MACHINERY'S REFERENCE SERIES

EACH NUMBER IS A UNIT IN A SERIES ON ELECTRICAL AND STEAM ENGINEERING DRAWING AND MACHINE DESIGN AND SHOP PRACTICE

NUMBER 85

MECHANICAL DRAWING

By Oscar E. Perrigo

PART I

INSTRUMENTS—GEOMETRICAL PROBLEMS

CONTENTS

49-55 Lafayette Street, New York City

CHAPTER I

INSTRUMENTS USED IN MECHANICAL DRAWING

To the young mechanic, or the man who aspires to be a first-class workman, there is no more important study that should claim his attention than Mechanical Drawing, or at least such a portion of it as will give him a fair elementary knowledge of this subject, qualifying him for making simple detail drawings and enabling him to read readily and understand correctly any of the mechanical drawings which may come to him in the course of his practical work in the shop.

There has never been a time when drawings were as generally used in all the mechanical arts and in general manufacturing enterprises as they are at the present time. Wherever there are ideas to be developed, articles to be manufactured, machinery and many other products to be marketed, drawings of some kind, and nearly always mechanical

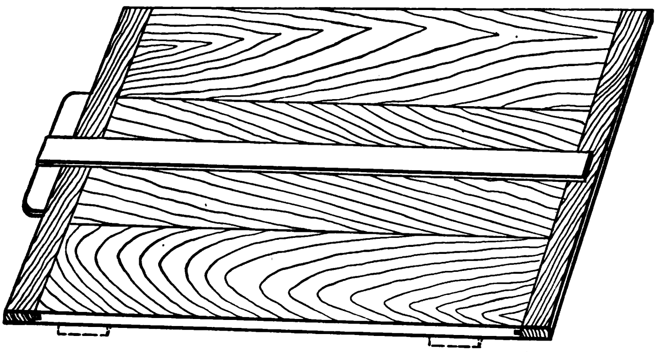

Fig. 1. Drawing Board

drawings, are in demand. There is not the slightest reason why any bright and intelligent man cannot learn to make simple mechanical drawings if he will apply himself with energy to the instruction given in this series, and avail himself of the advantages thus offered.

Considered in an elementary manner, drawing is the method by which we represent the forms of solid objects by lines on a plane surface, as, for example, on the paper fastened upon the drawing board. For mechanical purposes there are two general classes of drawings. First, those made by hand only, without the aid of any instrument but the pen or pencil, and which are called free-hand drawings. In mechanical engineering they are usually called sketches. Second, purely mechanical drawings, which are made with the aid of the drawing board, T-square, triangles, measuring scales and the usual drawing instruments. All instruments, appliances and accessories necessary to the production of the drawing are included in the general term drawing instruments, except the various kinds of paper, cloth, etc., upon which the drawing is made. These latter are included under the head of drawing materials.

The Drawing Board

The drawing board should be made of well-seasoned soft pine of first quality, from ¾ to 1¼ inch thick, according to its dimensions. For use in the study of drawing it should be ¾ inch thick, and at

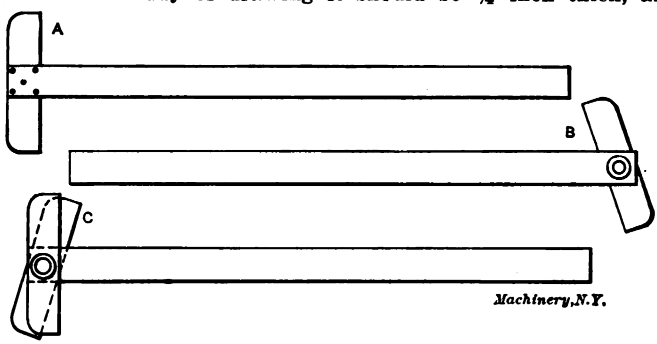

Fig. 2. Different Types of T-Squares

least an inch wider and longer than the paper used. The board may be composed of several strips glued together edgewise to form the principal part of the board. If of moderate dimensions, it should have end pieces of the same thickness as the board proper. These are fitted across the end of the board by a tongue and groove, and fastened to the board by comparatively long nails, but must not be glued. (See Fig. 1.)

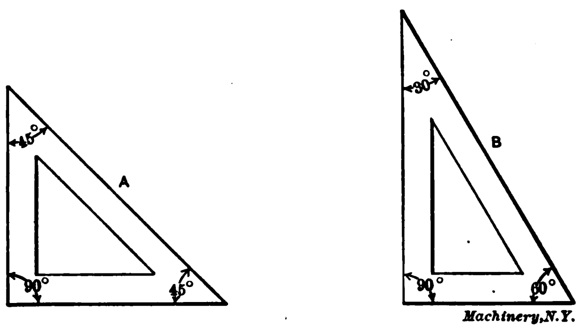

Fig. 3. Usual Types of Triangles

Thumb tacks are used for fastening the drawing paper to the drawing board. They are so called because they are formed with very sharp points and comparatively large heads so as to adapt them for being pressed into place by the thumb.

T-Squares, Triangles and Curves

The T-square consists primarily of a thin ruler used as an aid in drawing straight pencil or ink lines, and having secured to it at one end a head, normally set at right angles to it, and adapted to be held against the edge of the drawing board with the left hand. The impossibility of keeping the corners of a board exactly square precludes its use for drawing vertical lines. T-squares are made in two forms: First those with a fixed head as shown at *A*, Fig. 2, and those with a swivel or pivoted head, secured in any desired position by a thumb nut, as shown at *B* and *C*. In Fig. 1 the T-square is shown in its normal position on the drawing board as when in use by the draftsman.

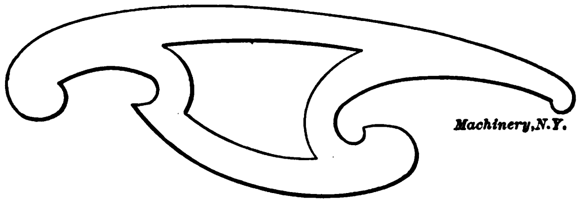

Fig. 4. Draftsman's Curve

Ordinarily all horizontal lines are drawn by the aid of the T-square held in the position shown in Fig. 1, and moved up or down as may be necessary, the head always in contact with the left edge of the drawing board. Vertical and inclined lines are usually drawn with the aid of triangles, usually called "angles" by draftsmen. These are made of the forms shown in Fig. 3, that is, the one shown at *A* having one angle of 90 degrees and two angles of 45 degrees, and the one shown

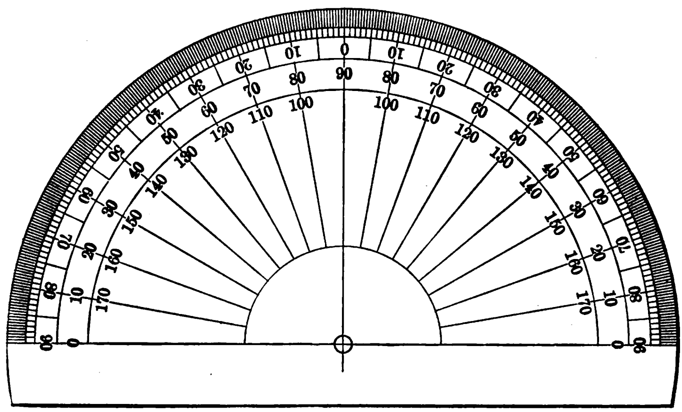

Fig. 5. Simple Protractor Used by Draftsmen

at *B* having one angle of 90 degrees and the other two of 30 and 60 degrees. They are 1/16 to 1/8 inch in thickness and from 3 to 15 inches in length, according to the kind of drawing for which they are used. They are made of various kinds of hard wood, hard rubber, celluloid or similar substances. For special work, triangles of many different angles are used, but are so formed that in nearly all of them there is one angle of 90 degrees.

Curves are made of materials similar to those used for triangles, and are of a great variety of sizes and forms. The most common are those consisting of a portion—usually one-fourth—of an ellipse, a half of a parabola, or a part of an involute. For special purposes they are made of any curve called for by the drawing to be made. A common form is shown in Fig. 4.

Protractors

The protractor is usually made of German silver, and forms one-half of a circle, although protractors are not infrequently made of a

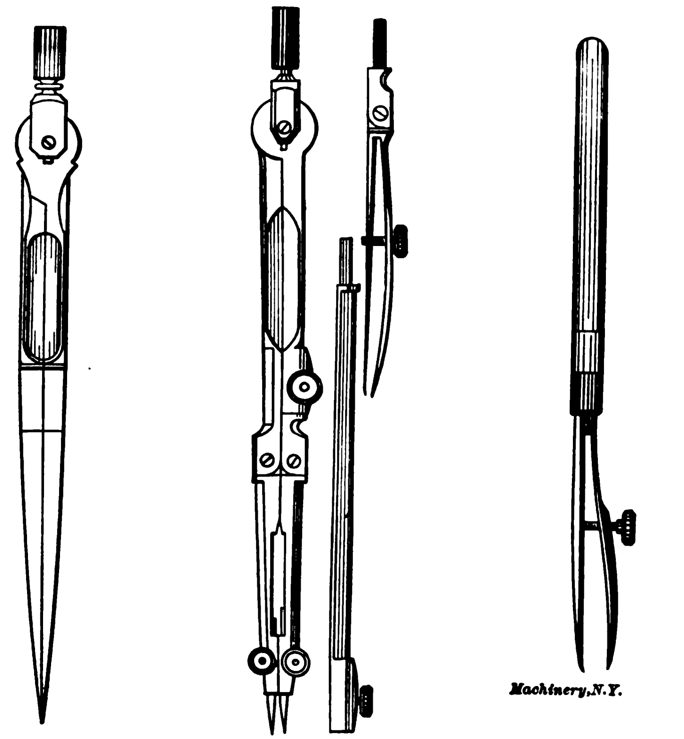

Fig. 6. Plain Dividers

Fig. 7. Dividers with Pencil, Pen and Lengthening Bar

Fig. 8. Regular Type of Drawing Pen

greater portion of a circle, even of the entire circle. In some instances they are provided with an arm pivoted at the center and swinging around the circle. The use of the protractor is to measure, or to set off, angles of any required number of degrees. The smaller protractors are divided into degrees, while larger ones show half or quarter degrees. Those with a swinging arm are usually provided with a vernier scale by which small fractions of degrees, three or five minutes, for example, are read. A good example of this instrument in its simpler form is shown in Fig. 5.

Dividers

Dividers are frequently called "compasses." They are of a number of different forms, according to the purpose for which they are used. With the exception of the T-square, angles and pencils, they are the most frequently and continuously used of any of the draftsman's instruments. The most simple form is that called plain dividers, which are shown in Fig. 6. The upper portions of the legs are jointed to each other by an adjustable friction joint. The lower ends of the legs are made of steel and terminate in round and very sharp steel points. This form of dividers is used for setting off distances when the scale cannot be applied directly to the drawing, for spacing around a circle and for similar work.

A type of dividers quite generally used in mechanical drawing is shown in Fig. 7. In the cheaper kinds one leg is made solid and one removable. Fitted to the latter is a pencil holder, a pen point and a

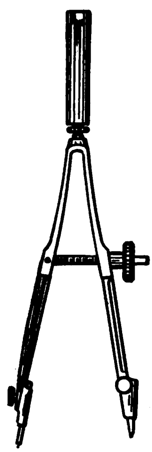

Fig. 9. Bow Pencil

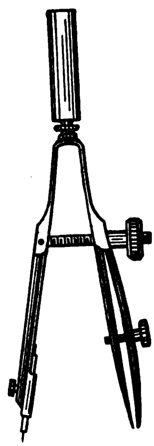

Fig. 10. Bow Pen

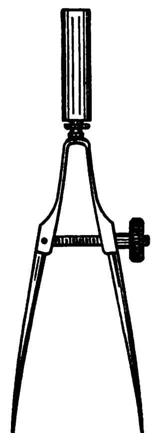

Fig. 11. Spacing Dividers

lengthening bar. The last piece is used for extending the radius of the divider points to a greater distance than is possible by means of the legs alone. The pencil holder and the drawing pen points should be provided with joints. In the better class of instruments both legs are made removable, and the leg carrying the round steel point is so constructed as to hold a small needle which will make but a very fine hole in the drawing paper. These parts are called "needle points," and dividers having this construction are commonly called "needle point dividers."

The bow pencil and bow pen are properly considered as small dividers since they are used for drawing circles. As their small size precludes the use of separate pencil and pen points, interchangeable at will, two complete instruments are necessary. The construction of the bow pencil is shown in Fig. 9. It is made of steel, the upper half of each leg being a spring connected at the top and so constructed that the tension keeps the legs separated, except as confined by the adjusting screw. The bow pen is of similar construction, the only difference being that suggested by its name; that is, it is fitted with the blades of a drawing pen instead of a socket for carrying a pencil. It is shown in Fig. 10.

The spacing dividers shown in Fig. 11 are of a construction similar to that of the bow pencil and bow pen, but are provided with two

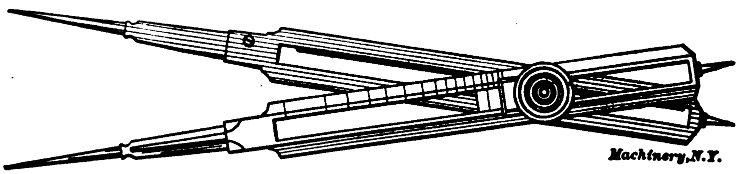

Fig. 12. Proportional Dividers

slender, round and very sharp points. Their use is similar to that of the plain dividers shown in Fig. 6, but for much smaller and more accurate work.

Proportional dividers are made with two entirely separate legs having steel points at each end. These legs are joined to each other by a screw and thumb-nut sliding in a slot formed in each leg for considerably more than half its length, as shown in Fig. 12. The pivot screw passes through a compound sliding block formed of two parts, each

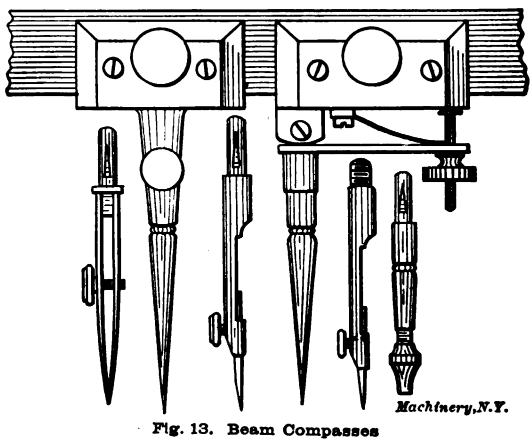

Fig. 13. Beam Compasses

fitting the slot in its respective leg, by which construction the joint or pivot of the instrument can be changed to any point desired. Thus the double pointed legs form practically two dividers the relative lengths of whose legs are adjustable at will. If the pivot screw is so placed that its distance from one point is one-third of the entire length of the leg from point to point and clamped in that position, the dividers are set at a proportion of 1 to 2; that is, if the divider legs are opened until the shorter leg points are one inch apart, the points of the longer will be two inches apart. It follows that by shifting the position of the pivot screw any other relative proportion can be obtained. The position of the pivot screw is determined by a set of graduations upon one of the legs, to which a single line upon the sliding block may be adjusted.

Beam compasses consist of a beam, or strip of hard wood carrying two heads provided with needle point, pencil holder and pen. The head carrying the needle point is usually clamped at one end of the beam or bar, while the one carrying the pencil holder or pen is adjusted at any point along the beam that may be required for the radius of the arc or circle to be drawn. (See Fig. 13.)

Drawing Pens

The regular form of drawing pen is shown in Fig. 8. The pen consists of two blades; the blades are so constructed as to normally spring

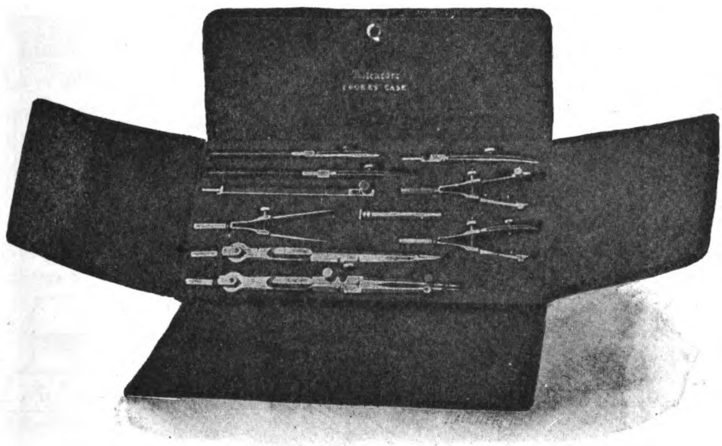

Fig. 14. Case with Drawing Instruments in Place

away from each other, and are held together and properly adjusted to the desired width of line by a small thumb screw. The inking pens of the dividers and beam compasses are similarly constructed.

These instruments are usually sold in sets, and for their proper care and preservation they are contained in cases lined with velvet and provided with suitable depressions or recesses fitting the instruments contained in them. Such a case, with the instruments in place, is shown in Fig. 14.

Scales

The draftsman's scale is understood to be any piece of paper, wood, steel, celluloid or similar composition, so divided as to measure distances on a drawing. Ordinarily the draftsman's scale is either flat, with beveled edges, or triangular, with the flat sides relieved by semicircular grooves. Occasionally he uses scales of paper or thin bristol board. The flat form of scale, shown in Fig. 15, has both edges beveled to a very acute angle so that the graduations and figures are very easily read. While the flat scale has but two faces upon which graduations can be made, the triangular scale shown in Fig. 16 has six faces for graduations.

There are two classes of graduations. The first includes graduations for "full size" drawings, that is, drawings made exactly the same size as the actual parts they represent, and second, graduations that are adapted for drawings made on a scale much smaller than the parts represented.

In the first class the inches are divided into eighths, sixteenths, thirty-seconds and sixty-fourths, or tenths and hundredths; in the second, graduations are made for so many inches to the foot, as 1½, 3 or 6 inches to the foot, which are the ordinary scales used by mechanical draftsmen, and for so many feet to the inch, which, in addition to the above are used by architects, civil engineers, etc.

Pencils

Drawing pencils are usually made of hexagonal form to avoid the tendency of a round pencil to roll off an inclined drawing board. The

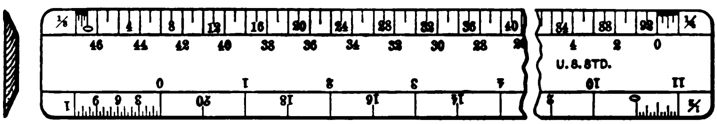

Fig.15

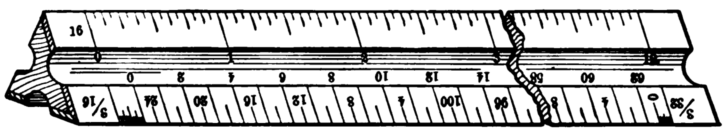

Fig.16 *Machinery,N.Y.*

Figs. 15 and 16. Drafting Scales

usual grades of pencils for mechanical drawings are those marked HH, HHHH, and HHHHHH. Some manufacturers simplify these marks by making them read 2H, 4H and 6H. The higher the number the harder the lead of the pencil.

Generally the 6H pencil is used, as very fine and clear lines can be made with it; more accurate measurements can be made from the lines made with it; and the fine point of the pencil will last much longer than if a softer pencil is used. The drawing pencil is sharpened with a much longer point than one for writing or free-hand sketching. The entire length of the pointed form should be about 1¼ inch. The lead being much harder than in pencils used for writing, it is customary to form the desired point by rubbing it upon No. 0 sandpaper glued to a flat stick about ¼ by 1 inch, and 6 or 8 inches long.

It is often said that "the best is always the cheapest," meaning that in important matters, when good wearing qualities and efficiency are considered, the greater investment is a good one. This is true of drawing instruments, since good ones have been known to remain perfectly serviceable through the use of two generations of draftsmen.

While all drawing instruments and accessories should be of the best construction to insure accuracy and lasting qualities, this is particularly required of dividers of all the different forms. Scales, protractors, etc., must necessarily be very accurate and only those of first-class construction should be purchased. All instruments should be well taken care of and kept clean, so as to be at all times ready for use.

There are a great many kinds of drawing-paper made to suit various purposes. It is most convenient for the student to use paper made and sold in sheets. Manila paper is commonly used for drawings, and is made either smooth or with a slight grain. A smooth-surfaced manila paper is, however, not as suitable for pencil work as a paper having a slight grain or roughness. Weston's linen ledger papers are very good for making neatly appearing drawings. These papers are sold at a medium price. German drawing-papers are usually of good quality and are sold at a reasonable price. They have a good hard surface, capable of standing hard usage under the rubber, and are made in all the usual sizes. More complete and detailed information relating to drawing papers will be contained in Part IV of this treatise, MACHINERY's Reference Series No. 88.

The best and most convenient drawing ink the student can use is that sold ready made in bottles. Higgins' inks are probably the most commonly used of all black drawing inks.

CHAPTER II

GEOMETRICAL DEFINITIONS

Mechanical drawing is based, fundamentally, upon elementary geometry, without a thorough knowledge of which no man can claim to be a properly qualified mechanical draftsman. Without such knowledge, he may secure a position in a drafting-room and succeed in holding a subordinate position, but he will always be considered a copyist rather than a draftsman, and never rise to the position of a designer of machinery. In the actual and every-day practice of mechanical drawing, the principles of geometry are constantly in use, and the man who is not thoroughly and perfectly familiar with them is at a very great disadvantage, both as to the amount and the accuracy of his work; and both quantity and quality are factors too important to be neglected by the man who has the ambition to succeed.

It, therefore, is necessary to begin with the fundamental laws and basic principles of geometry, and when these are thoroughly mastered, to pass on to the practical applications of these principles as applied to the drawing of parts of machinery.

Geometry is defined as "that branch of mathematics which investigates the relations, properties and measurements of solids, surfaces, lines and angles." Hence, all mechanical drawing consists to a greater or less extent of geometrical problems; and without a conception of geometry, mechanical drawing would be an utter impossibility both in theory and practice. Every branch of technical science or mechanical arts has its own vocabulary of words and it is necessary at the outset to know and memorize these thoroughly, since they will be used frequently later on, and an imperfect knowledge of them will prove not only very awkward, but retard the clear and proper understanding of the more advanced work. We will, therefore, commence with the most simple form of geometrical conceptions, namely lines, defining the various kinds and their purposes; then proceed with the use of two lines forming angles; then three lines, forming triangles; then four, forming quadrilaterals; and a greater number forming polygons, and so on. We will later consider the properties of circles and follow this with the characteristics of solid figures. Explanatory titles, reference letters and notes are used on the accompanying engravings, Figs. 17 and 18, so that the application of the text to the illustrations may be readily seen, and the definitions and terms more easily applied and memorized.

Definitions of Lines

A *straight* line is the shortest distance between two points.

A *horizontal* line is one parallel with the horizon, which may be represented by the surface of water at rest in an open vessel.

A *vertical* line is one at right angles to a horizontal line, or as ordinarily understood, an upright line.

An *inclined* line is a line in any other position than horizontal or vertical.

A *perpendicular* line is one at right angles to another line, whatever its position. Perpendicular and vertical do not mean the same position, since a line at right angles to an inclined line is perpendicular to it, although itself inclined, as shown at *ABCD* in Fig 17.

A straight line has been defined as the shortest distance between two points. A *curved* line between two points is longer than the straight line, and is composed of one or more curves of an infinite number of forms, as the arc of a circle, an involute, a cycloid, an ellipse, etc. (These curves will be described later.)

A *broken* line is composed of a number of straight lines joined together. When composed of a succession of straight and curved lines it is usually called a *compound*, or *mixed* line.

A *dotted* line, shown at *EF*, Fig. 17, is composed of a succession of very short lines or dots of equal length. It is used in mechanical drawing to indicate the form of a part that is hidden by another part.

A *center* line, shown at *GH*, is composed of a succession of short lines. It is used in mechanical drawing to indicate the center lines of circles, cylinders and similar parts of symmetrical contour.

A *dimension* line, as shown at *KL*, is composed of alternate dots and short lines, and is used in mechanical drawing to indicate dimensions from one point to another.

Parallel lines are lines having the same direction, and an equal distance apart at all points.

Divergent lines, as shown at *M*, continually increase their distance from each other, the further they are prolonged.

Convergent lines, as shown at *P* and *N*, are those which, if prolonged, will continually approach each other, and meet at a point more or less distant, as at *O*.

Definitions of Angles

Angles are formed by the meeting of two lines as *RS* and *ST*. All angles must be one of three kinds, *viz.*: *right, acute* or *obtuse.*

Angles are measured by the use of the protractor, a complete circle being composed of 360 parts or degrees; hence, a half-circle equals 180 degrees, and a quarter of a circle, 90 degrees.

A *right* angle is composed of two lines meeting at an angle of 90 degrees.

An *acute* angle is composed of two lines meeting at less than 90 degrees.

An *obtuse* angle is composed of two lines meeting at more than 90 degrees.

Definitions of Triangles

Triangles are plane figures bounded by three straight sides.

An *equilateral* triangle is one whose sides are all equal.

An *isosceles* triangle is one in which two of its sides, and therefore two of its angles, are equal.

A *scalene* triangle is one in which no two sides or angles are equal.

A *right-angled* triangle is one in which one angle is a right angle or an angle of 90 degrees.

An *oblique* triangle is one which has no right angle.

The sum of the three angles of a triangle will always equal 180 degrees.

Definitions of Quadrilaterals

Quadrilaterals are plane figures having four straight sides.

A *square* is a figure having four straight sides, all the sides being of equal length, and all angles right angles.

A *rectangle* is a figure having four straight sides, opposite sides being of equal length, and all angles right angles.

A *parallelogram* is any figure having four straight sides, opposite sides being parallel and of equal length. The square and rectangle, hence, are only special cases of parallelograms.

A *trapezoid* is a figure having four straight sides, in which only two sides are parallel.

A *trapezium* is a figure having four straight sides, and in which no two sides are parallel.

The *base* of a plane figure is its bottom line, as shown at *X*, Fig. 17. The sides are the lines rising from the base.

The *altitude* is the vertical height, as shown at *Y*.

A *diagonal* is a straight line drawn between opposite angles, as at *Z*.

Definitions of Polygons

A *polygon* is a plane figure of more than four sides. *Regular* polygons have all sides composed of straight lines of equal length, and all of the angles equal. Polygons are distinguished by names which indicate the number of sides.

A *pentagon* is a polygon having five sides.

A *hexagon* is a polygon having six sides.

An *octagon* is a polygon having eight sides.

The Circle

A *circle*, as shown in Fig. 18, is a plane figure bounded by a uniformly curved line called the *circumference*, every part of which is at an equal distance from a point within called the center, shown at *A*.

The *diameter* of a circle is the line passing through the center and terminating at two opposite points in the circumference, as the line *DE*, Fig. 18.

The *radius* of a circle is the line extending from the center *B* to any point on the circumference, as the line *BF*.

An *arc* is any portion of the circumference, as the line *HJ*.

A *chord* is a straight line joining the two extremities of an arc, as the straight line from *H* to *J*.

A *segment* is a plane figure bounded on one side by an arc and on the other by a chord, as shown by the shaded space at *C*.

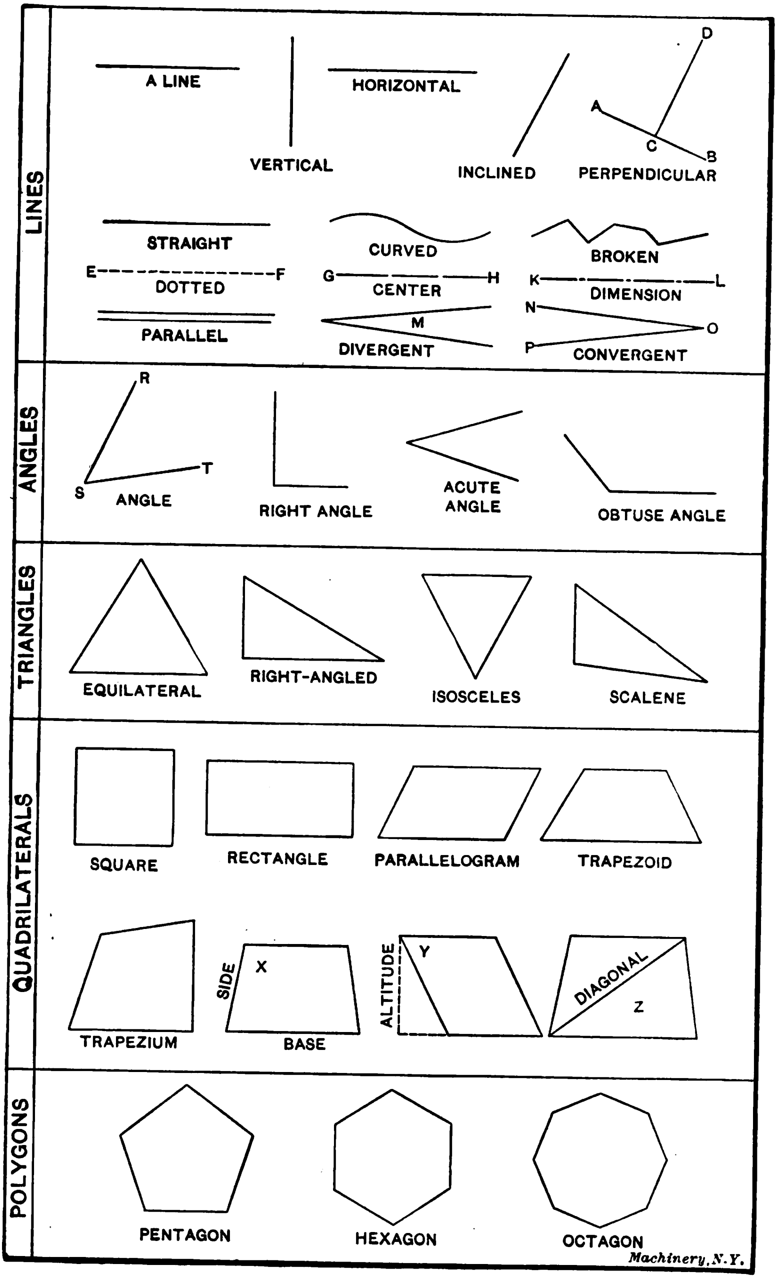
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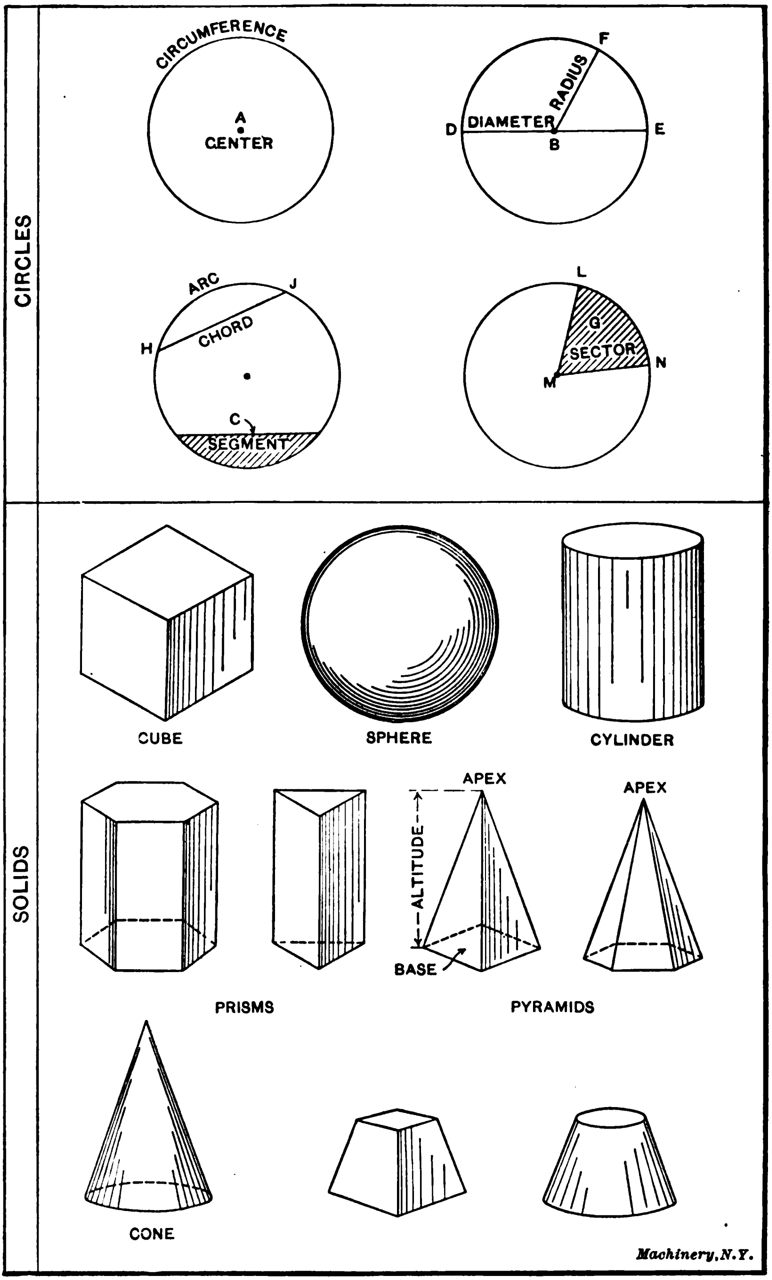
Fig. 17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ALTITUDE
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PRISMS
PYRAMIDS
CONE
Machinery, N.Y.

Fig. 18

A *sector* is a plane figure bounded by two radii, as *LM* and *MN*, and an arc, as *LN*, as shown by the shaded space, *G*.

Definitions of Solids

Thus far we have considered only lines and their uses in the formation of plane or "flat" figures, or figures having only length and breadth. We will now proceed further and consider figures having a third dimension in addition to its length and breadth, namely height or thickness. With the exceptions noted below all solids are bounded by four or more surfaces in the form of triangles, quadrilaterals or polygons.

A *cube*, Fig. 18, is a solid having six sides, each of which is a square. All its sides are equal, and all 'ts angles are right angles.

A *sphere* is a solid body bounded by a single surface, every part of which is equally distant from a point within, called the center of the sphere.

A *cylinder* is a solid body whose ends are circles of equal diameter, and whose exterior surface is at all points an equal distance from a line passing through the center of its circular ends, and called its axis.

A *prism* is a solid figure whose ends are equal in shape and consisting of triangles, quadrilaterals or polygons. The popular idea that a prism must have three sides only is not correct, since it may have any number of sides and still be within the definition. Hence we speak of a triangular prism so as to indieate its number of sides.

A *square* prism is bounded by rectangles on all sides.

A *pyramid* is a solid figure whose base is a triangle, quadrilateral, or a polygon, and whose sides are triangles, the upper angles of which are joined at the top in a point called the *apex*. The bottom surface is called the base, and the vertical height, the altitude. Pyramids may be classified according to the form of their base. Hence we speak of a triangular pyramid, a square pyramid, a hexagonal pyramid, etc.

A *cone* is a solid body similar to a pyramid, except that its base is a circle.

A pyramid or cone is described as *truncated* or as a *frustum*, when the upper portion is cut away, as shown in Fig. 18.

CHAPTER III

PRACTICAL GEOMETRICAL PROBLEMS

As the art of mechanical drawing depends upon a thorough knowledge of the fundamental principles of geometry, we will now proceed to consider such elementary problems as are most essential, and which will prove most useful to the draftsman in the practice of the profession of not only mechanical drawing. but also in the higher and more advanced science of mechanical engineering, to which he may some day aspire. These problems should be carefully worked out without the use of a T-square, except where specifically stated, using only the pencil dividers and a rule, or the side of a draftsman's triangle. The operations should be repeated with each problem until it is readily understood, and as far as possible the operations should be memorized, as they are often used in regular mechanical drawing of machine parts, etc., and will be found of much assistance in working out practical drawings accurately and quickly. The various problems are shown on the accompanying plates, and numbered the same as in the text matter in the following. These plates should be copied on drawing paper by the student. It will be well to make these drawings on a scale two or three times the size here given, as the work can be more easily done and the confusion of lines will not be as troublesome as when drawn on the small scale shown. The drawing of these problems should be very carefully done, so that the student may acquire that degree of precision which is necessary for a mechanical draftsman.

To firmly fix in the mind the principles contained in the following problems it will be necessary to draw them a number of times, and the more complicated ones with different dimensions and proportions, always being as careful and as accurate as possible. Habits of accuracy in the work are quite as necessary as the mental study of the theory of these operations. To be able to handle these problems promptly and correctly is the basis of the real constructive work of the trained and able draftsman, and the time spent on them is as well employed as that devoted to the later, and, apparently, more striking studies in mechanical drawing.

Problem 1. To bisect, or divide in equal parts, the given line *AB*. With the dividers set at a radius somewhat greater than half the length of the line *AB*, and with the needle point successively at *A* and *B*, describe the short arcs *CD* and *EF*. Through the intersection of these arcs draw the line *GH*, which will divide the line *AB* as required. This method is a very accurate one for dividing a line in two equal parts.

Problem 2. To erect a perpendicular at a given point *C* on the given line *AB*.

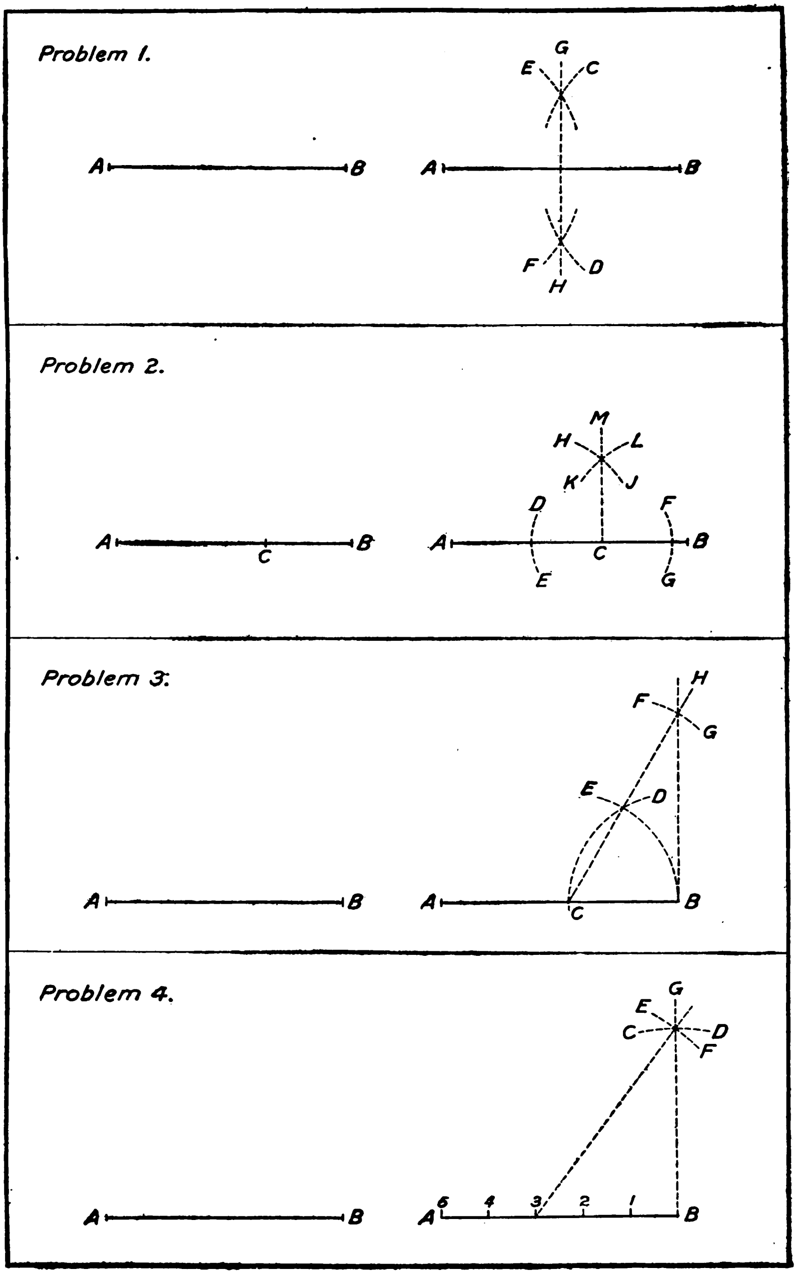


Plate I. Problems 1 to 4

Set the dividers to any convenient radius, and with the needle point at *C* as a center, describe the arcs *DE* and *FG*. With any convenient radius, and from the intersection of the arc *DE* with line *AB* as a center, describe the arc *HJ*. With the same radius, describe the arc *KL* from the intersection of the arc *FG* with the line *AB*. From the intersection of the arcs *HJ* and *KL*, draw a vertical line *MC*, which will be the perpendicular required.

Problem 3. To erect a perpendicular at the extremity of the given line *AB*.

With the dividers set at any convenient radius, place the needle point at *B* and describe the arc *CD*. With the same radius, and from the point *C* as a center, describe the arc *BE*. From the intersection of these two arcs as a center, and with the same radius, describe the arc *FG*. Through the point *C* and the intersection of the arcs *CD* and *BE* draw the inclined line *CH*. Through the point of intersection of this line with the arc *FG*, draw a vertical line to the point *B*, which will be the perpendicular line required.

Problem 4. A second method of solving Problem 3.

Divide the line *AB* into five equal parts and number these divisions from right to left as shown. Set the dividers to a radius of four of these parts, and with *B* as a center, describe the arc *CD*. Set the dividers to the full length of the line *AB*, and with the point 3 as a center, describe the arc *EF*. Through the intersections of these arcs and the extremity of the given line at *B* draw the line *BG*, which will be the perpendicular required.

Problem 5. To bisect, or divide equally, the angle *ABC*.

Set the dividers to any convenient radius and from the point *B* as a center, describe the arcs *DE* and *FG*. From the intersection of the arc *DE* with the line *AB* as a center, and with any convenient radius, describe the arc *HJ*. With the same radius and from the intersection of the arc *FG* with the line *BC* as a center, describe the arc *KL*. Through the intersection of the arcs *HJ* and *KL* and through point *B*, draw the line *BM*, which will be the bisecting line required.

Problem 6. To draw an angle equal to the given angle *ABC*.

Draw the inclined line *KL* as one side of the angle. With the dividers set at any convenient radius and with the point *B* (in the left-hand figure) as a center, describe the arc *DE*. With the same radius, and from the point *L* on the inclined line, previously drawn, as a center, describe the arc *FG*. Set the dividers to the exact radius of the distance between the points of intersection of the arc *DE* with the lines *AB* and *BC* (in the left-hand figure). With this radius, and from the point of intersection of the arc *FG* with the line *KL* (in the right-hand figure) as a center, describe the arc *HJ*. Through the intersection of the arcs *FG* and *HJ*, draw the line *LM*, which will complete the angle required.

Problem 7. To erect an angle of 60 degrees upon the given line *AB*.

Set the dividers to any convenient radius, and with the point *A* as a center, describe the arc *CD;* with the same radius, and from the

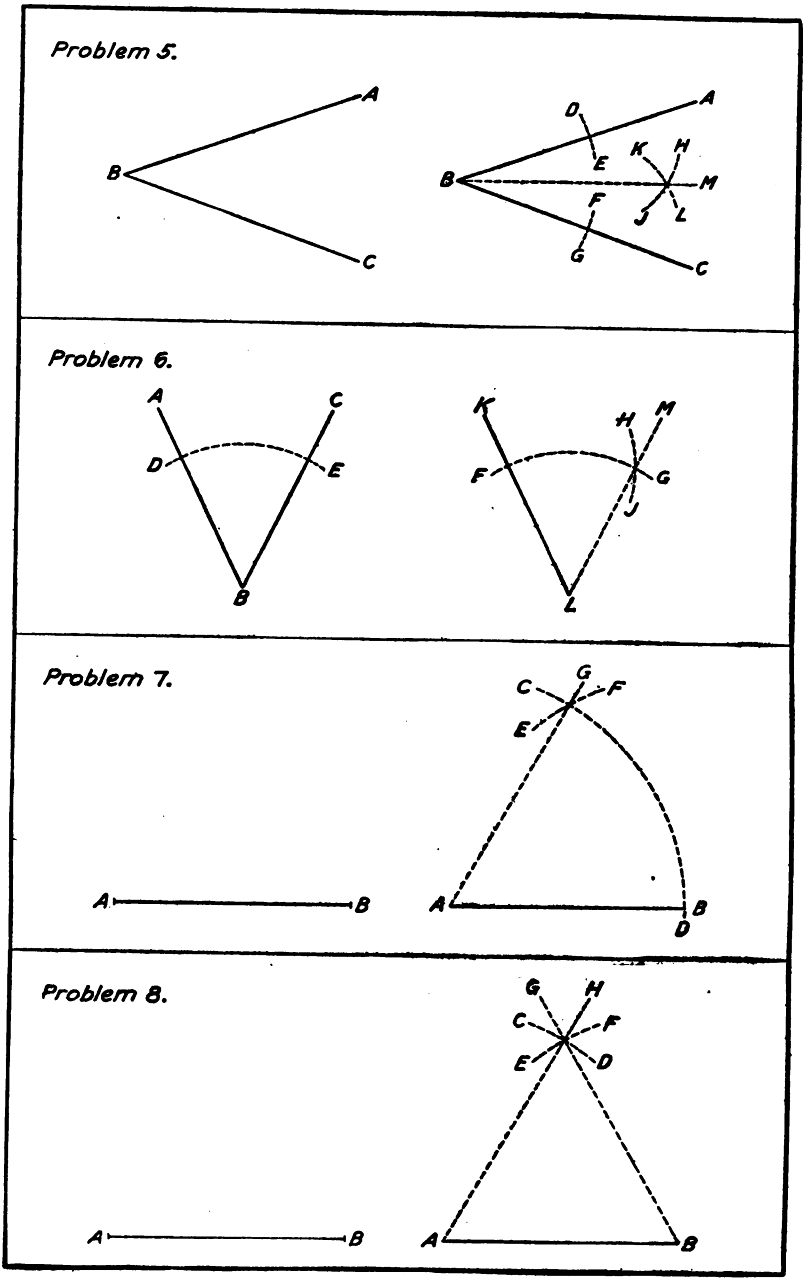


Plate II. Problems 5 to 8

intersection of the arc *CD* with the line *AB*, as a center, describe the arc *EF*. Through the point of intersection of the arcs *CD* and *EF*, draw the line *AG*, which will complete the angle required.

Problem 8. To draw an equilateral triangle whose sides are equal to a given line *AB*.

Set the dividers to the exact length of the given line *AB*, and with the point *A* as a center, describe the arc *CD*. With the same radius, and with the point *B* as a center, describe the arc *EF*. Through the intersection of the arcs *CD* and *EF*, and to the points *A* and *B*, respectively, draw the lines *AH* and *BG*, which will complete the required triangle.

Problem 9. To draw a triangle equal to the given triangle *ABC*.

Draw the base line *HK* equal to *AB*. With the dividers set exactly to the distance *AC*, and with the point *H* as a center, describe the arc *DE*. Set the dividers exactly to the distance *BC* and with the point *K* as a center, describe the arc *FG*. From the intersection of the arcs *DE* and *FG*, draw the lines *HL* and *KL*, completing the required triangle.

Problem 10. To draw a square with sides equal to a given line *AB*.

Set the dividers exactly to the length of the given line *AB*. With the point *A* as a center, describe the arc *BC*. With the same radius and with the point *B* as a center, describe the arc *AD*. With the intersection of the arcs *BC* and *AD* as a center, describe the circle *ABE*. With the radius *AB*, and with the intersection of the arc *BC* with the circle *ABE* as a center, describe the arc *FG*. With the same radius and with the intersection of the arc *AD* with the circle *ABE* as a center, describe the arc *HJ*. From the intersection of the arc *FG* and the circle *ABE*, draw the line *AK*. From the intersection of the arc *HJ* with the circle *ABE*, draw the line *BL*. From the intersection of the arc *BC* and the line *AK* draw the line *MN* to the intersection of the arc *AD* with the line *BL*. The figure *ABNM* is now the required square.

Problem 11. To draw a parallelogram, the length of whose sides is given and two of the angles of which are to be 60 degrees. The line *AB* represents the longer side, and the line *CD* the shorter.

Set the dividers to any convenient radius, and with the point *B* as a center, describe the arc *EF*. With the same radius, and with the intersection of the arc *EF* with the line *AB* as a center, describe the arc *GM*. Through the intersection of the arcs *EF* and *GM* draw the line *BJ*, which will form one side of the parallelogram. With the dividers set at the radius *CD*, and with *B* as a center, describe the arc *KL*. With the same radius and *A* as a center, describe the arc *OP*. With the dividers set at the radius *AB* and from the intersection of the arc *KL* with the line *BJ* as a center, describe the arc *MN*. Through the intersection of the arcs *OP* and *MN* draw the line *AT*, which will form another side of the required parallelogram. Through the intersection of the arcs *OP* and *MN* and of the arc *KL* and the line *BJ* draw the line *RS*, which will complete the required parallelogram.

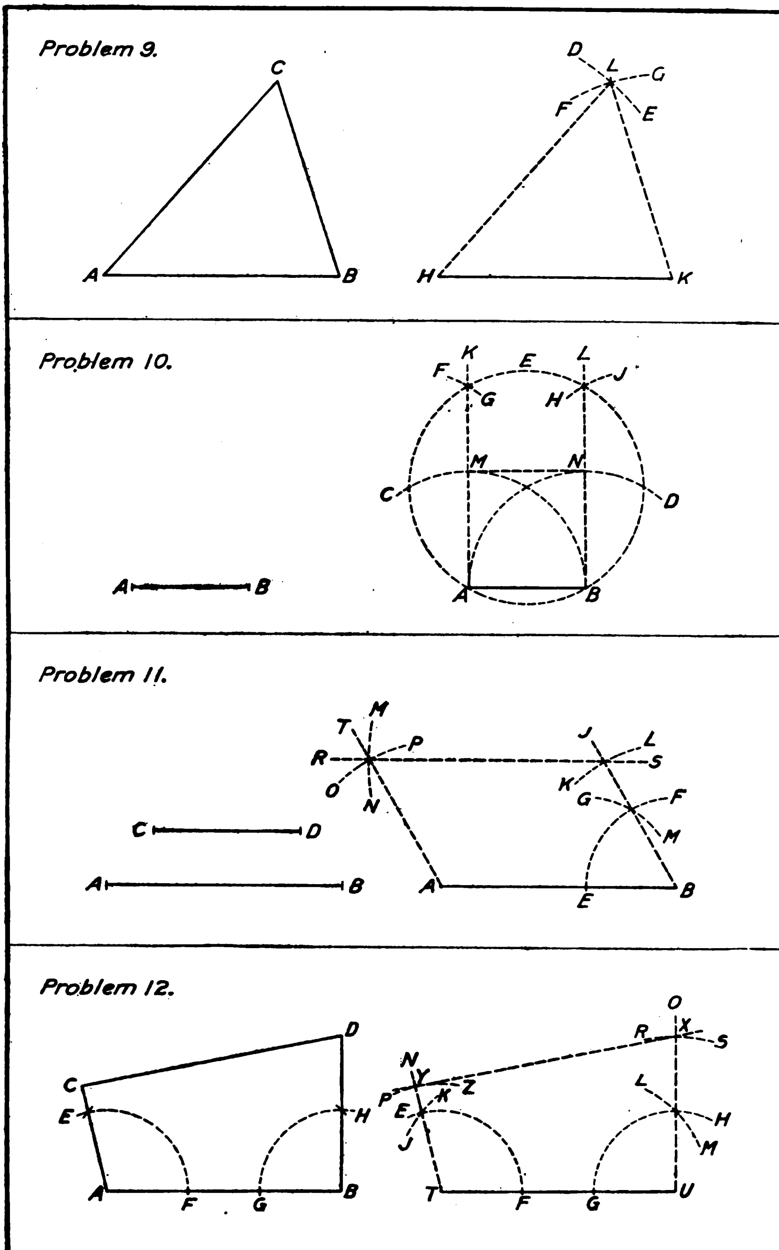


Plate III. Problems 9 to 12

Problem 12. To draw a trapezium equal to a given trapezium, as represented by lines *ABDC*.

With any convenient radius, and *A* and *T* as centers, describe the arcs *EF;* and with *B* and *U* as centers, describe the arcs *GH*. With a radius equal to the distance between the intersections of the arc *EF* with the lines *AB* and *AC*, and with the intersection of the line *TU* with arc *EF* at *F* as a center, describe the arc *JK*. Through the intersection of the arc *EF* with the arc *JK* draw the line *TN*, which forms one side of the required trapezium. With a radius equal to the distance between the intersections of the arc *GH* with the lines *AB* and *BD*, and from the intersection of line *TU* and arc *GH* at *G* as a center, describe the arc *LM*. Through the intersection of the arcs *GH* and *LM*, draw the line *UO*, which will form the third side of the trapezium. With a radius equal to the distance *AC*, and with *T* as a center, describe the arc *PZ*. With a radius equal to the distance *BD*, and with *U* as a center, describe the arc *RS*. From the intersection of the arc *RS* with the line *UO*, draw the line *XY* to the intersection between line *TN* and arc *PZ*. This line constitutes the fourth side, and completes the required trapezium.

Problem 13. To draw a circle of a given radius *AB*, through two given points *C* and *D*.

With the radius *AB*, and from the centers *C* and *D*, successively describe the arcs *EF* and *GH*. The intersection of these arcs will be the center of the required circle, which is described with the radius *AB*.

Problem 14. To draw a circle passing through three given points *A*, *B* and *C*.

With any convenient radius, and successively with *A* and *B* as centers, describe the arcs *DE*, *FG*, *HJ* and *KL*. Then with any convenient radius, and successively with *B* and *C* as centers, describe the arcs *MN*, *OP*, *QR* and *ST*. Through the intersection of these arcs draw the lines *UV* and *WX*, as shown. The intersection of these lines will be the center of the required circle. From this center describe the circle, through the given points *A*, *B*, and *C*.

Problem 15. To find the center of a given circle *AB*.

At any points on the circle locate the points *C*, *D* and *E*. Proceed to locate the center as described in Problem 14.

Problem 16. To draw a tangent through a given point *C*, on a given circle *AB*.

Through the given point *C* and the center *D* draw the line *CD*. By the method explained in Problem 2, erect the perpendicular *EF*, which will be the tangent required.

Problem 17. To draw a tangent to a given circle *AB* and passing through a given point *C* outside of the circle.

Through the given point *C* and the center *D* draw the line *CD*. With *C* as a center, and with a radius *CD*, describe the arc *DE*. With a radius equal to the diameter of the circle, and from the center *D*, describe the arc *FG*. Through the intersection of the arcs *DE* and

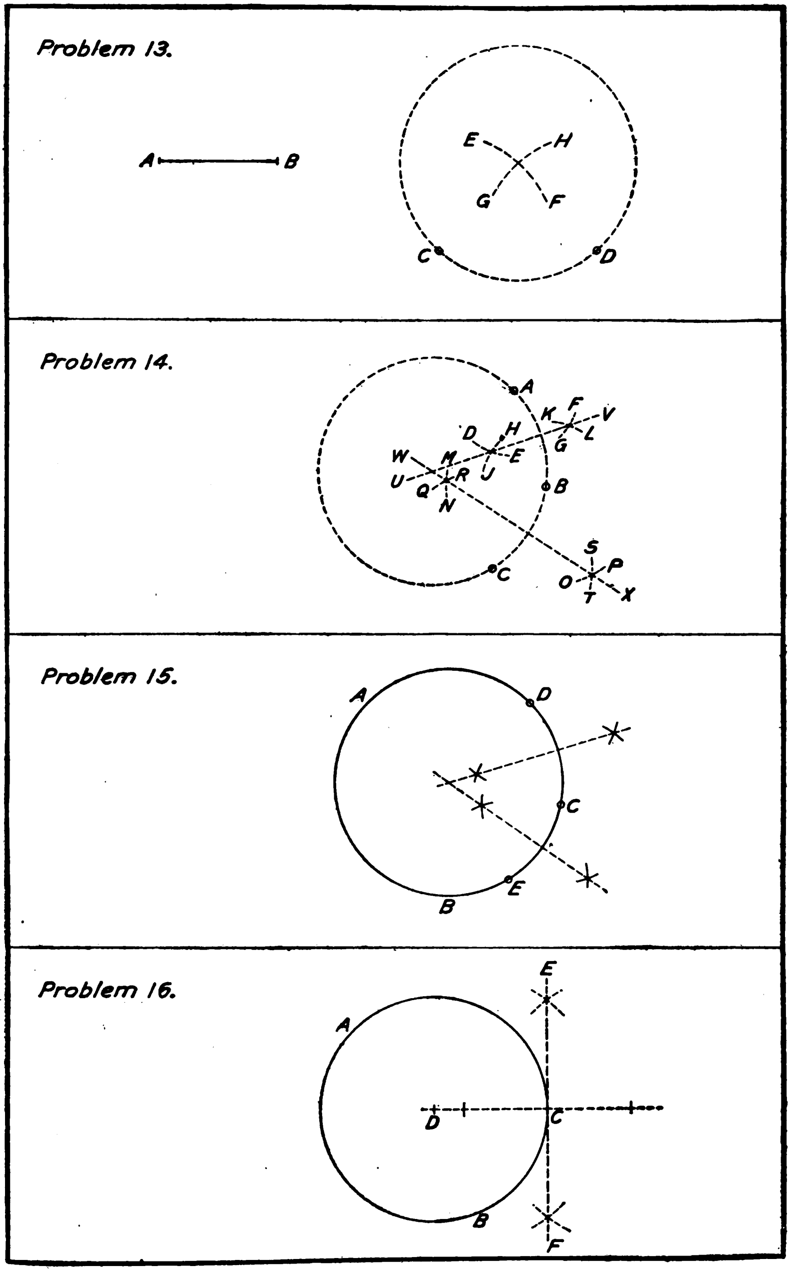


Plate IV. Problems 13 to 16

FG, and the center *D*, draw the line *DH*. Through the intersection of the line *DH* and the circle *AB*, and the given point *C*, draw the line *JK*, which will be the tangent required.

Problem 18. To draw a circle of a given radius *D* tangent to the sides of a given angle *ABC*.

With centers at any convenient points on the given angle, as *E*, *F*, *G*, and *H*, and with the given radius *D*, describe the arcs *JK*, *LM*, *NO*, and *PR*. Draw the lines *VS* and *TU* tangent to these arcs. (These lines are then parallel with lines *BC* and *AB*, respectively.) The intersection of these lines with each other is the center of the required circle. From this center, and with the radius *YW*, describe the required circle.

Problem 19. To draw a circle tangent to the three lines *AB*, *BC* and *CD*.

As explained in Problem 5, bisect the angle *ABC*. In the same manner bisect the angle *BCD*. The bisecting lines thus drawn will intersect each other at *E*, which will be the center of the required circle. The radius of the circle is the perpendicular distance from *E* to any of the three lines.

Problem 20. To draw a circle of a given radius *EF*, tangent to a given circle *AB* and a given line *CD*.

By the method explained in Problem 18, draw the line *GH* parallel to the line *CD*, and at a distance from it equal to the radius *EF*. With a radius equal to the radius of the circle *AB* added to the radius *EF*, and from the center *J*, describe the arc *LM*. The intersection of this arc with the line *GH* will be the center of the required circle, which is now drawn with the radius *EF*.

Problem 21. To draw a circle of a given radius *AB*, connecting with or tangent to a given circle *CD* at its intersection with a given line *EF*.

From the point of intersection of the circle *CD* with the line *EF*, describe the arc *HJ* with the radius *AB*. With the same radius, and with the intersection of the arc *HJ* with the line *EF* as a center, describe the required circle.

Problem 22. To join two given parallel lines *AB* and *CD* by two reversed curves, to which they shall be tangent, and connect with them at given points *E* and *F*.

As explained in Problem 1, bisect the line *EF* by the line *AG* at point *H*. In a similar manner bisect the line *EH* by the line *JK*, and the line *FH* by the line *LM*. As explained in Problem 2, draw the perpendiculars *NO* and *PR*. With the intersection of the lines *JK* and *NO* as a center, describe one of the required arcs *EH*. From the intersection of the lines *LM* and *PR* as a center, describe the other required arc *FH*.

Problem 23. To join two given parallel lines *AB* and *CD* by two reversed curves, connecting them at the given points *E* and *F*, and whose centers shall be on the given lines.

Draw the lines *NG*, *JK* and *LM* as in Problem 22. The intersection

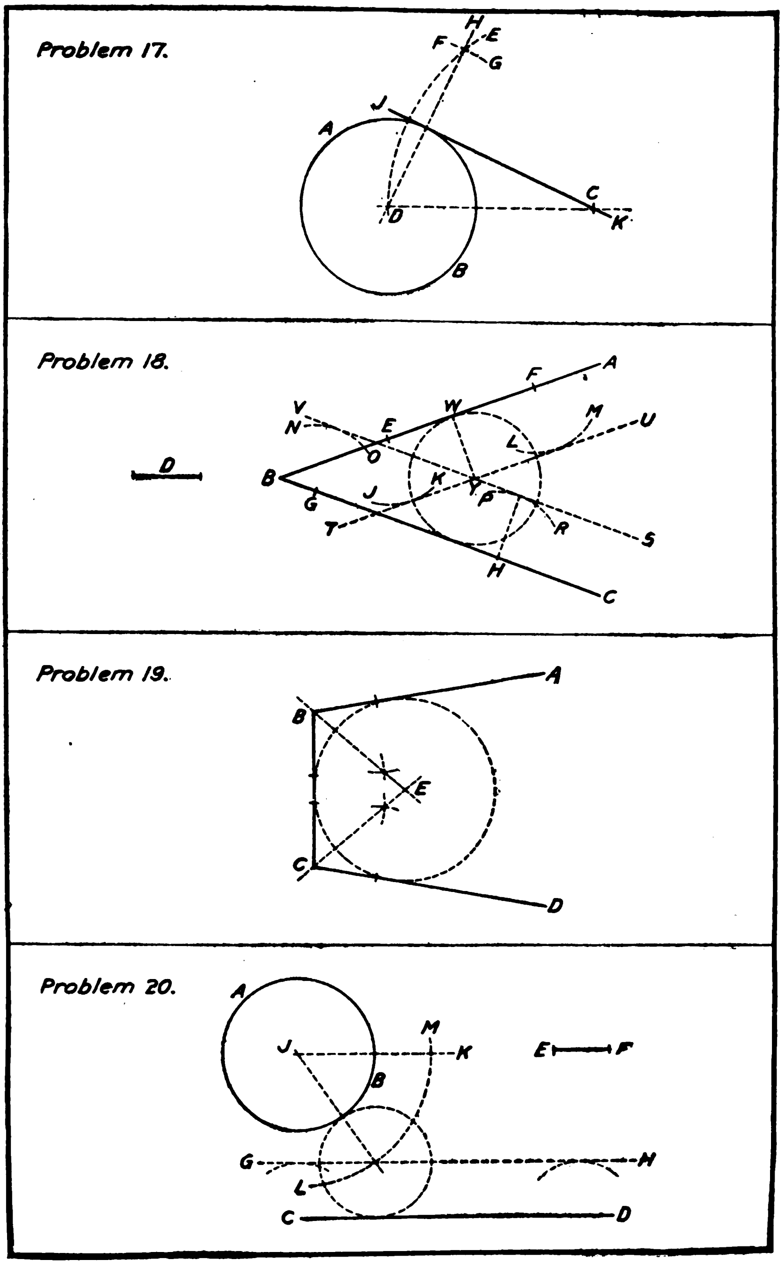


Plate V. Problems 17 to 20

of the lines *JK* and *AB* will be the center from which the arc *EH* is drawn; and the intersection of the lines *LM* and *CD* will be the center of the arc *FH*.

Problem 24. To inscribe a circle within a given triangle *ABC*.

As explained in Problem 5, bisect any two angles of the triangle by lines, as *BD* and *CE*. The intersection of these lines will be the center of the required circle, which, when drawn so as to touch or be tangent to one of the sides, will also be tangent to the other sides of the triangle.

Problem 25. To describe a circle around a triangle *ABC*.

Bisect the two sides *AB* and *AC* of the triangle, and erect the perpendiculars *DE* and *FG* in the manner described in previous problems. The intersection of these perpendiculars is the center of the required circle, whose radius will be the distance from this center to either of the angle points *A*, *B*, or *C*.

Problem 26. To inscribe circles between two divergent lines *AB* and *BC*, the circles to be tangent to each other and to the divergent lines; the first circle is to pass through a given point *O*.

Bisect the angle *ABC* in the manner described in Problem 5, and draw the line *BE*. From the given point *O* erect the perpendicular *FG*, whose intersection with the line *BE* will be the center of the first circle of the series, which is now described with a radius *OG*. From the intersection *H* of this circle with the center line *BE*, erect a perpendicular to the latter, cutting the line *AB* at *J*. With *J* as a center, and with the radius *HJ*, describe the arc *HK*. From the intersection of this arc with the line *AB*, erect the line *KL*, perpendicular to the line *AB*, whose intersection with the center line *BE* at *L* will be the center of the next circle, which is to be described with the radius *KL*. From the intersection *N* of the last circle with the center line *BE*, erect a perpendicular *MN* to the latter, and proceed as before. Any number of additional circles may be added in this manner.

Problem 27. To inscribe a circle within a square *ABDC*.

Draw the diagonals *AD* and *BC*, whose intersection will be the center of the circle. Bisect the line *BD* by the method described in Problem 1, and draw the perpendicular *EF*, passing through the center of the circle. With a radius equal to the distance from the center of the circle to the intersection of the line *EF* with the line *BD*, describe the required circle.

Problem 28. To inscribe a square within a given circle.

Draw the diameter *CD* through the center of the given circle. Erect the perpendicular *EF*, passing through the center of the circle. From the points of intersection of the diameters *CD* and *EF* with the circle, draw the lines representing the four sides of the required square.

Problem 29. To inscribe a regular pentagon within a given circle.

Draw the horizontal line *CD* passing through the center *G* of the given circle. Erect the perpendicular *EF*, passing through the same center. Bisect the radius by the line *HJ*, at *K*. With the intersection *K* as a center, and with the radius *KE*, describe the arc *EL*,

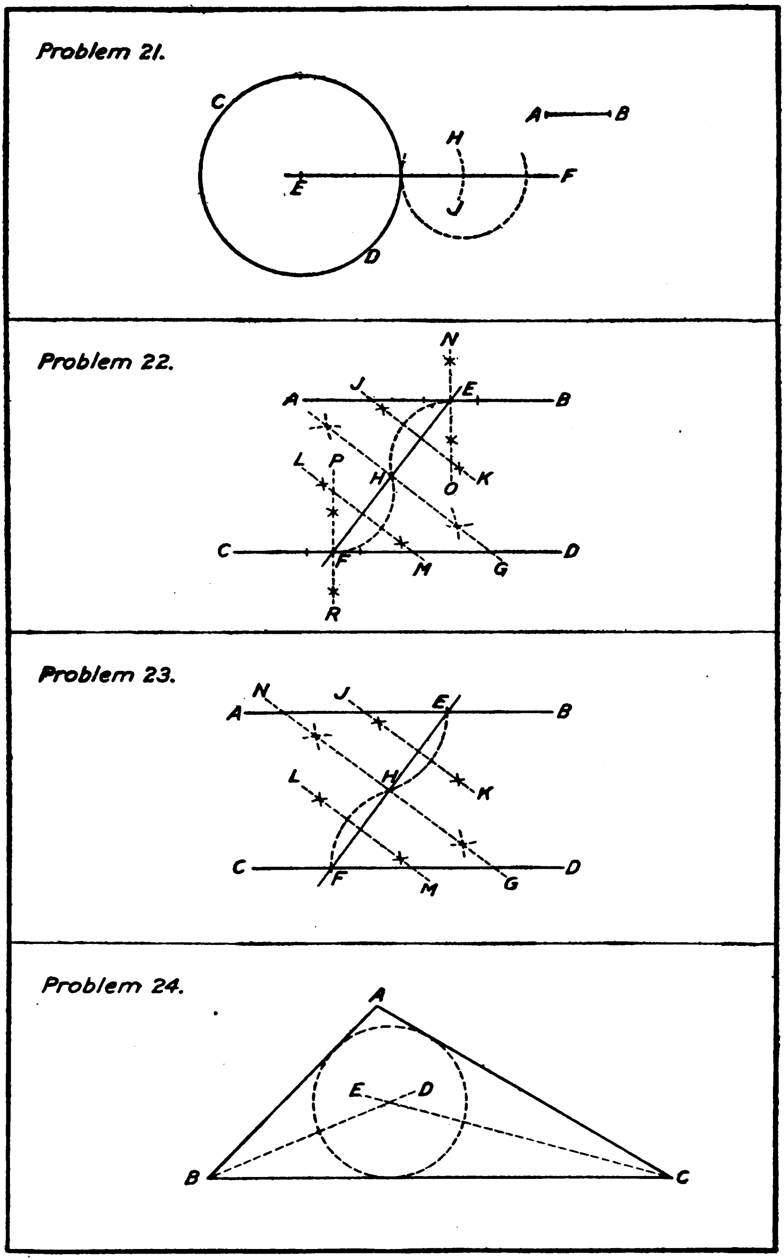


Plate VI. Problems 21 to 24

intersecting the line *CD* at *L*. With the point *E* as a center, and with the radius *EL*, describe the arc *NLM*, cutting the given circle at *M* and *N*, which will determine the length of each of the sides of the required pentagon. Draw the lines *EM* and *EN*, which will form two sides of the pentagon. From *M* and *N* successively, and with the radius *EM*, determine the points *O* and *P*, by short arcs cutting the given circle. Draw the lines *NO*, *OP* and *MP*, which will be the remaining sides of the required pentagon.

Problem 30. To draw a hexagon with sides of a given length *AB*.

With *A* and *B* successively as centers, and with a radius equal to *AB*, describe the arcs *CD* and *EF*, whose intersection will be the center of a circle circumscribing the required hexagon. With the same radius as just used, describe the circle *ABG*. With the same radius, and successively with *A* and *B* as centers, determine the points *H* and *J*, by short arcs cutting the circle *ABG*. With the same radius, and successively with *H* and *J* as centers, determine the points *K* and *L* by short arcs cutting the circle *ABG*. Connect the points *AH*, *HK*, *KL*, *LJ* and *JB* with straight lines, which will complete the required hexagon.

Problem 31. To inscribe a regular hexagon within a given circle.

Draw the horizontal line *CD*, passing through the center of the given circle. With a center at the points of intersection, *C* and *D*, of this line with the given circle, and with a radius equal to the radius of the circle, determine the points *E* and *F*, and *G* and *H*, by short arcs cutting the given circle. Connect the points *CF*, *FG*, *GD*, *DH*, *HE* and *EC* by lines which form the required hexagon.

Problem 32. To draw a regular octagon whose sides shall equal a given line *AB*.

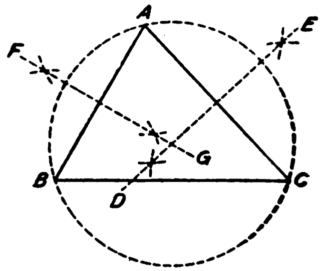
Extend the line *AB* to the right and left somewhat more than its length. With *A* and *B* successively as centers, and a radius equal to *AB*, describe the arcs *CD* and *EF*. From *A* and *B* erect the perpendiculars *AG* and *BH*. Bisect the angles *CAG* and *HBF* by the lines *AJ* and *BK*. Witn *L*, *D*, *E*, and *M* successively as centers, and with the radius *AB*, determine the points *N* and *O* by short arcs intersecting each other. With *N* and *O* successively as centers, and the radius *AB*, determine the points *G* and *H* by short arcs cutting the lines *AG* and *BH*. Connect the points *AL*, *LN*, *NG*, *GH*, *HO*, *OM* and *MB* by lines, which will form the required octagon.

Problem 33. To inscribe a regular octagon within a given circle.

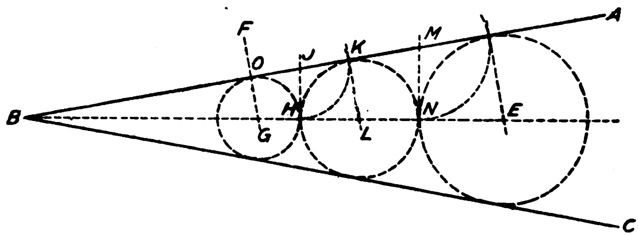
Draw the horizontal line *CD*, passing through the center *E* of the given circle. Erect the perpendicular line *FG*, passing through the center of the given circle. Draw the lines *HJ* and *KL*, bisecting the angles *FED* and *CEF*. These lines cut the given circle at the points *C*, *K*, *F*, *J*, *D*, *L*, *G* and *H*, which, when connected by lines, will form the required octagon.

Problem 34. To inscribe an octagon within a given square.

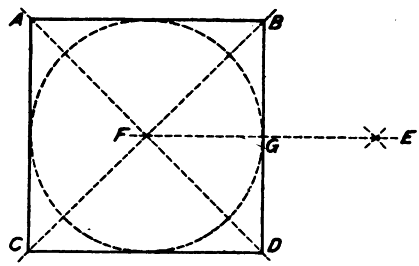
Draw the diagonals *CD* and *EF*, intersecting at *G*. From the points *C*, *E*, *D* and *F* successively as centers, and with a radius equal to *CG*, Problem 25.



Problem 26.



Problem 27.



Problem 28.

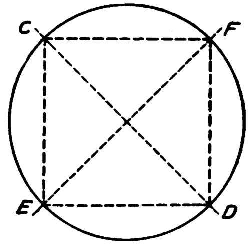


Plate VII. Problems 25 to 28

describe arcs intersecting the sides of the given square at the points *H*, *J*, *K*, *L*, *M*, *N*, *O* and *P*. Connect these points by lines which will form the required octagon.

The Drawing of Curves Other than Circles

In the study of mechanical engineering and in the practice of mechanical drawing, a number of very important curves are used, and it is very necessary that every man who aspires to the position of a designer of machinery should know the correct geometrical methods of laying out or "generating" these curves. To be able to handle these problems readily and accurately will be found to be of very great advantage.

Problem 35. To draw an involute curve.

The involute curve (or, simply, the involute) may be defined as a curve which may be traced by a point, as a pencil, fixed to the end of a flexible cord, when unwound from the surface of a cylinder. This curve is represented by the line *A* in the left-hand figure; *B* is the generating cylinder or circle from which the cord is supposed to have been unwound. For ordinary purposes this curve may be approximately drawn with a generating circle of a given diameter by the following method. (See the right-hand figure.) Within the generating circle *B* inscribe a square, extending the lines forming its sides, as shown, to *C*, *D*, *E* and *F*. With the point *G* as a center, and the distance *GK* as a radius, scribe an arc extending from the line *FG* to the line *CG*. With *H* as a center, extend the dividers to the point where the last arc ceased on the line *CG*, and continue the curve to the line *DH*. With *J* as a center, and the radius extended to the curve at the line *DH*, continue the curve to the line *EJ*. Continue these operations until a spiral of sufficient length has been produced.

If this curve is generated on a large scale a greater number of basic lines, as *CG*, *DH*, etc., should be made, so as to increase the accuracy of the curve. It should be understood that an accurate involute curve cannot be described with the dividers, since no part of it is the arc of a circle.

In drawing this curve mechanically, for instance, as a curve on large wood pattern work, a generating cylinder of wood of proper diameter is used, and around this is placed a very fine copper wire, to the end of which a drawing pencil is fastened. By this means very accurate work can be done. It may be well to state that, mathematically, the diameter of the generating circle multiplied by 3.1416 will give the distance between one convolution and the next, as shown by the distance *M* in the right-hand figure.

Problem 36. To draw an ellipse.

The ellipse may be popularly described as a flattened circle. By pressure on opposite sides of a flexible circle (as a hoop), we at once loose its center as a fixed point equally distant from every point of the circumference; the flattened circle becomes an ellipse, and the point formerly the center is replaced by two points called the *foci* (singular:

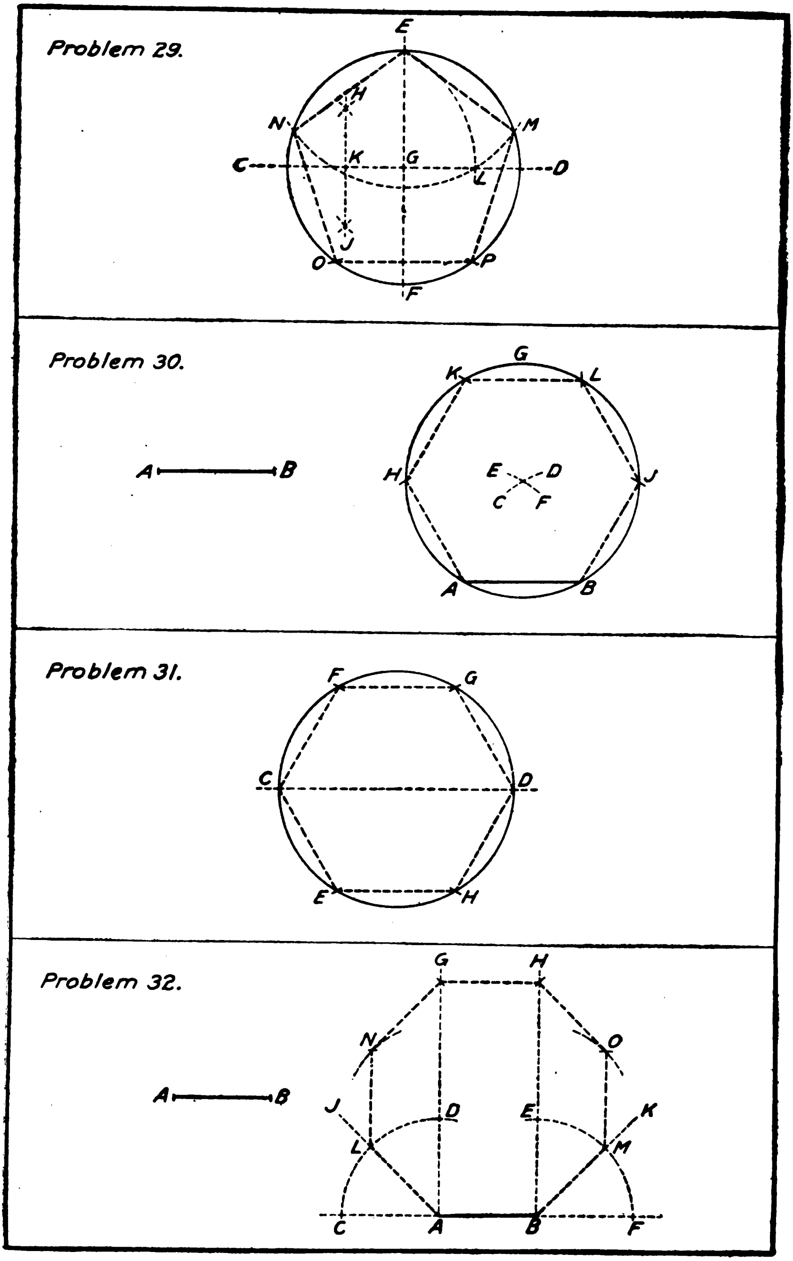


Plate VIII. Problems 29 to 32

focus). In the figure (Problem 36) the longer or conjugate axis of the ellipse is from *A* to *B*. The shorter or transverse axis is from *C* to *D*. The two foci are always located on the conjugate axis, and are shown at *E* and *F*.

Mathematically, the ellipse is defined as a figure bounded by a curved line, all points of which are so located with respect to two points within the curved line, called the foci, that the sum of the distances from any point on the ellipse to the foci is constant or equal for any one ellipse. Referring to the figure, the combined length of the two lines *ED* and *DF* is the same as that of the lines *EG* and *GF*, or of the lines *EH* and *FH*.

From these facts it follows that if we place a pin at each of the foci, and fasten to them the ends of a flexible cord of exactly the length to reach from the focus *E* to the point *C* and back to the other focus *F* (when drawn taut), we may place a pencil inside of the cord at *C* and moving it to the left, describe the exact form of one-fourth of the ellipse. This is a mechanical method of drawing the ellipse and is often used in large wood pattern work. In such a case a very fine copper wire is generally used. The method of determining the location of the two foci is as follows: With *C* as a center, and a radius equal to one-half the conjugate axis *AB*, describe arcs intersecting the conjugate axis. The points of intersection, *E* and *F*, are the foci.

Problem 37. To draw an ellipse by determining points at intervals along the line of the curve. (First method.)

Assume that *AB* is the conjugate axis; *CD* the transverse axis, and *E* and *F* the two foci. Divide that portion of the conjugate axis between the focus *F* and the transverse axis into eight equal parts, and number them from left to right as in the drawing. With the focus *E* as a center, and with the distance from *B* to 7 as a radius, describe the short arc *G*. In a similar manner, with the radius *B*6 describe the short arc *H*. Proceed in a like manner to describe the short arcs *J*, *K*, *L*, *M*, and *N*. With the radii *A*1, *A*2, *A*3, etc., and with the focus *F* as a center, describe successively the short arcs *O*, *P*, *Q*, *R*, *S*, *T*, and *U*, cutting the short arcs previously described. The intersections of these short arcs will be points on the required curve forming the ellipse. Only one-fourth of the entire curve is here shown, the other portions being but repetitions of the curve just drawn.

Problem 38. To draw an ellipse by determining points at intervals along the line of the curve. (Second method.)

Assume that *AB* is the conjugate axis and *CD* the transverse axis of the required ellipse. Describe the circle *ABE*, with a diameter equal to the conjugate axis, and the circle *CFD*, with a diameter equal to the transverse axis. Divide the arc *AE* of the larger circle into eight equal parts. By radial lines from the points thus determined divide the arc *CF* of the smaller circle into eight equal parts. From the points *G*, *H*, *J*, etc., on the outer circle, draw vertical lines. From the points *K*, *L*, *M*, etc., on the smaller circle, draw horizontal lines.

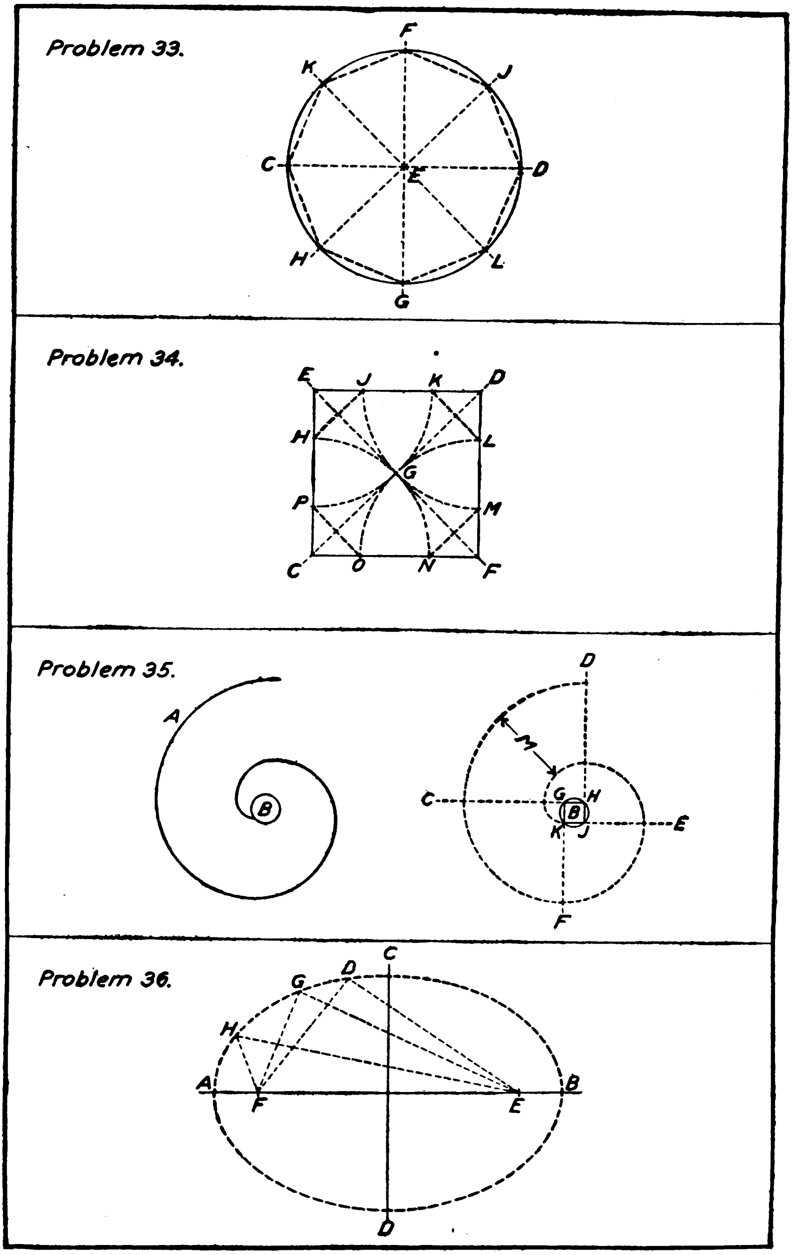


Plate IX. Problems 33 to 36

The intersections of these horizontal lines with the vertical lines will be points on the required curve forming the ellipse.

Problem 39. To describe an ellipse by the use of straight lines only, and without the determination or use of the foci.

Assume that *AB* is the conjugate axis, and *CD* the transverse axis of the required ellipse. Draw the line *CE* parallel to the conjugate axis *AB*. Draw the line *AE* parallel to the transverse axis. Divide the line *CE* into eight equal parts and number the points from right to left. Divide the line *AE* into eight equal parts and number them from the top downward. Draw straight lines between the points on the horizontal line *CE* and the points having the same numbers on the vertical line *AE*. These lines will be tangents to the curve of the required ellipse; this method, however, is only approximate, and while it is satisfactory for general work, it is not a method to be recommended when accurate results must be obtained.

Problem 40. To describe a curve similar to that drawn in Problem 39, but on base-lines forming an obtuse angle.

Proceed as in Problem 39, dividing the lines *AE* and *CE* into eight equal parts, numbering these points and drawing straight lines in a similar manner as before. The lines are all tangents of the required curve. The method described is, however, like that in Problem 39, only approximate, and should not be used if accurate or theoretically correct results are required.

Problem 41. To describe a curve similar to that drawn in Problem 39, but on base-lines forming an acute angle.

Proceed as in Problem 39, dividing the lines *AE* and *CE* into eight equal parts, numbering these points and drawing the straight lines in a similar manner, as before. The lines are all tangents of the required curve. This method, being the same in principle as that used in Problems 39 and 40, is only approximate, and should not be used when very accurate results are required.

Problem 42. To develop accurately a small portion of an involute curve from a comparatively large given circle.

In Problem 35, the method of developing the involute curve (or, as commonly called, the involute) for ordinary purposes is described. When a great degree of accuracy is required and only a short portion of the curve is needed, as in generating a suitable curve for the teeth of gears, a much more accurate method must be used. In the use of this curve as applied to the teeth of gears, it is not unusual to use from twelve to twenty tangent lines to a fourth part of the circle. From a fifth to an eighth of the given circle is usually required in this work.

Draw the vertical line *CD*, whose intersection with the generating circle will mark the beginning of the required curve. From this point and toward the right, lay off six to eight equal spaces, of from three- to five-sixteenths of an inch each. Number them from left to right. Draw radial lines from each of these points to the center *D* of the given circle. By the use of a ruler or T-square blade and a 90-degree angle, draw lines at right angles to each of these radial lines,

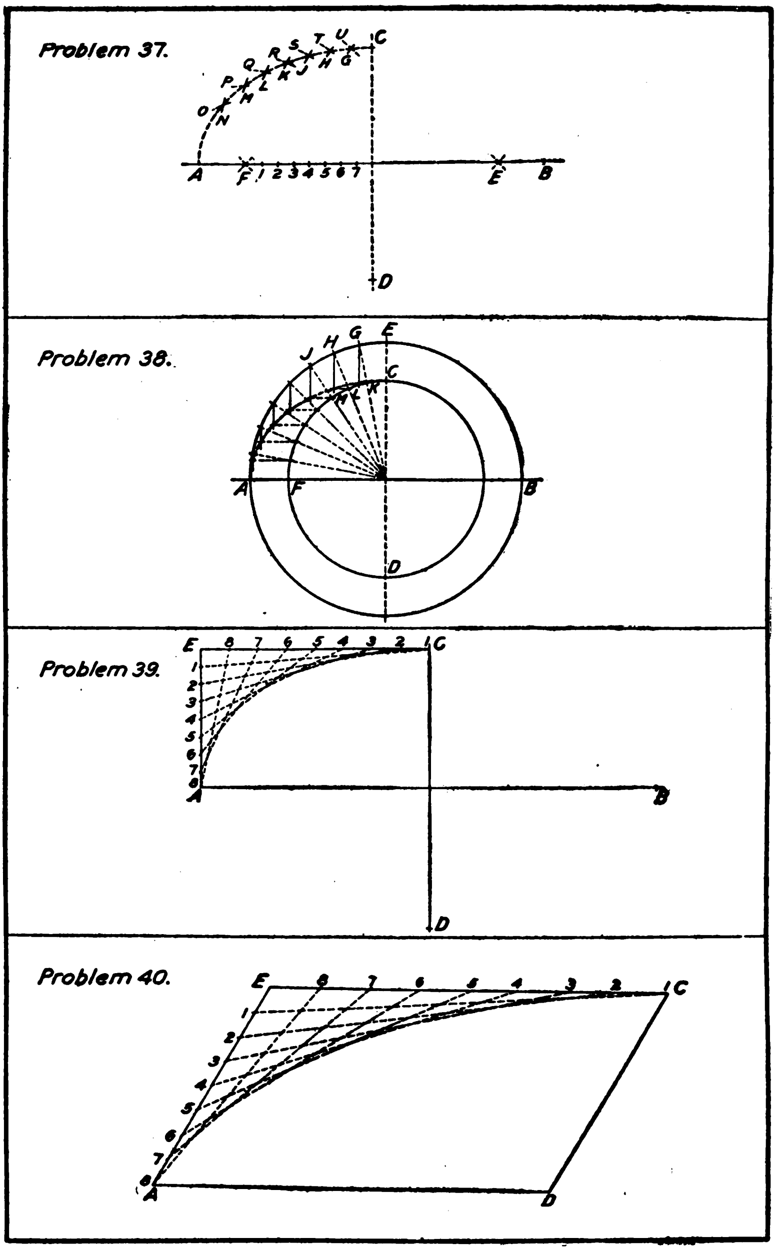


Plate X. Problems 37 to 40

tangent to the circle, and number these tangents with similar figures. With 1 on the generating circle as a center, and the distance from this center to the vertical line *CD*, as a radius, describe the very short portion of the involute curve from the given circle to the tangent line 1. With point 2 on the given circle as a center, and with the distance from this center to the termination of the portion of the curve just drawn, describe the next portion of the required curve from the tangent line 1 to line 2. Proceed in the same manner, using the radial lines 3, 4, 5, etc., as centers, enlarging the radius at each step and continuing the required curve from one tangent to the next. In actual practice this work must be done with good drawing instruments, with a very hard and sharp, round pointed pencil, and on a very hard and smooth surfaced paper or bristol board.

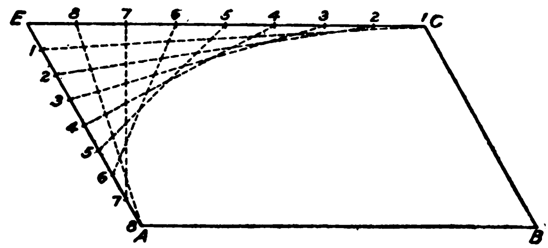
Problem 43. To draw a cycloid curve described by a point in the generating circle *AB* rolling along the straight line *CD*.

The cycloid is a curve described by a fixed point in a generating circle rolling along a straight line. It is constructed in the following manner. From the center *E* of the generating circle *AB* draw the line *EF*, parallel to the line *CD*, which will be the line followed by the center of the generating circle *AB* as it rolls along the line *CD*. Through the center *E* draw the line *GH*, at right angles to the line *CD*. The intersection of the line *GH* with the circle will indicate the beginning of the required curve. Divide the left half of the generating circle into an even number of equal parts (in this case twelve), and number them, beginning at the lower point. Divide the line *EF* into equal parts, of the same length as those into which the half-circle is divided, beginning at the line *GH*, and number them from left to right. Through the points in the generating circle, draw lines parallel to the line *EF*. With the same radius as that of the generating circle, and with the point 1 on the line *EF* as a center, describe the short arc *J*, intersecting the horizontal line from the point 1 on the generating circle. With the same radius, and the point 2 on the line *EF* as a center, describe the short arc *K*, intersecting the horizontal line from the point 2 on the generating circle. With the same radius, and in a similar manner, with centers at the points 3, 4, 5, etc., on the line *EF*, describe short arcs *L*, *M*, *N*, etc., intersecting the horizontal lines from the points 3, 4, 5, etc., on the generating circle. The intersections of these short arcs and the corresponding horizontal lines are points on the required cycloid. In the drawing, the point 12 carries the generating circle through one-half a revolution. The remaining half revolution would be a counterpart and return to the line *CD*.

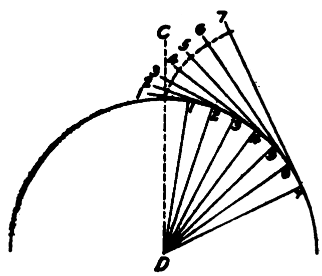
Problem 44. To describe an epicycloid upon a given circle *AB*, with a generating circle *CD*.

The cycloid is developed by a generating circle rolling upon a straight line. The epicycloidal curve is one produced by the generating circle rolling upon the outside of another circle. It is drawn as follows:

Problem 41.



Problem 42.



Problem 43.

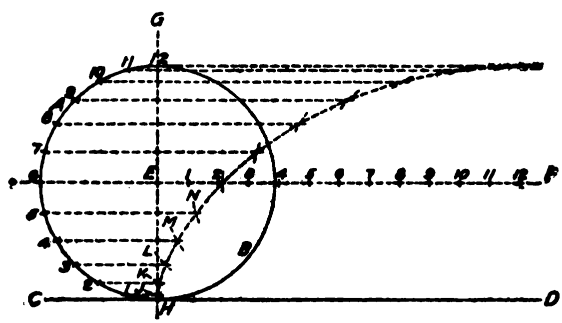


Plate XI. Problems 41 to 43

Through the centers of the given circles draw the vertical line *EF*, the intersection of which with the circles determines the beginning of the required curve. From this point lay off toward the left on the generating circle *CD*, and toward the right on the given circle *AB*, a number of equal distances, numbering the points 1, 2, 3, etc., as shown. Through the center of the generating circle, and with the center *F* of the given circle as a center, describe the arc *GH*, upon which the center of the generating circle will travel as it rolls along. Through the points 1, 2, 3, etc., on the given circle draw the radial lines *J*, *K*, *L*, etc., intersecting the arc *GH*. Through the points 1, 2, 3, etc., on the generating circle, and with *F* as a center, describe the arcs *O*, *P*, *Q*, *R*, etc. With the radius of the generating circle *CD*, and the intersections of the radial lines *J*, *K*, *L*, etc., with the arc *GH*, used successively as centers, describe short arcs intersecting the arcs *O*, *P*, *Q*, etc. These intersections are points on the required epicycloidal curve.

Problem 45. To describe a hypocycloid within a given circle *AB*, by a generating circle *CD*.

A hypocycloid is generated in the same manner as an epicycloid, except that the generating circle rolls on the inside of another circle. It is constructed as follows: Draw the vertical line *EF* through the centers of the given circle *AB* and the generating circle *CD*, the point of intersection of this line with these circles determining the beginning of the required curve. With the center *F* of the given circle *AB* as a center, describe the arc *GH* passing through the center of the generating circle *CD*. Divide the generating and given circles into spaces, as described in Problem 44, and through the points on the given circle draw radial lines intersecting the arc *GH*. With the center *F* of the given circle as a center, describe the arcs *O*, *P*, *Q*, *R*, etc., passing through the points 1, 2, 3, etc., on the generating circle. With the radius of the generating circle *CD*, and the intersections of the radial lines with the arc *GH* used successively as centers, describe short arcs intersecting the arcs *O*, *P*, *Q*, *R*, etc. These intersections are points on the required hypocycloidal curve.

Problem 46. To describe a parabolic curve within given limits.

The parabola is a curve formed by the contour of the section of a cone when cut on a plane parallel to one of its sides. One of its principal uses in practice is for the form of the reflector of a search light, the source of light being situated in its focus. By reason of its peculiar form, all rays of light are projected straight ahead, or in very slightly divergent rays. The parabola may be constructed as follows: Assume that *AB* is the directrix, or center line. The lines *CF* and *DE* represent the greatest width of the conic section, and *CD* its extreme length. Divide the line *CD* into eight or more equal parts and number them from left to right. Divide the line *AC* into the same number of equal parts and number them from the line *AB* upward. From the point *A* draw straight lines to each of the points 1, 2, 3, etc., on the horizontal line *CD*. From the point *D* draw straight lines to each of the points 1, 2, 3, etc., on the vertical line *AC*. The intersections of lines

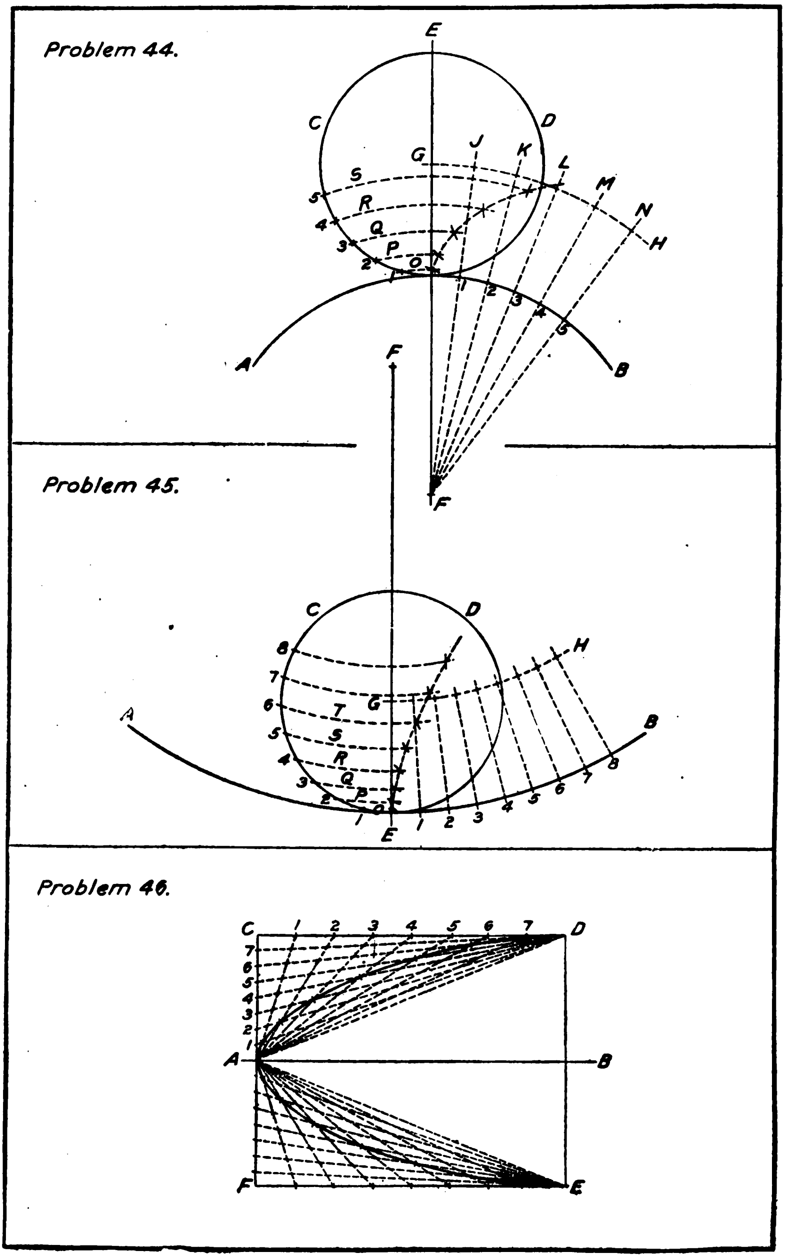


Plate XII. Problems 44 to 46

from the same number are points on the required parabolic curve. The lower half of this curve is drawn in the same manner.

Problem 47. To describe a helix around a cylinder of given diameter *AB*, and having a given lead *CD*.

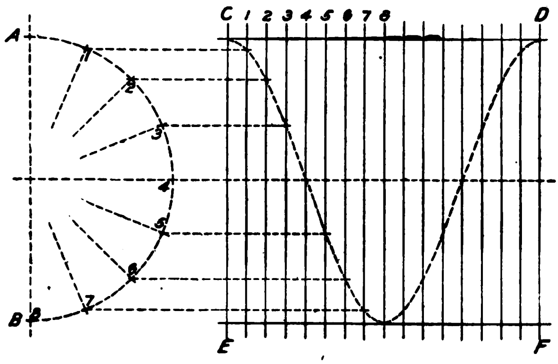
The helix is a curve represented by a flexible cord wound around a cylinder, and is well illustrated in practice by the thread of a screw. The distance from one convolution to the next is called the lead. The helix may be single, as in an ordinary screw, or double, in which case two separate threads, beginning on opposite sides of the surface of the cylinder, are used. If triple, three threads are used, beginning at points 120 degrees apart on the surface of the cylinder. A helix is drawn as follows: Divide one-half of the circumference of the given cylinder into eight or more equal parts and number them consecutively as shown. Draw the lines *CE* and *DF* representing the diameter of the given cylinder. Draw the lines *CD* and *EF* representing the lead, or the distance which the helical curve extends along the cylinder in one convolution. Along the line *CD*, divide one-half the lead into the same number of equal parts as the half-circle has been divided into and number them as shown. Draw vertical lines through these points. Draw horizontal lines through the points 1, 2, 3, etc., of the circle, intersecting the vertical lines. The intersections of vertical and horizontal lines of the same numbers are points on the required helical curve. The remaining half of the convolution is drawn in the same manner, terminating at *D*.

The application of the helix is shown in Problems 48 and 49, as applied respectively to a V-thread and a square thread of a screw.

Problem 48. To draw the two helical curves of a V-thread screw of given diameter and with a thread of a given lead and 60-degree angle.

Let *AB* represent the outside diameter of the screw; *CD* is the given lead of the V-thread. Draw the horizontal line *CG* as the top of the cylinder, and the vertical lines *GF* and *CE* as the sides. Continue the spacing *CD* down along the line *CE*, thus indicating the lead of the thread. Divide the line *GF* in a similar manner, noting the fact that the point which is the top of the thread on one side is the bottom of the thread on the other. With the T-square and a 30-degree triangle, draw the V-form of the thread on each side of the cylinder as shown. The bottom of the thread is thus found at *KK*, which gives the diameter of the secondary cylinder represented by the circle *KK* in the view above. Divide the half-circle *AB* into eight parts and number them as shown. Through these points draw the radial lines *L*, *M*, *N*, *O*, etc., dividing the inner circle *KK* into an equal number of parts. Divide one-half of the lead into eight equal parts, or the whole lead into sixteen parts, as at *CD*, and number the division points as shown. From the points in the outer circle *AB* draw vertical lines intersecting the corresponding horizontal lines. The intersections of corresponding vertical and horizontal lines are points on the required helical curve *RST*, representing the top of the thread. In a similar manner the points on the curve *UVW*, representing the bottom

Problem 47.



Problem 48.

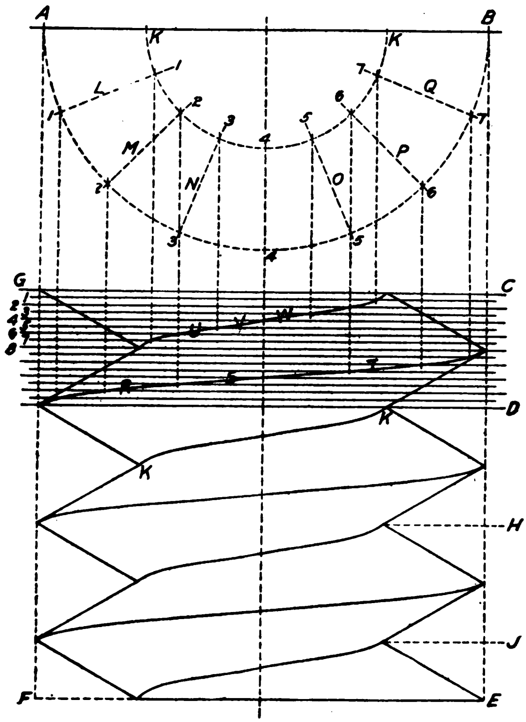


Plate XIII. Problems 47 and 48

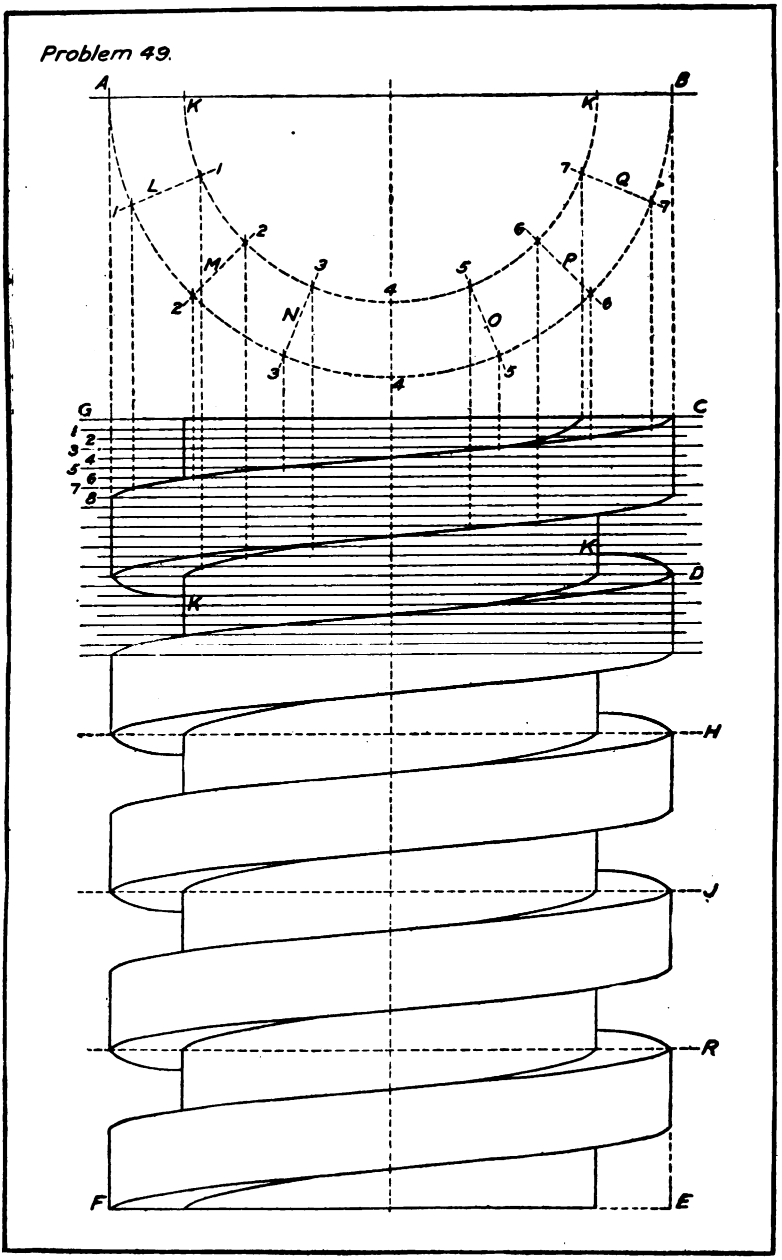


Plate XIV. Problem 49

of the thread, are determined. These curves are then drawn by straight lines of proper inclination representing about one-third of the curve at the center, while the extremities are drawn by the use of an irregular curve.

Problem 49. To draw the helical curves of a square thread of a screw.

The operation of determining the points necessary to draw the helical curves are identical with those described for Problem 48, but the work of laying out the form of the thread is different, as we have now a square thread instead of a V-thread. Divide the lead *CD* into two parts, as before. Let one of these parts form the thread and the other the groove between this thread and the next. Continue the division of the line *CE* into spaces as indicated at *H*, *J*, *R*, and *E*. Divide them in half as before. Divide the line *GF* in a similar manner. Note that the space on one side which represents the thread will represent the groove between the threads on the opposite side. In the actual practice the thread is made slightly thinner than the space, but in laying out the work on a drawing the two dimensions are made the same.

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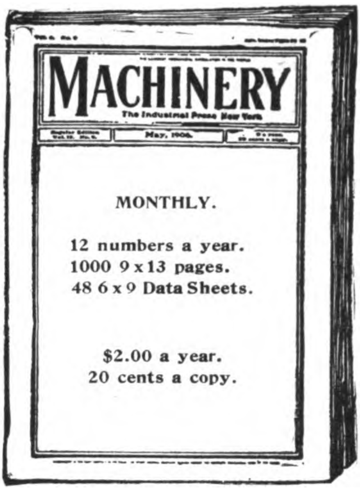

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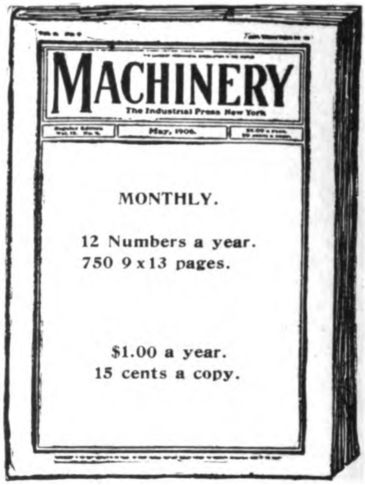

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