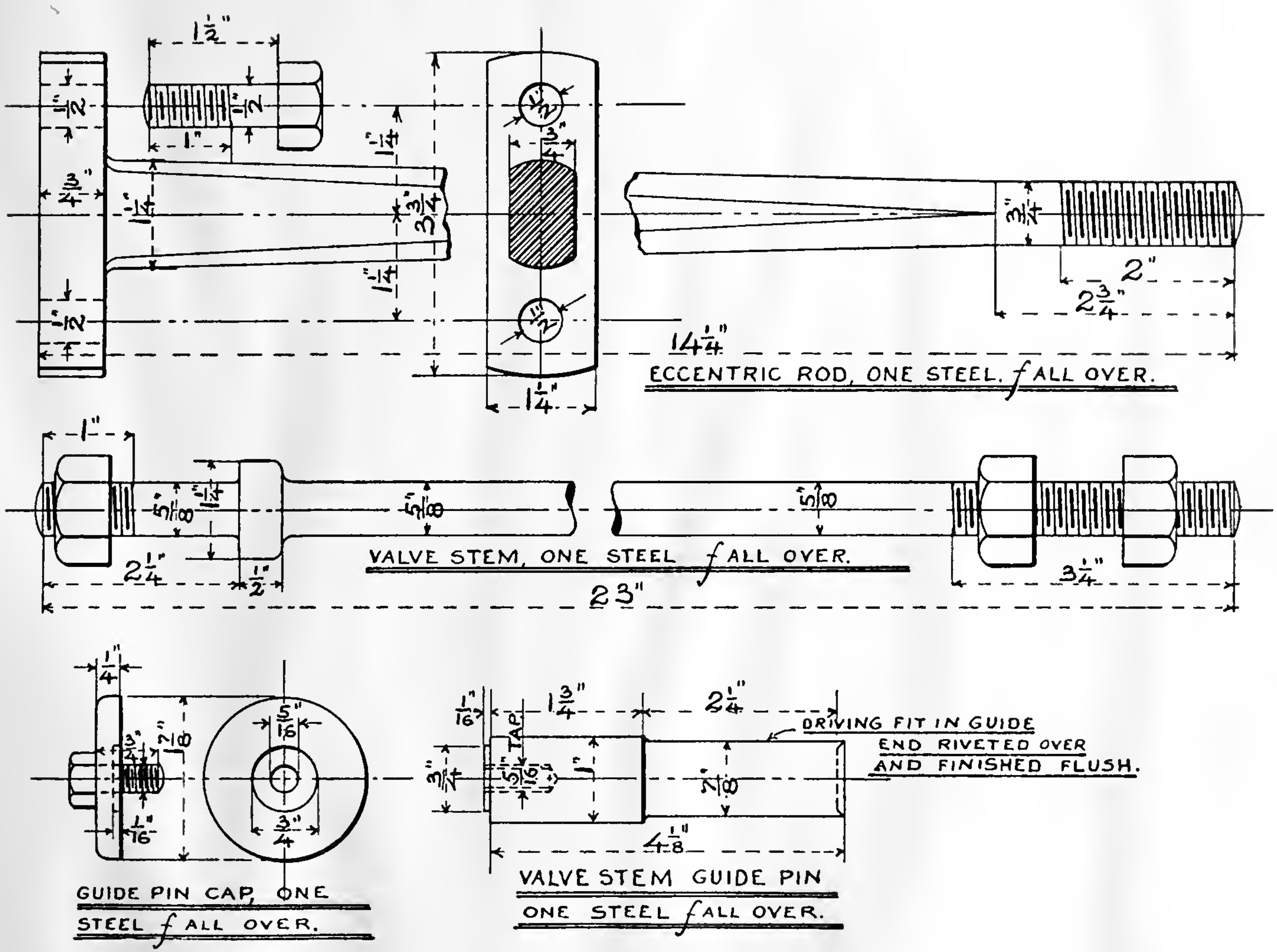


FILLER FOR GIB, TWO,
BRASS, FINISHED.

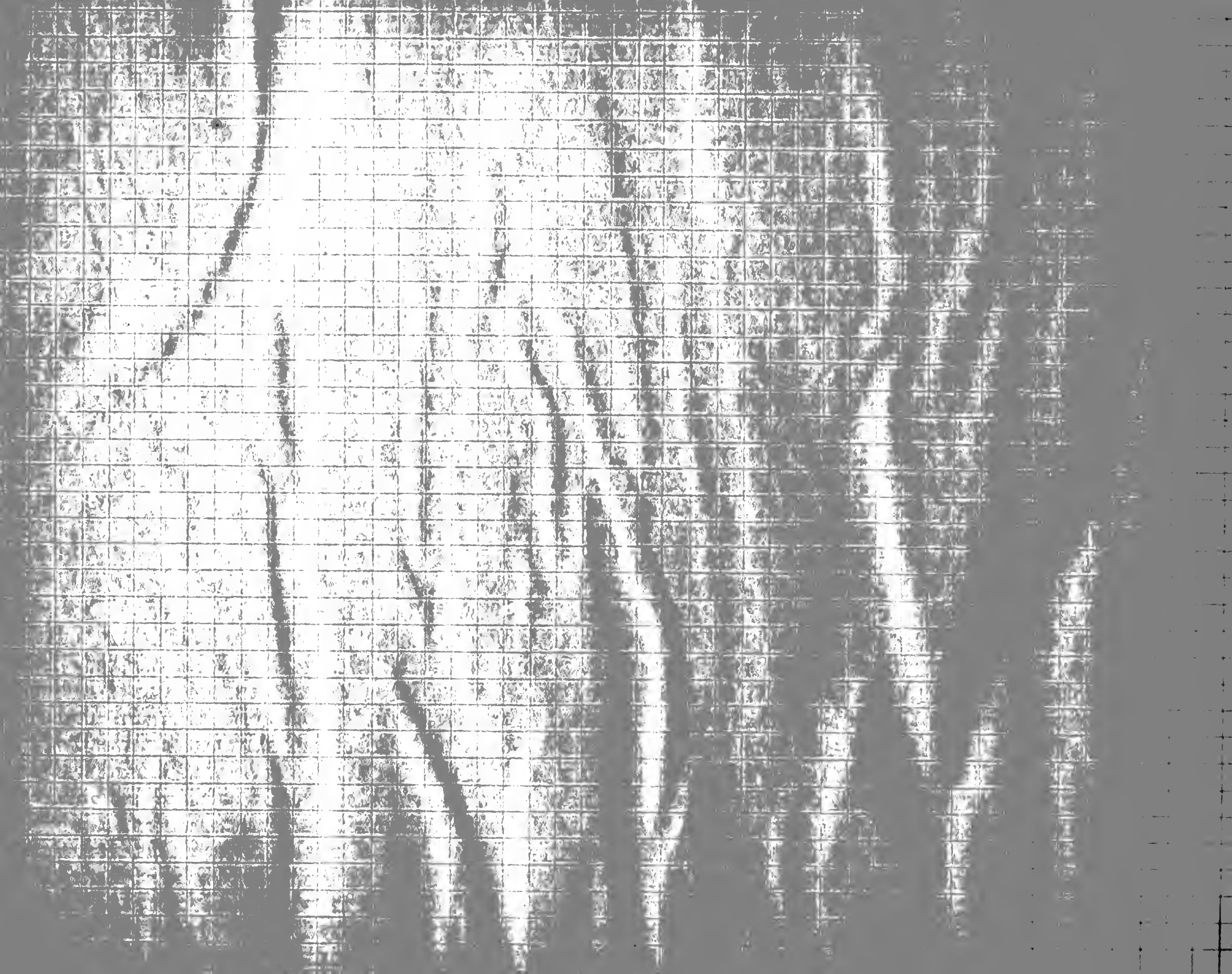


GIB BOLT TWO, STEEL
FINISHED.

DETAILS 8" x 6" VERTICAL ENGINE.



DETAILS 8" x 6" VERTICAL ENGINE.



INDEX.

PLATES OF VERTICAL ENGINE AND DETAILS.