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MECHANICAL DRAWING

A PRACTICAL MANUAL OF SELF-INSTRUCTION IN THE ART
OF DRAFTING, LETTERING, AND REPRODUCING
PLANS AND WORKING DRAWINGS, WITH
ABUNDANT EXERCISES AND PLATES

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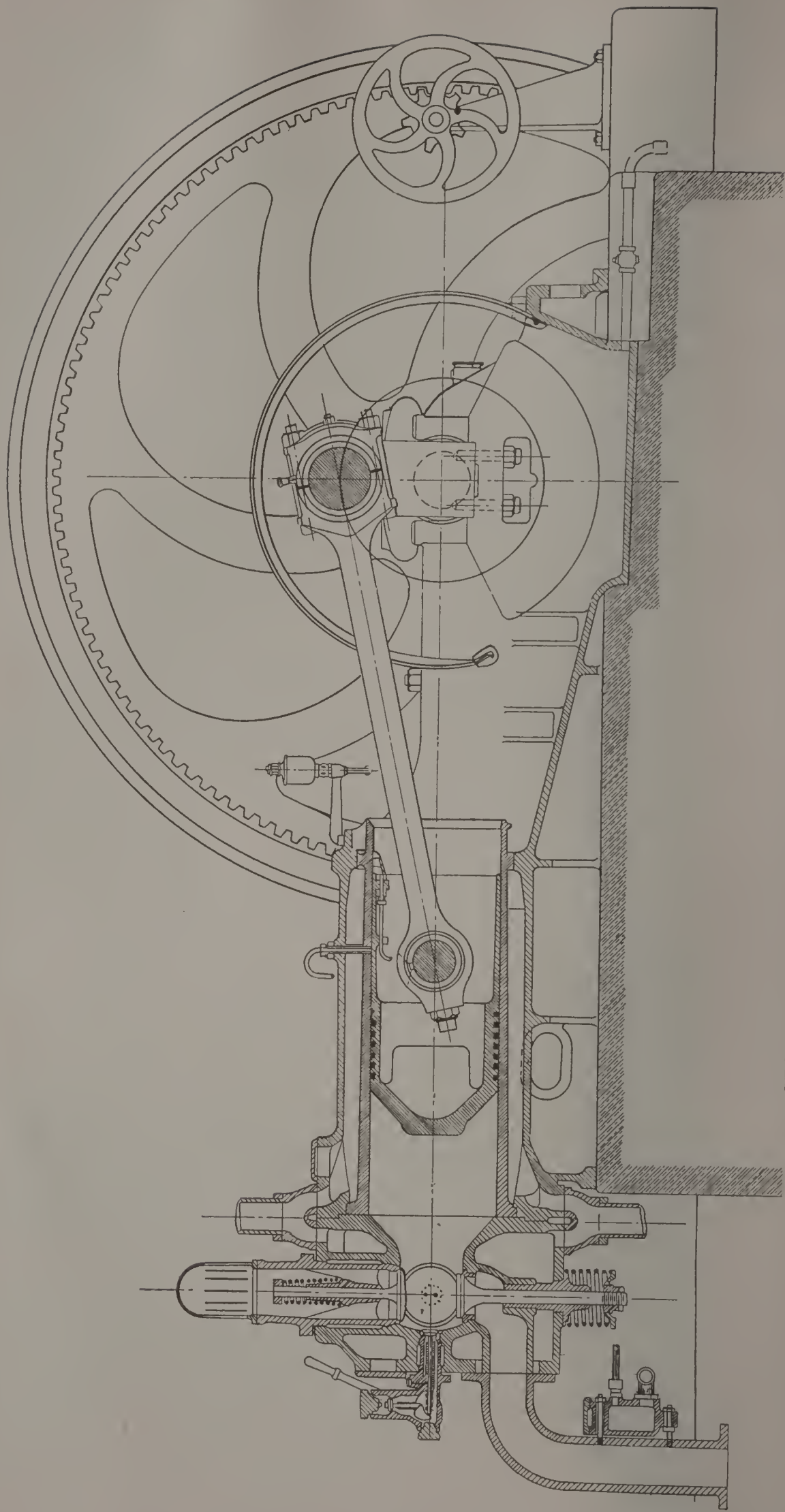
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INTRODUCTION

A TRAINED architect or architectural draftsman will execute a set of plans for a house or flat building with a dispatch and precision which is a delight to anyone sufficiently acquainted with these details to appreciate the ability shown. The knowledge of the conventions used, the accuracy of scale, the methods of representing this or that detail of construction show a wonderful facility of execution and broad acquaintance with such work. Likewise, the structural or the machine draftsman, with the same precision and with no mean engineering ability and inventive skill, will draw the complete details for a bridge truss, a steel frame of an office building, or a complicated machine. He will give just the information necessary for the steel fabricator, for the contractor on the work, for the pattern maker, and for the shop man.

¶ All of these details represent advanced processes in architectural and engineering drafting. And yet, these same men who show such skill had to acquire their training through careful and painstaking study and practice of the rudiments of mechanical drawing. They had first to lay their foundation for the more advanced work by learning the kind of equipment necessary for drawings of various kinds, the use of the T-square, the triangles, the ruling pen, and all the other instruments which must be used from time to time. They had to train their eyes to visualize objects and measure distances, and their hands to draw, with precision, lines of uniform width and accurate direction. They had to learn the rules of geometrical construction; the methods of representing plans and elevations of objects; and the principles of orthographic and isometric projection and profile work.

¶ All of these important features are carefully treated in this work; the studies are illustrated by diagrams and plates, and the student is carried from the simplest drawing problems to those which, in difficulty, border on the architectural and engineering fields. It is the hope of the publishers that the book will be found a useful addition to engineering literature.



SECTIONAL ELEVATION OF NEW CROSSLEY OIL ENGINE
Courtesy of Crossley Brothers, Manchester, England

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PROJECTIONS

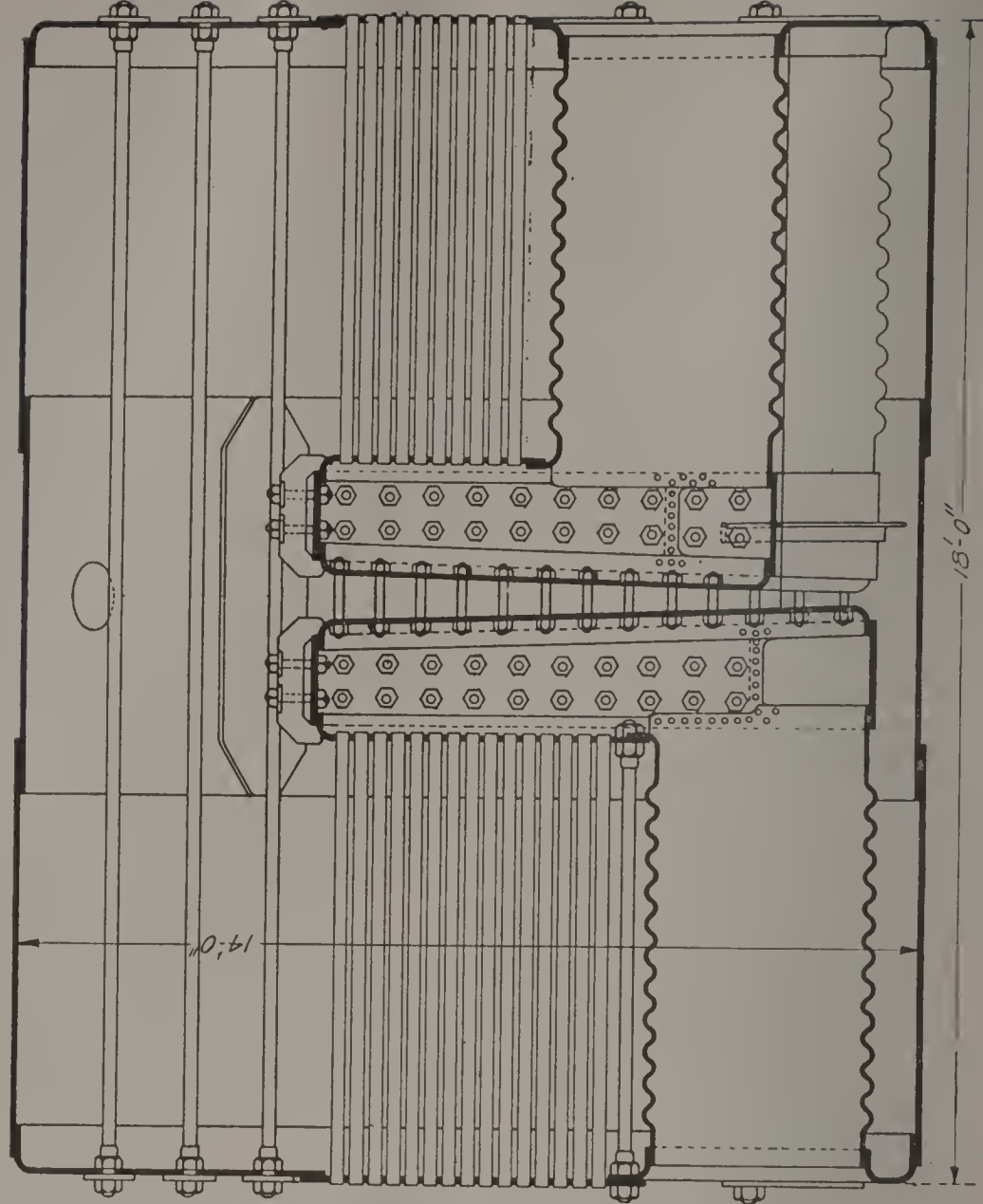
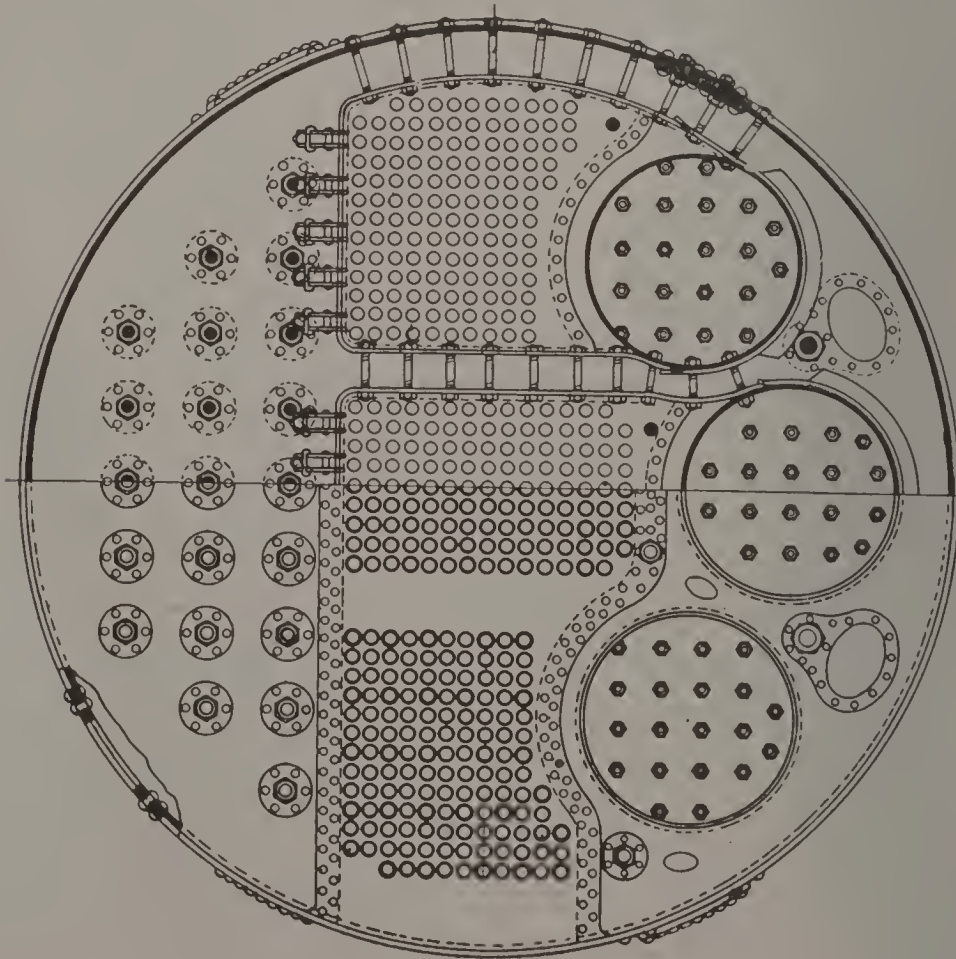
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VERTICAL AND LONGITUDINAL SECTIONS OF 3-FLUE, DOUBLE-ENDED RETURN-TUBE BOILER

MECHANICAL DRAWING

PART I

The subject of mechanical drawing is of great interest and importance to all mechanics and engineers. Drawing is a method of showing graphically the minute details of machinery; it is the language by which the designer speaks to the workman; it is the most graphical way of placing ideas and calculation on record. A brief inspection of an accurate, well-executed working drawing gives a better idea of a machine than a lengthy written or verbal description. The better and more clearly a drawing is made, the more intelligently the workman can comprehend the ideas of the designer. Thorough training in this important subject is necessary to the success of everyone engaged in mechanical work.

The draftsman is dependent for his success, to a certain extent, upon the quality of the instruments and materials which he uses. As a beginner, he will find a cheap grade of instrument sufficient for his needs; but after he has become expert, it will be necessary for him to procure those of better construction and finish to enable him to do accurate work. It is a better plan to purchase the well-made instruments, if possible, at the start.

INSTRUMENTS AND MATERIALS

Drawing Paper. In selecting drawing paper, the first thing to be considered is the kind of paper most suitable for the proposed work. For shop drawings, a manila paper is frequently used on account of its toughness and strength, for these drawings are likely to be subjected to considerable hard usage. If a finished drawing is to be made, the best white drawing paper should be obtained, so that the drawing will not fade or become discolored with age. A good drawing paper should be strong; should have uniform thickness and surface; should stretch evenly and lie smoothly when stretched

or when ink or colors are used; should neither repel nor absorb liquids; and should allow considerable erasing without spoiling the surface. It is, of course, impossible to find all of these qualities in any one paper, as great strength cannot be combined with fine surface. However, a kind should be chosen which combines the greatest number of these qualities for the given work. Of the higher grades of papers, Whatman's are considered by far the best. This paper, either side of which may be used, is made in three grades: the *hot pressed*, which has a smooth surface and is especially adapted for pencil and very fine line drawing; the *cold pressed*, which is rougher than the hot pressed, has a finely grained surface, and is more suitable for water color drawing; and the *rough*, which is used for tinting. For general work, the cold pressed is the best as erasures do not show as plainly on it, but it does not take ink as well as the hot pressed.

Whatman's paper comes in sheets of standard sizes as follows:

Cap	13×17 inches	Imperial	22×30 inches
Demy	15×20 "	Atlas	26×34 "
Medium	17×11 "	Double Elephant	27×40 "
Royal	19×24 "	Antiquarian	31×53 "
Super-Royal	19×27 "		

The usual method of fastening paper to a drawing board is by means of thumb tacks or small one-ounce copper or iron tacks. First fasten the upper left-hand corner and then the lower right, pulling the paper taut. The other two corners are then fastened, and a sufficient number of tacks placed along the edges to make the paper lie smoothly. For very fine work, however, it is better to stretch the paper and glue it to the board. Turn up the edges of the paper all the way round—the margin being at least one inch—then moisten the surface of the paper by means of a sponge or soft cloth, and spread paste or glue on the turned-up edges. After removing all the surplus water on the paper, press the edges down on the board, commencing at one corner and stretching the paper *slightly*—if stretched too much it is liable to split in drying. Place the drawing board in a horizontal position until the paper is dry, when it will be found to be as smooth and tight as a drum head.

Drawing Board. The drawing board, Fig. 1, is usually made of well-seasoned and straight-grained soft pine, the grain running lengthwise of the board. Each end of the board is protected by a

side strip— $1\frac{3}{4}$ to 2 inches in width—whose edge is made perfectly straight for accuracy in using the T-square. Frequently the end



Fig. 1. Drawing Board

pieces are fastened by a glued matched joint, nails or screws. Two cleats on the bottom, extending the whole width of the board, will reduce the tendency to warp. Drawing boards are made in sizes to accommodate the sizes of paper in general use.

Thumb Tacks. Thumb tacks are used to fasten the paper to the drawing board. They are usually made of steel, pressed into shape—as in the cheaper grades—or with heads of German silver, the points being screwed and riveted to them. For most work, draftsmen use small one-ounce copper or iron tacks, as they are cheap and can be forced flush with the drawing-paper, thus offering no obstruction to the T-square.

Pencils. Lead pencils are graded according to their hardness, the degree of which is indicated by the letter H—as HH, 4H, 6H, etc. For general use a lead pencil of 5H or 6H should be used, although a softer 4H pencil is better for making letters, figures, and points. The hard lead pencil should be sharpened as shown in Fig. 2 so that in penciling a drawing the lines may be made very fine and light. The wood is cut away so that about $\frac{1}{4}$ or $\frac{1}{2}$ inch of lead

projects. The lead can then be sharpened to a chisel edge by rubbing it against a bit of sand paper or a fine file, and the corners slightly rounded. In drawing the lines the draftsman should place the chisel

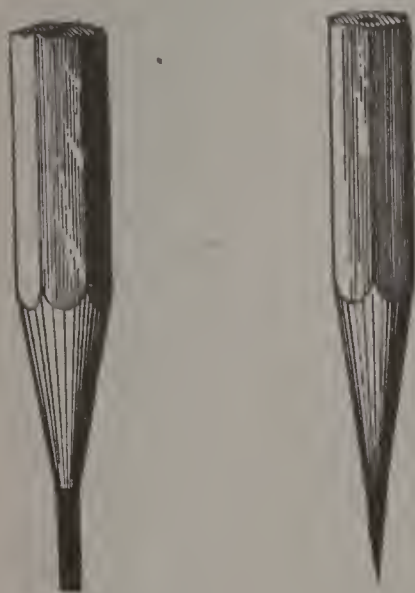


Fig. 2. Pencil Sharpened to a Chisel Point

edge against the T-square or triangle, thus enabling him to draw a fine line exactly through a given point. If the drawing is not to be inked, but is made for tracing or for rough usage in the shop, a softer pencil, 3H or 4H, may be used, so as to make the lines somewhat thicker and heavier. The lead for compasses may also be sharpened to a point although some draftsmen prefer to use a chisel edge for the compasses as well as the pencil.

In using a very hard lead pencil a light pressure should be used as otherwise the chisel edge will make a deep impression in the paper which cannot be erased.

Erasers. What little erasing is necessary in making drawings, should be done with a soft rubber. To avoid erasing the surrounding work some draftsmen use a card in which a slit is cut about 3 inches

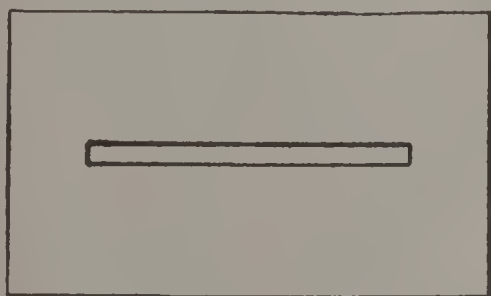


Fig. 3. Erasing Shield

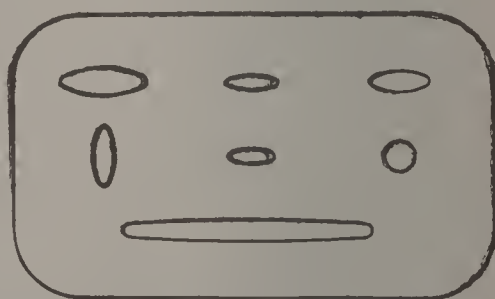


Fig. 4. Metal Erasing Shield

long and $\frac{1}{8}$ to $\frac{1}{4}$ inch wide, Fig. 3. An erasing shield of thin metal, Fig. 4, is also very convenient, especially in erasing letters. For cleaning drawings when they are completed, a sponge rubber or a preparation called "art gum" may be used, but in either case care should be taken not to make the lines dull by too hard rubbing.

T-Square. The T-square, which gets its name from its general shape, consists of a thin straight-edge, the *blade*, with a short piece, the *head*, fastened at right angles to it, Fig. 5. T-squares are usually made of wood, the pear and maple woods being used in the cheaper grades, and the harder woods, like mahogany, with protecting edges

of ebony or celluloid, Fig. 6, in the more expensive instruments. The head is designed to fit against the edge of the drawing board, allowing the blade to extend across the surface of the board. It is

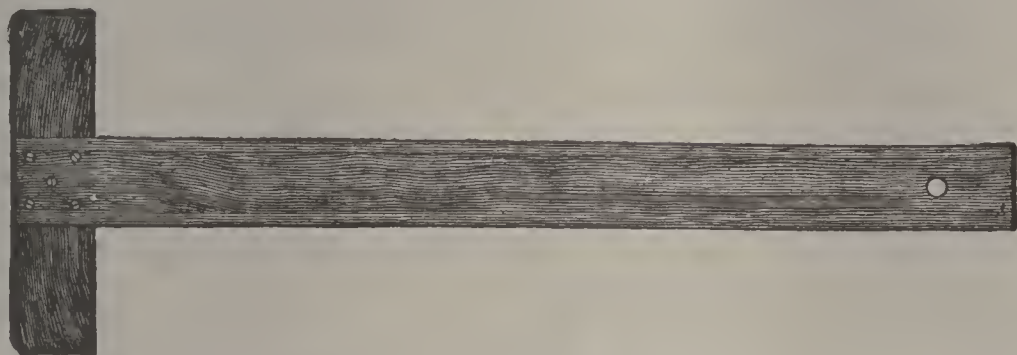


Fig. 5. Common T-Square

desirable to have the blade of the T-square make a right angle with the head, but this is not absolutely necessary, if the head is always placed against the left-hand edge of the board, for the lines drawn

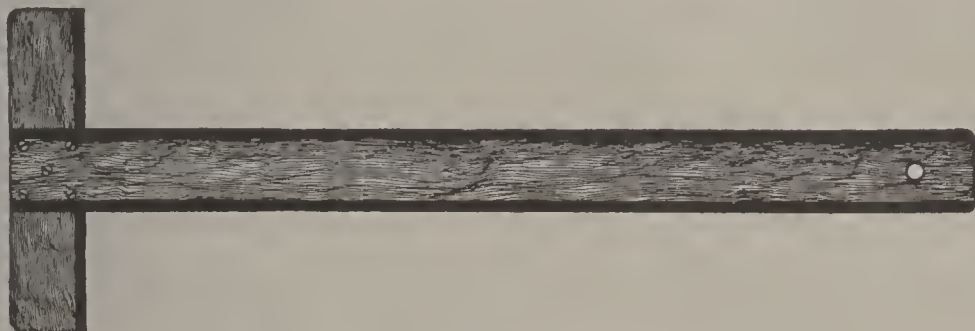


Fig. 6. Mahogany-Bound T-Square

with the T-square will then be referred to one edge of the board only, and if this edge is straight, the lines will be parallel to each other.

T-squares are sometimes provided with swiveled heads as it is frequently very convenient to draw lines parallel to each other which are not at right angles to the left-hand edge of the board. To use the T-square in drawing parallel horizontal lines,* place the head of the T-square in contact with the left-hand edge of the board, Fig. 7, and draw the pencil along the *upper edge* of the blade at each new position of the T-square. Only the upper edge should be used as the

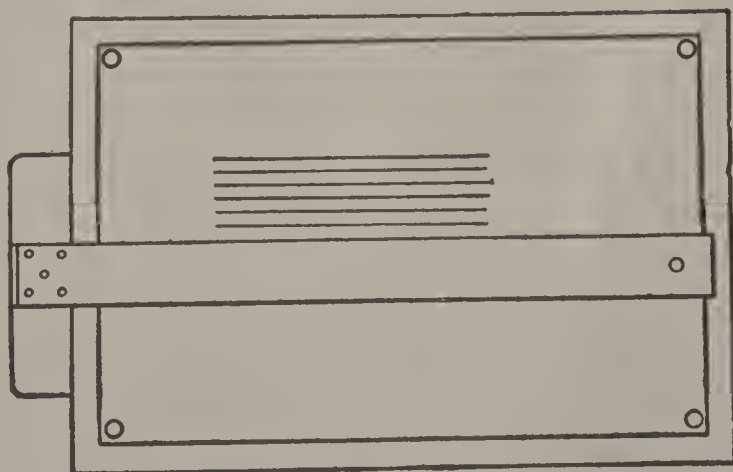


Fig. 7. Drawing Parallel Lines

* See page 23.

two edges may not be exactly parallel and straight. In trimming drawings or cutting the paper from the board, always use the *lower edge* of the T-square so that the upper edge may not be made untrue.

For accurate work it is absolutely necessary that the upper edge of the T-square be exactly straight. To test the straightness of the

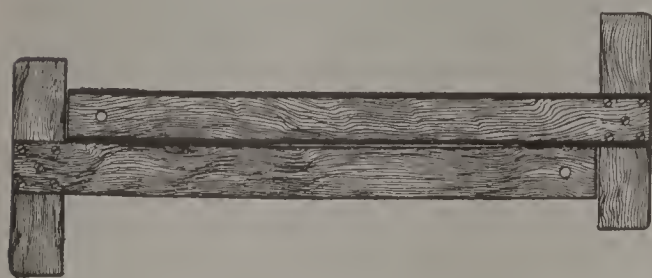


Fig. 8. Testing the Edge of T-Square

edge two T-squares may be placed together as shown in Fig. 8. However, a lack of contact such as shown in the figure does not prove which edge is crooked, and for this determination a third blade must be used and tried

with the two given T-squares successively.

Triangles. Triangles are made of various substances such as wood, rubber, celluloid, and steel. Wooden triangles are cheap but are likely to warp out of shape; rubber triangles are frequently used, and are, in general, satisfactory; celluloid triangles are extensively used on account of their transparency, which enables the draftsmen to see the work already done even when covered with the triangle.

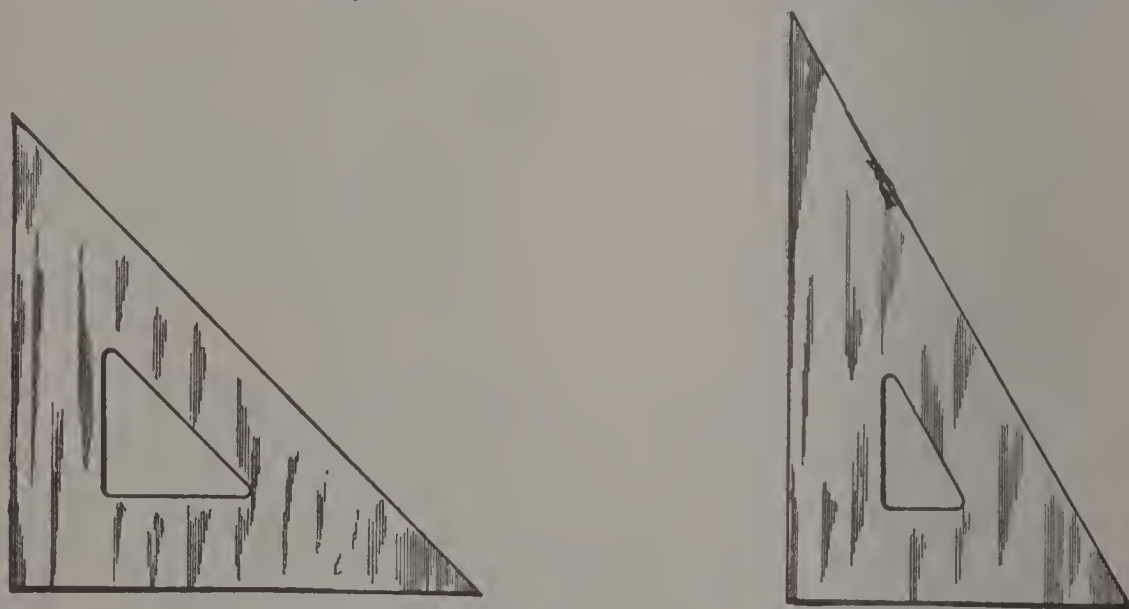


Fig. 9. 45° and 30° - 60° Triangles

In using a rubber or celluloid triangle take care that it lies perfectly flat and is hung up when not in use; when allowed to lie on the drawing board with a pencil or an eraser under one corner it will become warped in a short time, especially if the room is hot or the sun happens to strike the triangle.

Triangles from 6 to 8 inches on a side will be found convenient for most work, although there are many cases where a small triangle

measuring about 4 inches on a side will be found useful. Every draftsman should have at least two triangles, one having two angles of 45 degrees and one right angle; and the other having angles of 30, 60, and 90 degrees, respectively, Fig. 9.

The value of the triangle depends upon the accuracy of the angles and the straightness of the edges. To test the accuracy of

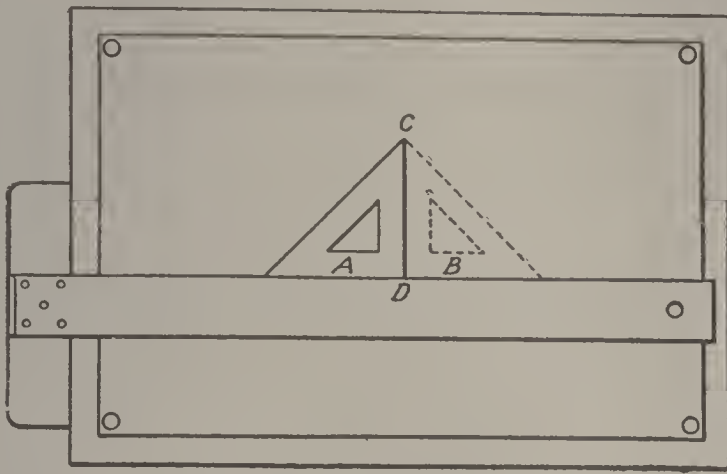


Fig. 10. Testing a Right Angle (45° Triangle)

the right angle of a triangle, place the triangle with the lower edge resting on the T-square in position *A*, Fig. 10. Now draw the line *CD*, which, if the triangle be true, will be perpendicular to the edge of the T-square. Transfer the triangle to position *B*, and if the right angle of the triangle is exactly 90 degrees the left-hand edge of the triangle will exactly coincide with the line *CD*.

To test the accuracy of the 45-degree angles place the triangle with the lower edge resting on the working edge of the T-square,

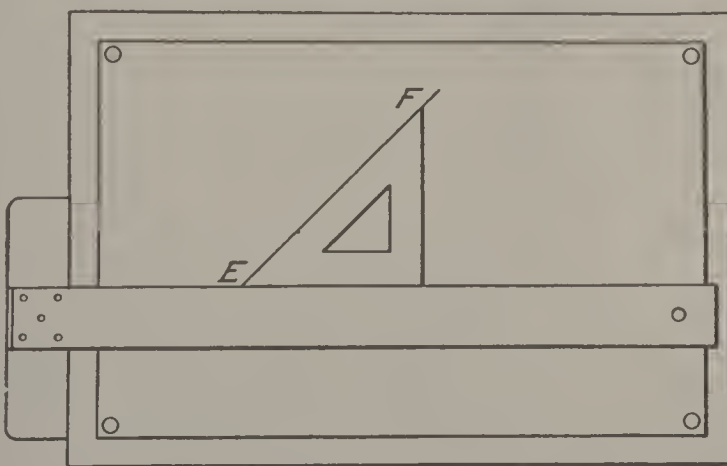


Fig. 11. Testing 45° Angle (45° Triangle)

and draw the line *EF*, Fig. 11. Now without moving the T-square place the triangle so that the other 45-degree angle is in the position occupied by the first. If the two 45-degree angles coincide they are accurate.

Triangles are used in drawing lines at right angles to the T-square, Fig. 12, and at an angle with the horizontal, Fig. 13. If it is desired to draw a line through the point P , Fig. 14, parallel to a given

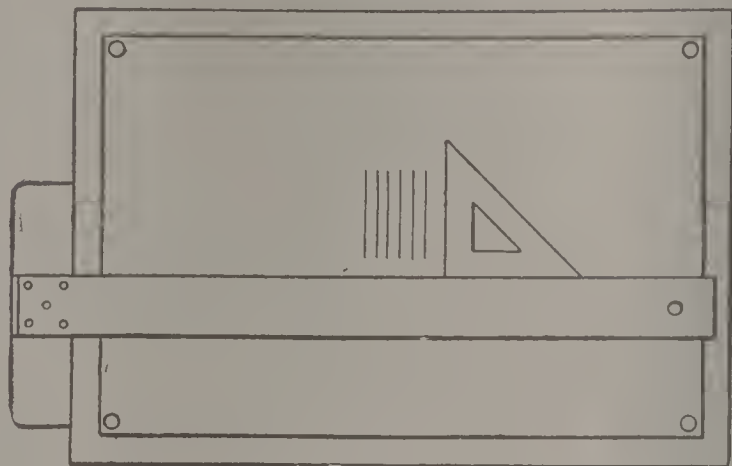


Fig. 12. Drawing Vertical Parallel Lines

line EF , two triangles should be used. First, place triangle A with one edge coinciding with the given line. Now take triangle B and place one of its edges in contact with the bottom edge of triangle A . Holding triangle B firmly with the left hand, slide triangle A to the right or to the left until its edge reaches the point P . The line MN may then be drawn passing through the point P . In place of the triangle B any straight-edge such as a T-square may be used.

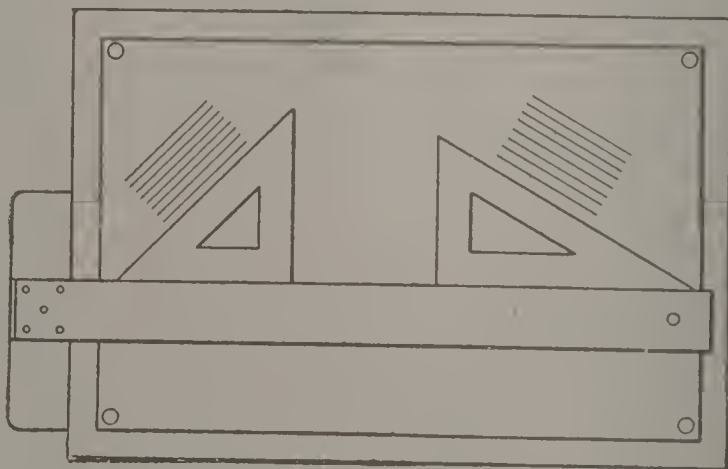


Fig. 13. Drawing Parallel Lines at an Angle with the Horizontal

A line may be drawn through a point, perpendicular to a given line by means of triangles as follows: Let EF , Fig. 15, be the given line, and let the point be D . Place the longest side of triangle A so that it coincides with the line EF . Place the other triangle (or any straight-edge) in the position of the triangle B ; then holding B with the left hand, place the triangle A in the position C , so that the longest side passes through the point D . A line may then be drawn through the point D perpendicular to EF .

In previous figures it has been shown how lines may be drawn making angles of 30, 45, 60, and 90 degrees with the horizontal.

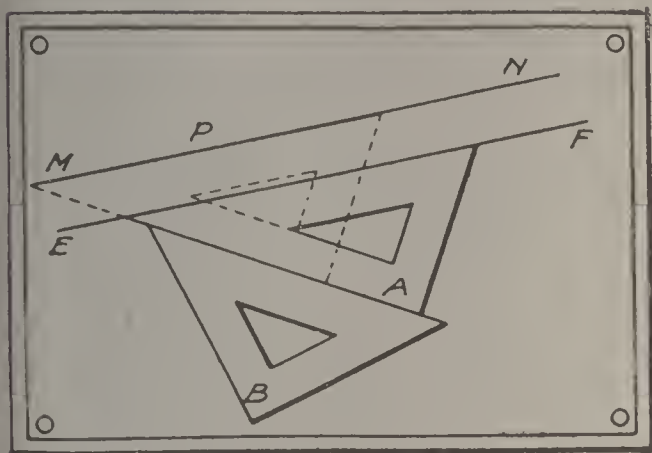


Fig. 14. Drawing a Line Parallel to a Given Line

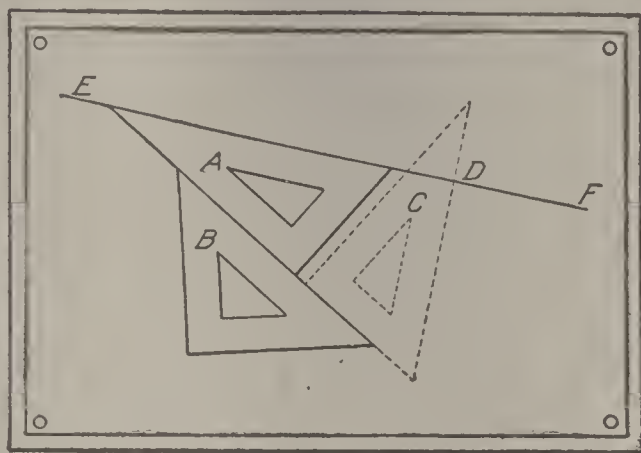


Fig. 15. Drawing a Line Perpendicular to a Given Line

It is possible to draw lines forming angles of 15 and 75 degrees by placing the triangles as shown in Fig. 16.

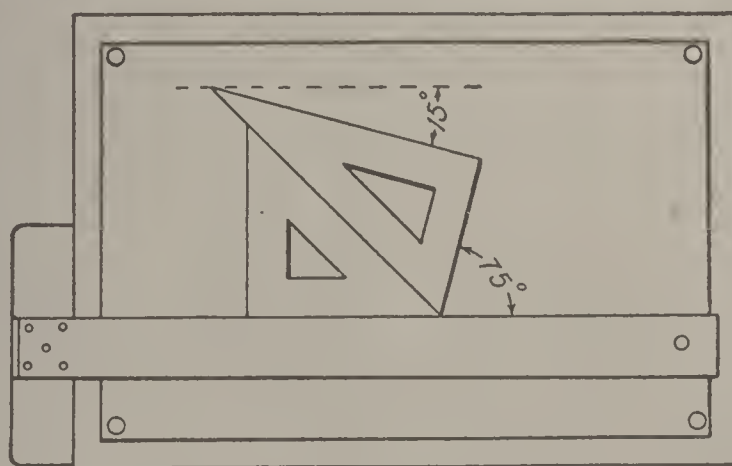


Fig. 16. Drawing Angle of 15° and 75°

By the use of the triangles and T-square almost any line may be drawn. Suppose it is desired to draw a rectangle having one side

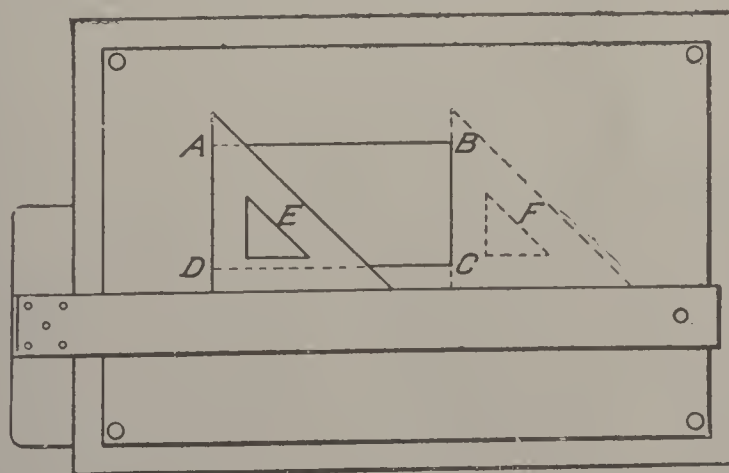


Fig. 17. Drawing a Rectangle with T-Square and Triangle

horizontal. First draw by means of the T-square the sides AB and DC horizontal and parallel, Fig. 17. Now place one of the

triangles on the T-square and in positions *E* and *F* draw the vertical lines *D A* and *B C*.

If the rectangle is to be drawn in some other position on the board, as shown in Fig. 18, place the 45-degree triangle *F* so that the longest edge is in the required direction of the side *D C*. Now, hold the triangle *F* in position and place another triangle in position *H*. By holding *H* in position and sliding triangle *F*, the sides *A B* and *D C* may be drawn. To draw the sides *A D* and *B C* change triangle *F* to position *E* and repeat the process.

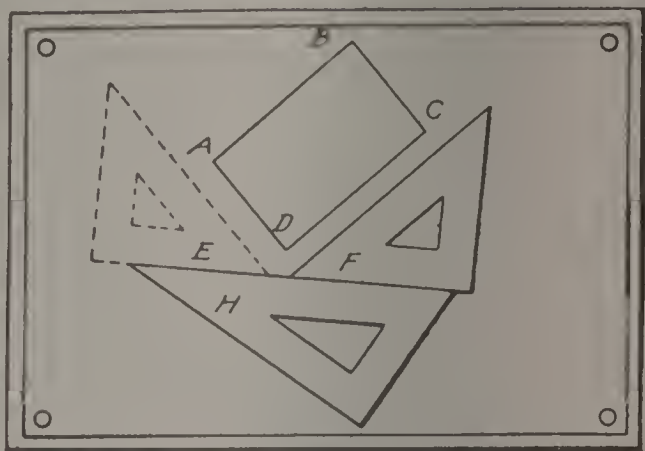


Fig. 18. Rectangle Drawn with Triangles

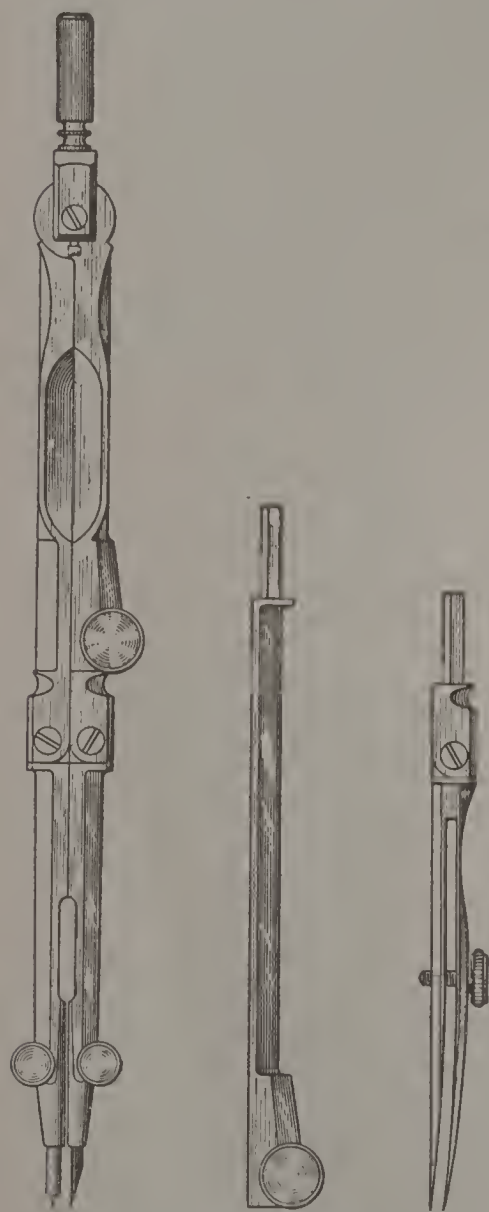


Fig. 19. Compasses and Attachments

Compasses. Compasses are used for drawing circles and arcs of circles. The cheaper class of instruments are made of brass, but they are unsatisfactory on account of the odor and the tendency to tarnish. The best material is German silver, as it does not soil the hands, has no odor, and is easy to keep clean. Aluminum instruments possess the advantage of lightness, but on account of the softness of the metal they do not wear well.

The compasses are made in the form shown in Fig. 19 and are provided with pencil and pen points. Fig. 20 shows the compass in position for drawing circles. One leg has a socket into which the shank of the pencil or pen mounting may be inserted. The other leg is fitted with a needle point which is placed at the center of the circle. In most instruments the needle point projects through a piece of round steel wire with a square shoulder at one or both ends.

In some instruments the joints are held in position by lock nuts,

made of thin disks of steel, with notches for using a wrench or forked key. Fig. 21 shows the detail of the joint of a high grade instrument.

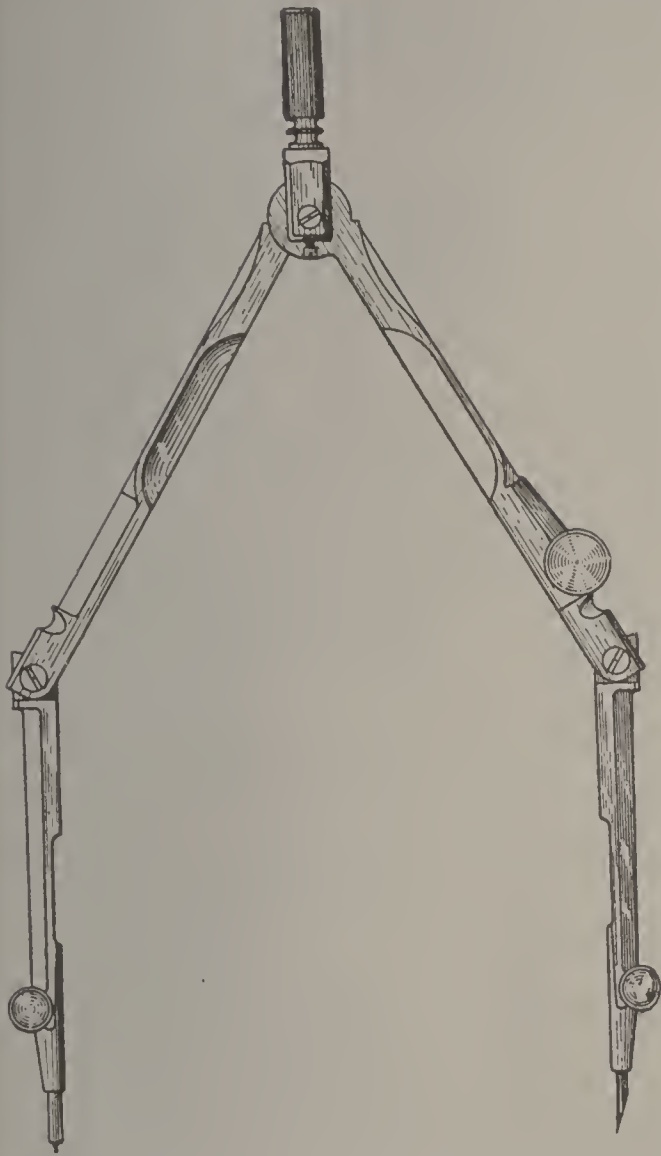


Fig. 20. Compasses Set for Drawing Circles in place by means of the screw. arrangement is not durable because the sharp corners soon wear, and the pressure on the set screw is not sufficient to hold the shank firmly in place.

In Fig. 23 is shown a round shank, the shank having a flat top, with a set screw to hold the shank in position. A still better form of socket is shown in Fig. 24, the hole being circular and tapered. The shank fits accurately into the split socket and is clamped by a screw on the side; it is held in perfect alignment by a small steel key.

Both legs of the compass are jointed in order that the lower part

Both legs are alike at the joint, and two pivoted screws are inserted in the yoke. This permits ample movement of the legs, yet gives the proper stiffness. The flat surface of one leg is faced with steel, the other with German silver, so that the rubbing parts may be of different metals. Small set screws are used to prevent the pivoted screws from turning in the yoke. The contact surfaces of this joint are made circular to exclude dirt and to prevent rusting of the steel face.

The details of the socket are shown in Fig. 22, Fig. 23, and Fig. 24; in some instruments the shank and socket are pentagonal, Fig. 22, the shank entering the socket loosely, and being held Unless used very carefully this

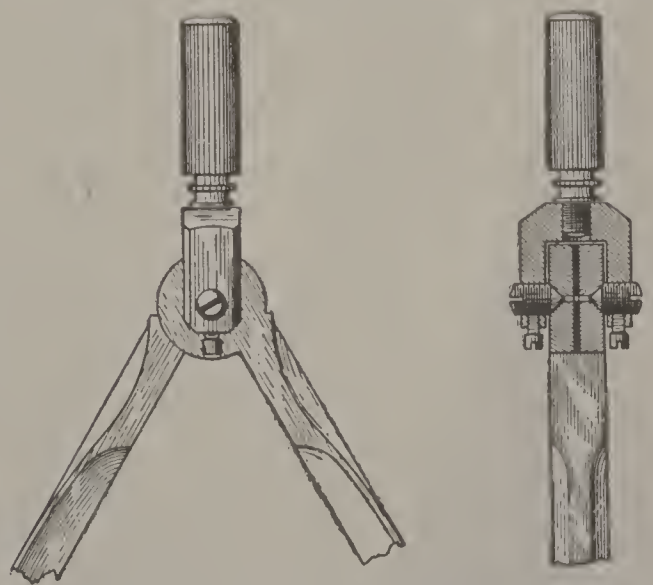


Fig. 21. Details of Compass Joint

The shank fits accurately into the split socket and is clamped by a screw on the side; it is held in perfect alignment by a small steel key.

of the legs may be perpendicular to the paper while drawing circles. In this way the needle point makes but a small hole in the paper, and both nibs of the pen will press equally on the paper. In penciling circles it is not as necessary that the pencil should be kept vertical;



Fig. 22. Pentagonal Shank and Socket



Fig. 23. Circular Shank and Socket

it is a good plan, however, to learn to use them in this way both in penciling and inking. The compasses should be held loosely between the thumb and forefinger. If the needle point is sharp, as it should be, only a slight pressure will be required to keep it in place. While drawing the circle, incline the compasses slightly in the direction of revolution and press lightly on the pencil or pen.

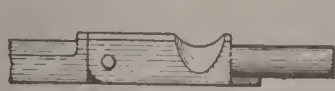


Fig. 24. Circular Socket with Set Screw



Fig. 25
Dividers

In removing the pencil or pen attachment from the compass it should be pulled out straight in order to avoid enlarging the socket, and thus rendering the instrument inaccurate. For drawing large circles use the lengthening bar, Fig. 19, steadying the needle point with one hand and describing the circle with the other.

Dividers. Dividers, which are similar to compasses, are used to lay off distances on the drawing, either from a scale or from other parts of the drawing, Fig. 25. They are also used for dividing a line into equal parts. To do this turn the dividers in the opposite direction each time, *i. e.*, move the point alternately to the right and to the left. The points of the dividers should be very sharp so that the holes made in the paper will be small, thus assuring accurate spacing. Compasses may be used as dividers by substituting for the pencil or pen point an extra steel point, usually furnished with the instrument. In place of dividers many draftsmen use a *needle point*. The needle, with the eye-end broken off, is forced into a handle of soft pine, making a convenient instrument for marking line intersections and distances.

Bow Pen and Bow Pencil. Ordinary large compasses are too heavy and the leverage of the long leg is too great to allow small circles to be drawn accurately. For this reason the bow compasses, Figs. 26 and 27, should be used on all arcs and circles having a radius of less than $\frac{3}{4}$ inch, such as those which represent boiler tubes and bolt

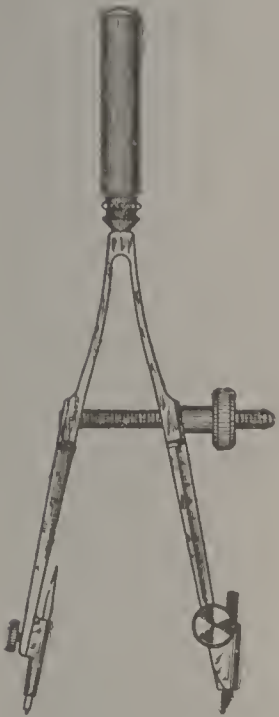


Fig. 26. Bow Pencil

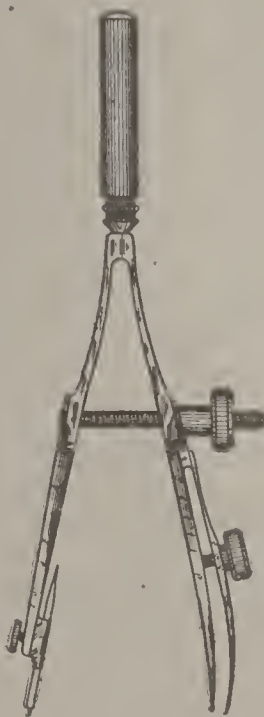


Fig. 27. Bow Pen

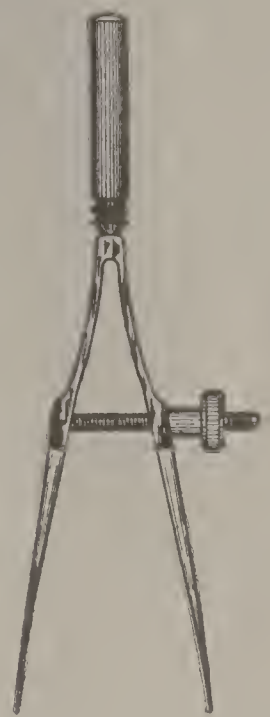


Fig. 28. Bow Divider

holes. When small circles are drawn, the needle point must be adjusted to the same length as the pen or pencil point. If a considerable change in radius is made, press the points together before turning the nut so as to prevent wear in the screw threads. The bow dividers, Fig. 28, replace the ordinary dividers in small work and have the advantage of a fixed adjustment.

Drawing Pen.* For drawing straight lines and curves that are not arcs of circles, the line pen—sometimes called the *ruling pen*—is



Fig. 29. Drawing Pen

used, Fig. 29. The distance between the pen points, which regulates the width of line to be drawn, is adjusted by the thumb screw, and the blades are given a slight curvature so that there will be a cavity for ink when the points are close together.

*See page 22.

The pen should not be dipped in the ink but should be filled by means of a common steel pen or quill, to a height of about $\frac{1}{4}$ or $\frac{3}{8}$ inch; if too much ink is placed in the pen it is likely to drop out and spoil the drawing. Upon finishing the work wipe the pen with chamois or a soft cloth, because most liquid inks corrode the steel.

In using the pen, care should be taken that both blades bear equally on the paper, in order that the line may be smooth. The pen is usually inclined slightly in the direction in which the line is drawn and should touch the triangle or T-square lightly so as not to press the blades together and thereby change the width of the line; the pen must not be tipped outward, however, as the danger of blotting is greatly increased when the line is drawn so close to the guide.

Sharpening the Drawing Pen. When it is impossible to make a smooth line with the drawing pen, it should be sharpened. Screw the blades together and grind them to a parabolic shape by drawing the pen back and forth over a small, flat, close-grained oilstone. This process, of course, makes the blades dull but insures their being of the same length. Now separate the points slightly and rub one of them on the oilstone, keeping the pen at an angle of from 10° to 15° with the face of the stone, and giving it a slight twisting movement. This part of the operation requires great care as the shape of the ends must not be altered. After one point has become fairly sharp, grind the other in a similar manner, grinding always on the *outside* of the blades and removing the burr from the inside with leather or pine wood. Test the pen by filling with ink and drawing several lines. Unless the lines are smooth, the grinding must be continued.

Ink. India ink is always used for drawing as it makes a permanent black line; it is obtainable in solid stick or liquid form. The liquid form is much more convenient but contains acid which corrodes steel and makes it necessary to keep the pen perfectly clean.

To prepare the ink in stick form for use, put a little water in a saucer and place one end of the stick in it; then by a twisting motion grind enough ink to make the water black and slightly thickened. Now draw a heavy line on a sheet of paper and if after drying the line has a grayish appearance, more grinding is necessary. Wipe the stick dry after using to prevent crumbling. It is well to grind the ink in small quantities as it does not dissolve readily a second time; however, if covered it will keep for two or three days.

Scales. The scales used for obtaining measurements on drawings are made in several forms, the most convenient being the *flat*, with beveled edges, and the *triangular*. The scale is usually graduated for a distance of 12 inches. The triangular scale, Fig. 30, has six

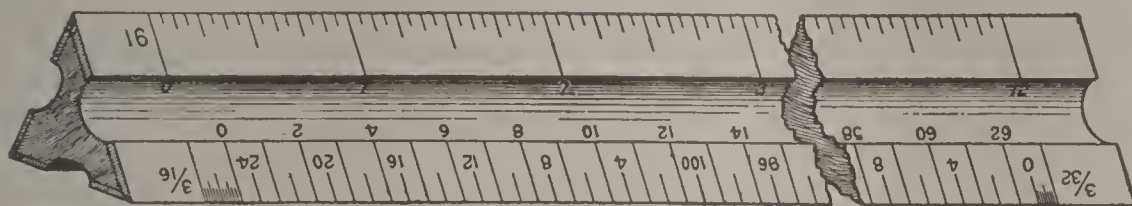


Fig. 30. Triangular Scale

surfaces for different graduations, and the scales are arranged so that the drawings may be made in any proportion to the actual size. For mechanical work, the common divisions are multiples of two; thus drawings are made full size, $\frac{1}{2}$ size, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, $\frac{1}{32}$, $\frac{1}{64}$, etc. If a drawing is $\frac{1}{4}$ size, 3 inches equals 1 foot, hence 3 inches is divided into 12 equal parts and each division represents one inch. If the smallest division on a scale represents $\frac{1}{16}$ inch, the scale is said to read to $\frac{1}{16}$ inch.

Scales are often divided into $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{30}$, $\frac{1}{40}$, etc., for architects and civil engineers, and for measuring indicator cards.

The scale should never be used as a substitute for the triangle or T-square in drawing lines.

Protractor. The protractor, an instrument used for laying off and measuring angles, is made of steel, brass, horn, or paper. When

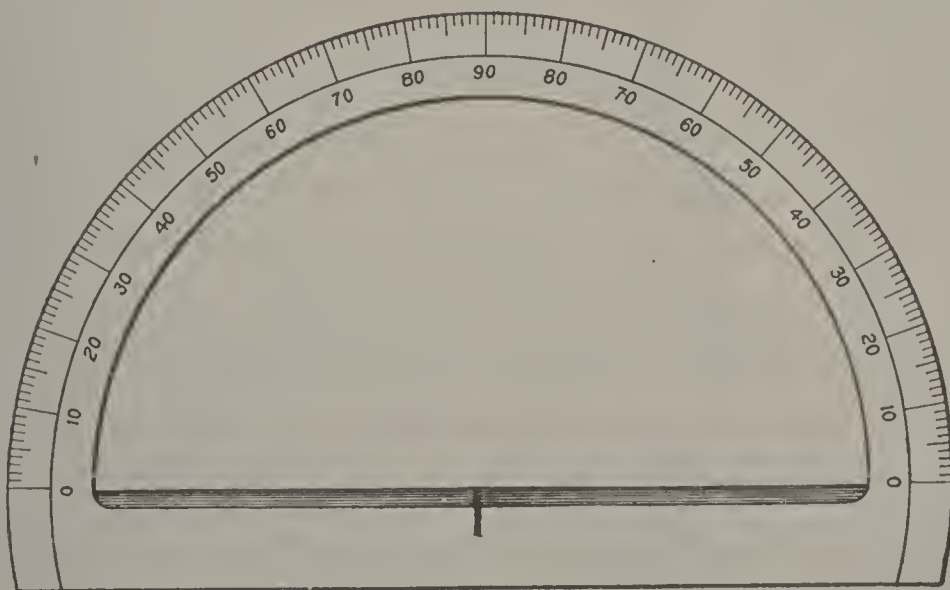


Fig. 31. Protractor

made of metal the central portion is cut out, Fig. 31, so that the draftsman may see the drawing. The outer edge is divided into degrees

and tenths of degrees. To lay off the required angle—use a very sharp, hard pencil in order that the measurements may be accurate—place the protractor so that the two zero marks are on the given line, produced, if necessary, and the center of the circle is at the point through which the desired line is to be drawn.

Irregular Curve. One of the conveniences of a draftsman's outfit is the *French* or *irregular curve*, which is used for drawing curves other than arcs of circles, with either pencil or line pen. This instrument, which is made of wood, hard rubber, or celluloid—celluloid being the best—is made in various shapes, one of the most common being shown in Fig. 32. Curves drawn with an irregular curve are called *free hand curves*.

To draw a curve through a series of located points find that position of the irregular curve that passes through three points,

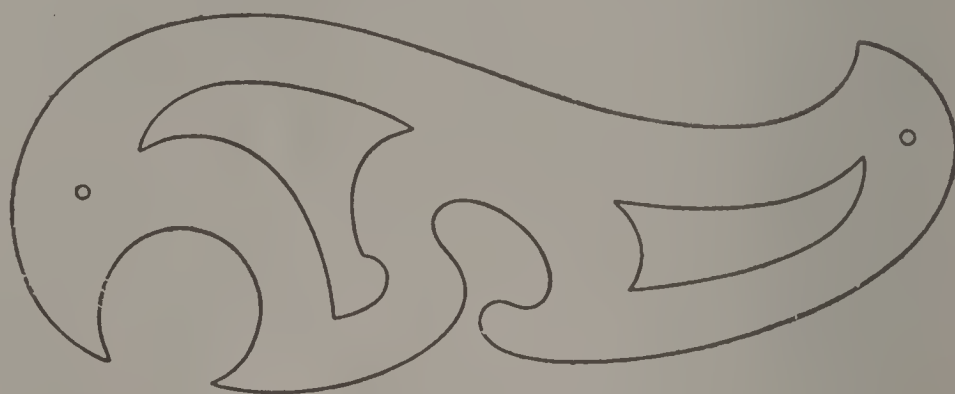


Fig. 32. Typical Irregular Curve

say, and draw the line through them, Fig. 33. Now shift the curve so as to include a part of the curve already drawn and two or three more points. Draw the curve through these points, continuing this process until the curve is completed. If, at each new setting, the line is not carried quite as far as the coincidence of the irregular curve would permit, a smoother curve will result. It frequently facilitates the work and improves its appearance to draw a pencil curve free hand through the points and then use the irregular curve, taking care that it always fits at least *three* points. In inking the curve, the blades of the pen must be kept tangent to the curve. For certain kinds of work, irregular curves of plastic metal are sometimes used to fit exceptionally erratic curves.

Beam Compasses. The ordinary compasses are suitable for drawing circles up to 8 or 10 inches diameter. For larger circles beam compasses are provided. The two parts called *channels*

which carry the pen or pencil and the needle point are clamped to a wooden beam at a distance equal to the radius of the circle. The



Fig. 33. Channels of Beam Compass

thumb nut underneath one of the channel pieces makes accurate adjustment possible.

LETTERING

No mechanical drawing is finished unless all headings, titles, and dimensions are lettered in plain, neat type. Many drawings are accurate, well-planned, and finely executed but do not present a good appearance because the draftsman did not think it worth while to letter carefully. Lettering requires time and patience especially for the beginner; and many think it a good plan to practice lettering before commencing drawing. Poor writing need not necessarily mean poor lettering, for good writers do not always letter well.

In making large letters for titles and headings it is often necessary to use drawing instruments and mechanical aids, but small letters, such as those used for dimensions, names of materials, dates, etc., should be made free-hand.

Forming. The student is apt to think that lettering is a form of mechanical drawing, that the use of the straight-edge is the principal operation, and that letters, forms, and the spaces between are to be figured out by measurement. On the contrary, lettering is design, and the draftsman so distributes the letters in the spaces arranged for them as to make a combination that will be pleasing to the eye. The requirements for a good design are simplicity and uniformity. These are acquired by accuracy in detail and by good judgment and taste, as no practical rules can be followed which will

invariably produce the same result. Letter forms are, to a certain extent, standard. The lettering for a title is usually done very carefully and accurately, while practically all of the other lettering on a drawing is done rapidly and in a simple style. To develop a letter use the same method of procedure as in drawing a straight line between two points. First, draw the guide lines rather carefully and then block out the general form of the letter by a series of short strokes of the pencil. Continue this method, straightening the lines and rounding the curves of the latter until its form is satisfactory.

Spacing. The spacing of the letters is very important and is best obtained by the unaided eye just as are the proportions of the letters. Care must be taken to allow a clear distance between letters the space varying according to the combination. For instance, such letters as *A*, *V*, and *W* spread more at one part than at another and therefore do not fill the space completely. Of course, when the distance between letters is large any such irregularities will not be noticeable. The best method for obtaining good space values is by sketching in the letters roughly and then bringing them to a good appearance by correction and adjustment. The first results are, of course, unsatisfactory, but after the eye and hand have become trained, great improvement will be noticed. A simple aid to this development will be found in the use of a piece of cardboard with the widths of the enclosing rectangles or parallelograms of the different letters marked on its edge, by which the spacing made by the eye may be checked.

Inking. In practical work most of the lettering is penciled in and then finished in ink. As faults in letters which may not be noticed in the penciled work stand out clearly after inking, it is not advisable to ink in the penciled letter accurately, but rather to improve upon it.

For lettering free-hand, use a pen that will make the full weight of line desired without much pressure, holding it squarely on the paper and directly in front. A new pen, which is apt to give too fine a line, may be remedied by scratching a little on a rough surface. If a pen is kept clean and all hardened ink removed so that the nibs are not spread, the pen will last a long time. A coarser pen must be used on rough than on smooth paper.

To remove a faulty line or a blot, let the ink dry thoroughly,

then with a sand rubber, erase the spot carefully, rubbing around it, as well. Clean the sand out of the surface with a pencil eraser and finally polish down with a piece of ivory or smooth wood. Pencil in the parts erased as if doing the work for the first time and again ink in, using special care, as the ink is more likely to spread on an erased surface than anywhere else.

Style. There are many styles of letters used by draftsmen, but almost any neat letter free from ornamentation is acceptable in regular practice. For titles, large Roman capitals are preferred, although Gothic and black letters also look well and are much easier to make. The vertical and inclined or italicized Gothic capitals shown in Fig. 34 and Fig. 35, are neat, plain, and easily made. This

UPRIGHT GOTHIC

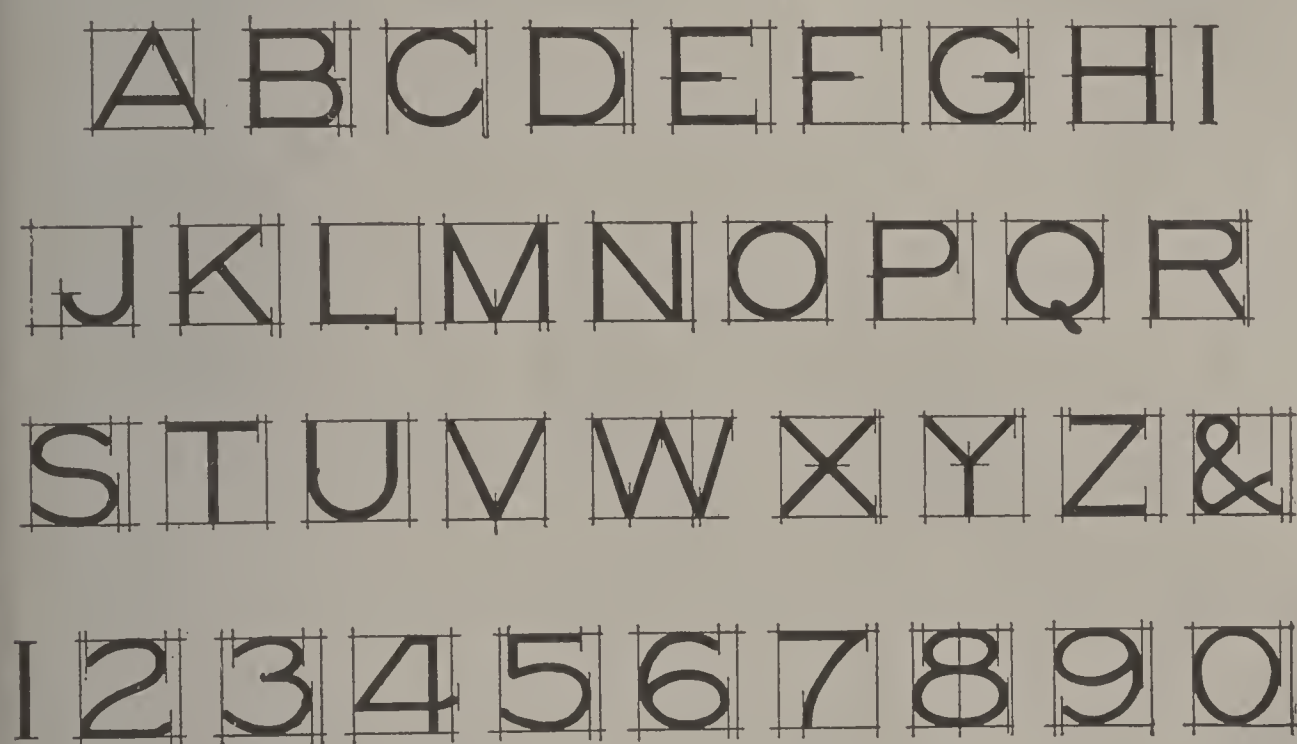


Fig. 34. Upright Gothic Capitals

latter style possesses the advantage over the vertical type in that a slight difference in inclination is not apparent.

The curves of the inclined Gothic letters such as those in *B*, *C*, *G*, *J*, etc., are somewhat difficult to make free-hand, especially if the letters are about one-half inch high. In the alphabet, Fig. 36, the letters are made almost wholly of straight lines, the corners only being curved.

The first few plates of this work will require no titles, the only lettering being the student's name, the date, and the plate number

which will be done in inclined Gothic capitals. Later the subject of lettering will again be taken up in connection with titles and headings for drawings which show the details of machines.

To make the inclined Gothic letters, first draw two parallel lines $\frac{5}{32}$ inch apart to mark the height for the letters of the date, name,

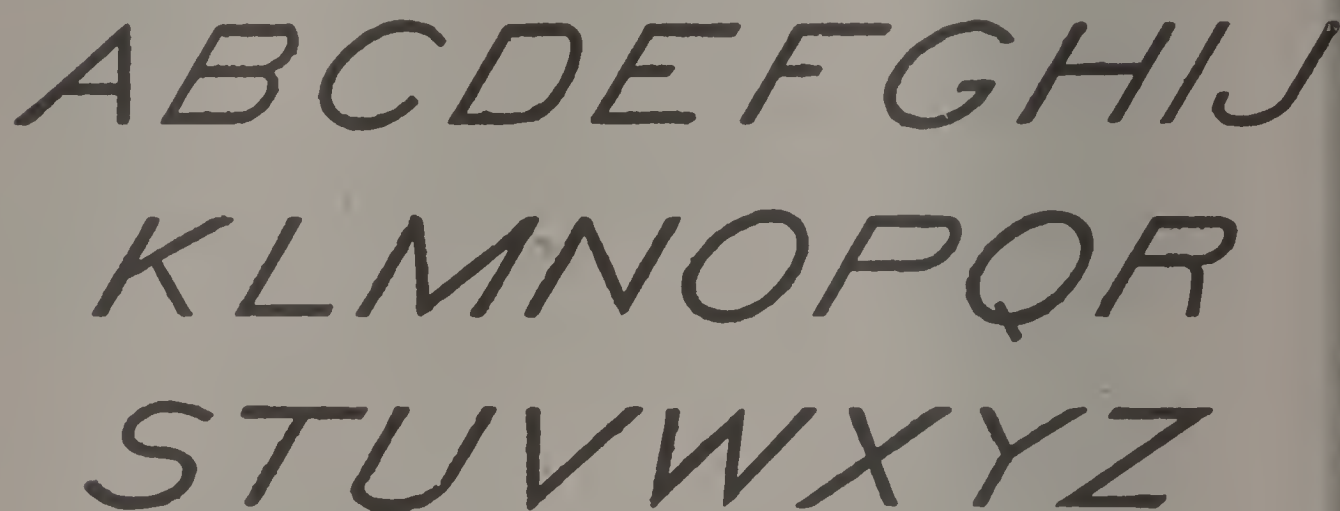


Fig. 35. Inclined Gothic Capitals

and plate number. This is the height to be used on all plates throughout this work, unless other directions are given. When two sizes of letters are used, the smaller should be about two-thirds as high as the larger. The inclination of the letters should be the same for all,

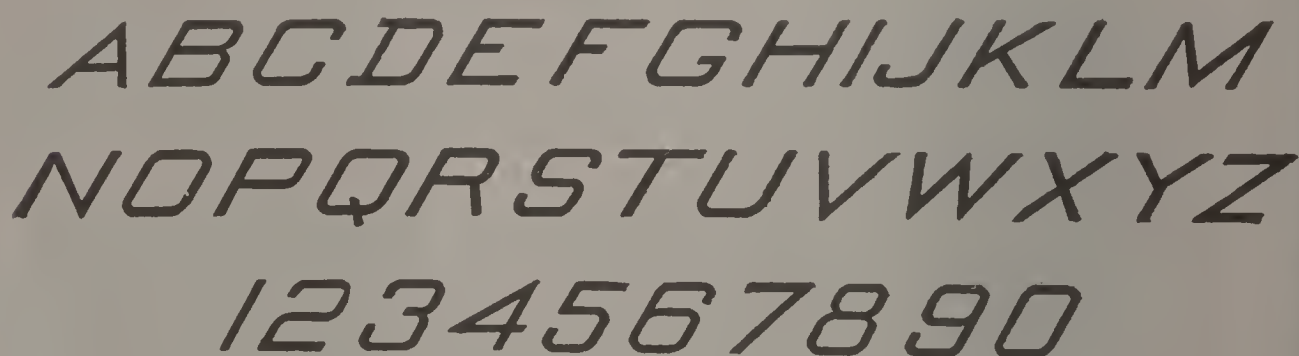


Fig. 36. Inclined Gothic Capitals—Straight Lines with Curved Corners

and as an aid to the beginner, light pencil lines may be drawn about $\frac{1}{4}$ inch apart, forming the proper angle with the parallel lines already drawn; this angle is usually about 70° , but if a 60° triangle is at hand, it may be used in connection with the T-square as shown in Fig. 38.

Capital letters such as *D*, *E*, *F*, *L*, *Z*, etc., should have their top and bottom lines coincide with the horizontal guide lines, as otherwise the work will look uneven. Letters, of which *C*, *G*, *O*, and *Q* are types, may be formed of curved or straight lines. If made of

curved lines, their height should be a little greater than the guide lines to prevent their appearing smaller than the other letters. In this work they may be made of straight lines with rounded corners as such letters are easily constructed and may be made of standard height.

To construct the letter *A*, use one of the 60° lines as a center line. Then from its intersection with the upper horizontal line drop a perpendicular to the lower guide line. Draw another line from the vertex meeting the lower guide line at the same distance on the other side of the center line. The cross line of the *A* should be a little below the center. The *V* is an inverted *A* without the cross line. For the letter *M*, the side lines should be parallel and about the same distance apart as the guide lines. The side lines of the *W* are *not* parallel but are farther apart at the top. The *J* is not quite as wide as such letters as *H*, *E*, *N*, *R*, etc. To make a *Y*, use the same spread as in making a *V* but let the diverging lines meet the center line a little below the middle.

The lower-case letters are shown in Fig. 37. In such letters

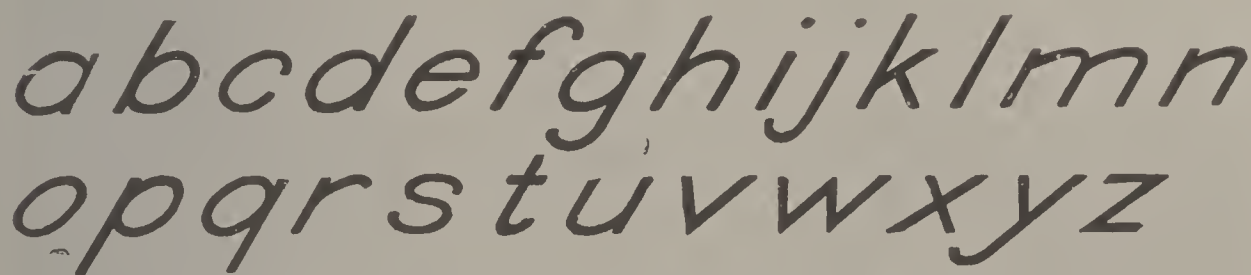


Fig. 37. Inclined Gothic Lower-Case Letters

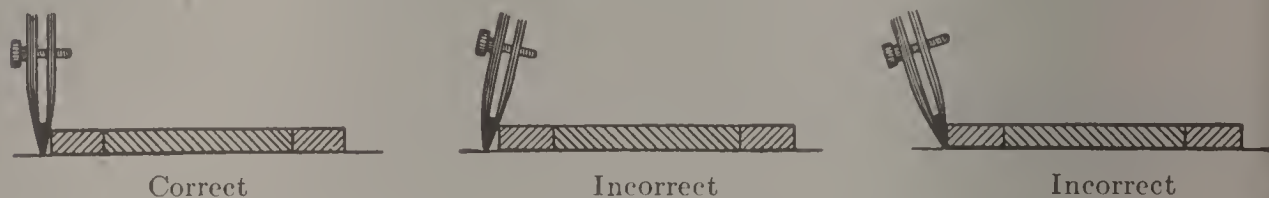
as *m*, *n*, *r*, etc., make the corners slightly rounding. The letters *a*, *b*, *c*, *e*, *g*, *o*, *p*, *q*, should be full and rounding.

The style of the Arabic numerals is given in Fig. 36; Roman numerals are made of straight lines.

At first the copy should be followed closely and the letters drawn in pencil; the inclined guide lines may be used until the proper inclination becomes firmly fixed in mind when they should be abandoned. The horizontal lines, however, are used at all times by most draftsmen. After considerable practice has been had the letters may be constructed in ink without first using the pencil. When proficiency has been attained in the simple inclined Gothic capitals, the vertical, block and Roman alphabets should be studied.

HOW TO HOLD DRAWING INSTRUMENTS

Position of Hand and Instruments. To the student who is just starting out with his drawing work, the position in which he holds his instruments and the free and easy posture of his hands are very important. Just as in playing the piano or in any other process where manual dexterity is required, this skill can only be attained by practice. The following studies should be used in connection with



Position 1. Right Line Pen against T-Square or Triangle

the instructions given in the forepart of this book and wherever references have been given to this section, it is expected that the student will study these plates so as to receive helpful suggestions in his work. In developing skill in Mechanical Drawing, practice is the only method of achieving results after the fundamental principles have been mastered. A very useful collection of "DON'TS" is given herewith and these will bear very close study.



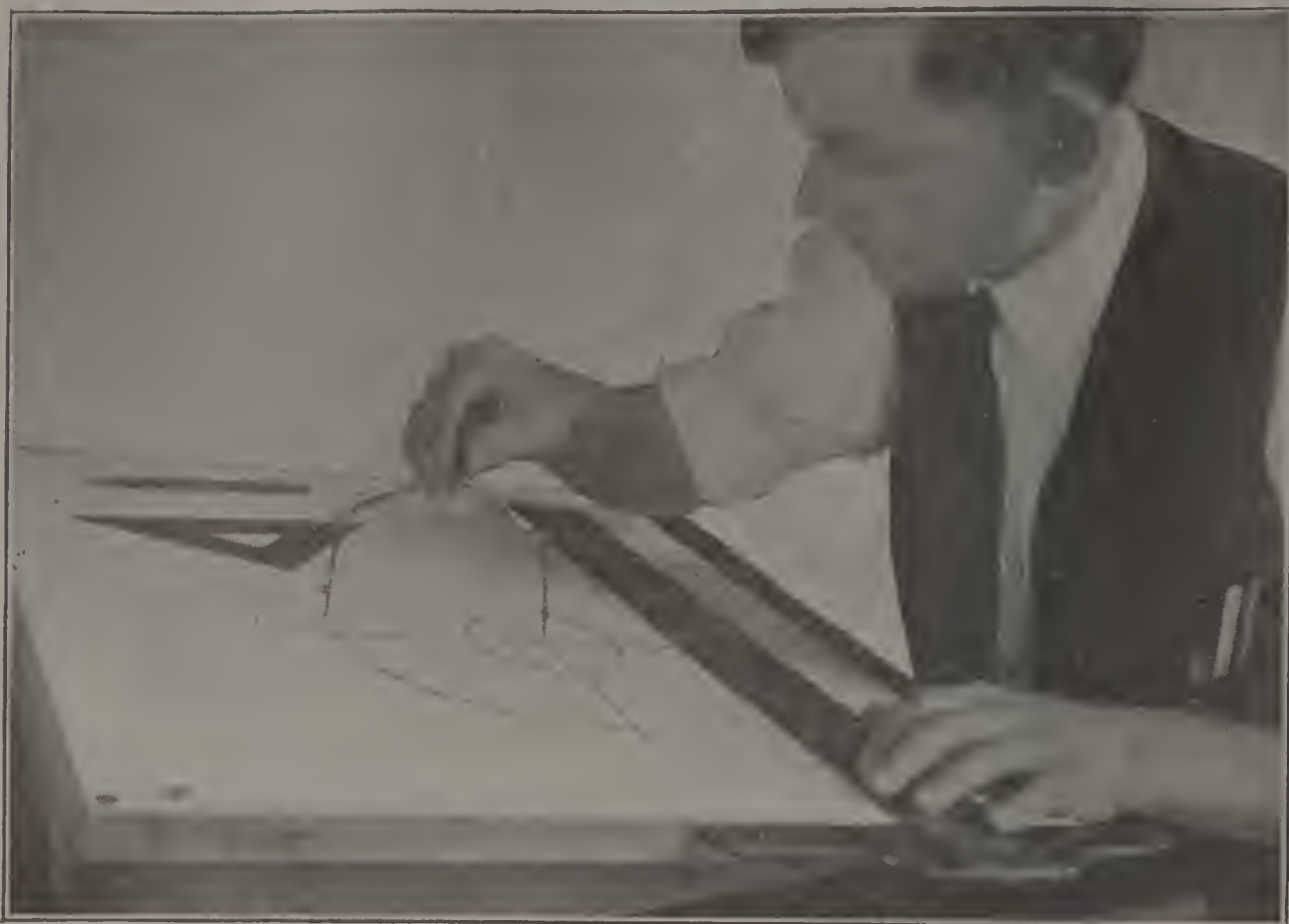
Position 2. Drawing Pencil Line with T-Square and Triangle



Position 3. Inking a Line with Pen and T-Square



Position 4. Drawing Small Circle with the Compass



Position 5. Drawing Large Circle with Compass with Bent Legs



Position 6. Drawing Very Large Circle with Spread Compass and Lengthening Bar



Position 7. Adjusting Dividers with One Hand. Note Second and Third Fingers between Legs

“DON'TS” IN DRAFTING WORK

- Don't fold a drawing.
- Don't stick the dividers into the drawing board.
- Don't use the dividers as picks.
- Don't use the scale to rule lines.
- Don't fail to clean the table, board, and instruments when beginning work.
- Don't draw on the lower edge of the T-square.
- Don't cut the sheets of drawing paper with the upper edge of the T-square and a knife; use the lower edge.
- Don't put the end of a pencil in the mouth.
- Don't oil the compass joints.
- Don't put away the instruments without cleaning, especially pens.
- Don't use the cheapest materials.
- Don't use the T-square as a hammer.
- Don't screw up the nibs of the pen too tight.
- Don't use a blotter on lines that have been inked.
- Don't run the pen or pencil backward over a line.
- Don't fill a pen over a drawing.

PRELIMINARY LINE PROBLEMS

To lay out the paper for the plates of this work, place a sheet *A B G F*, Fig. 38, on the drawing board 2 or 3 inches from the left-hand edge, called the *working edge*. If placed near the left-hand edge, the T-square and triangles can be used with greater firmness and the horizontal lines drawn with greater accuracy. In fastening the paper on the board, always true it up with the T-square according to the long edge of the sheet and use at least 4 thumb tacks—one at each corner. If the paper has a tendency to curl, 6 or 8

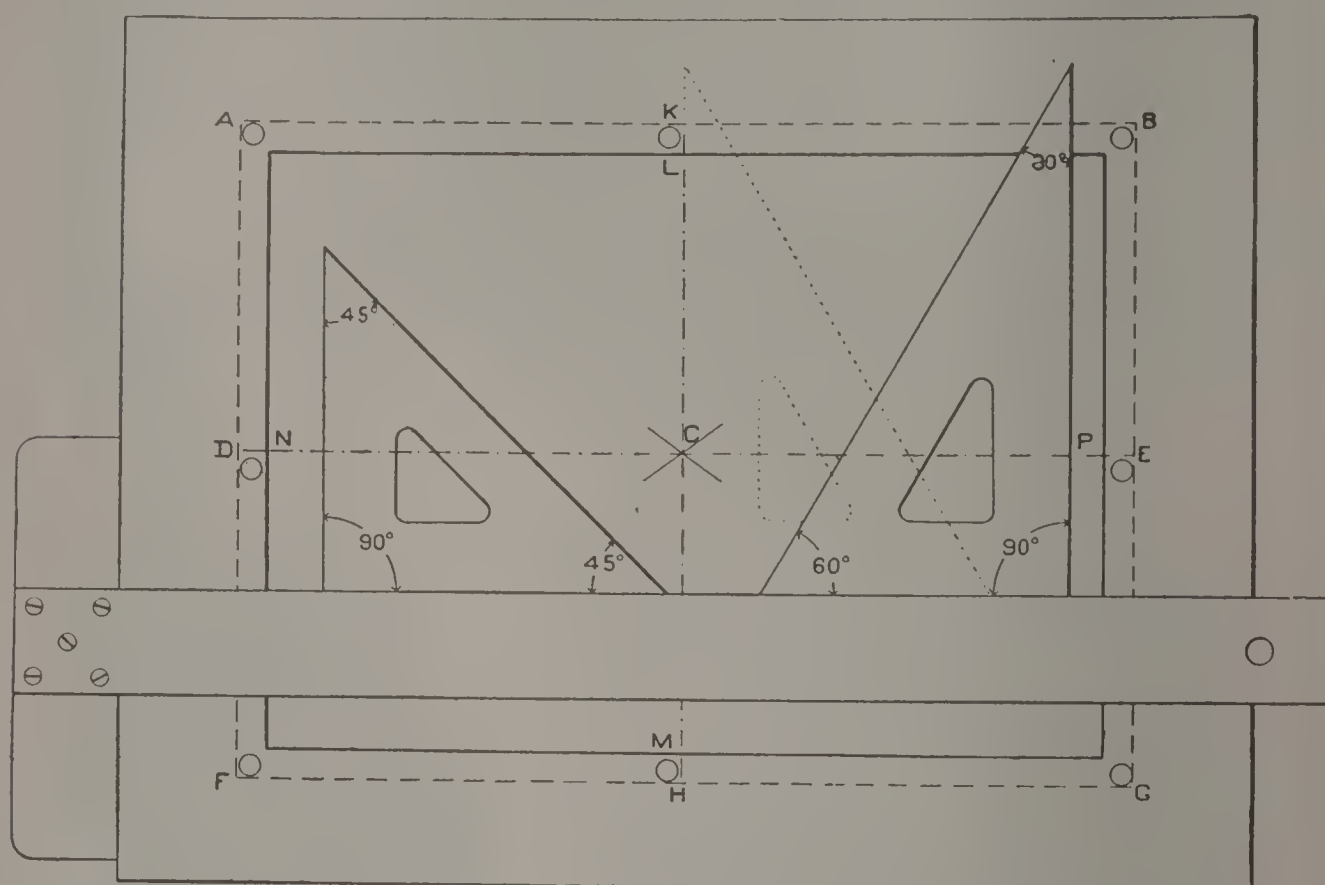


Fig. 38. Standard Lay-Out for Plates

tacks may be used placing them as shown in Fig. 38; many draftsmen prefer one-ounce tacks as they offer less obstruction to the T-square and triangles.

To find the center of the sheet place the T-square so that its upper edge coincides with the diagonal corners *A* and *G* and with the corners *F* and *B*, and draw short pencil lines intersecting at *C*. Now with the T-square draw through the point *C* the dot and dash line *D E*, and with the T-square and one of the triangles—shown dotted in Fig. 38—draw the dot and dash line *H C K*. It will probably be necessary to draw *CK* first and then by means of the T-square or triangle, produce (extend) *CK* to *H*. In this work always move

the pencil from left to right or from the bottom upward; except in certain cases.

After the center lines are drawn measure off 5 inches above and below the point *C* on the line *II C K*. These points *L* and *M* may be indicated by a light pencil mark or by a *slight* puncture by means of one of the points of the dividers. Now place the T-square against the left-hand edge of the board and draw horizontal pencil lines through *L* and *M*.

Measure off 7 inches to the left and right of *C* on the center line *D C E* and draw pencil lines through these points *N* and *P*, perpendicular to *DE*. These lines form a rectangle 10 inches by 14 inches, in which all the exercises and figures are to be drawn. The lettering of the student's name and address, date, and plate number are to be placed *outside* of this rectangle in the $\frac{1}{2}$ -inch margin. In all cases lay out the plates in this manner and keep the center lines *D E* and *K H* as a basis for the various figures. Ink in the border line with a heavy line when the drawing is finished.

Penciling. In laying out the first few plates of this course the work is to be done in pencil and then inked in; later the subject of tracing the pencil drawings on tracing cloth and the process of making blue prints from these tracings will be taken up. Every beginner should practice with his instruments until he understands them thoroughly and can use them with accuracy and skill. To aid the beginner in this work, the first three plates of this course are practice plates; they do not involve any problems and none of the work is difficult. The student is strongly advised to draw these plates two or three times before making the one to be sent to us for correction. Diligent practice is necessary at first; especially on *Plate I* as it involves an exercise in lettering.

Inking. To ink a drawing well requires great care and some experience. The student should not attempt to ink in his work until he can make a clear-cut, straight line with ease. It is well to practice inking in straight pencil lines, rectangles, and triangles in order to improve the work on lines, corners, and intersections. These latter should be very definite, each line stopping at exactly the right point.

Before starting to ink in, adjust the pen by means of the thumb screw until a good clear line of the desired width is obtained, making frequent test lines, on a piece of material similar to that which is to

be used. Keep the pressure of the pen on the paper uniformly light, remembering that different weights of lines are not obtained by pressure as with the ordinary writing pen but only by adjusting the nibs of the pen. If the lines are ragged the pen should be put in order, according to the instructions already given. Sometimes when the ink does not flow regularly, moisten the end of the finger and touch the point of the pen. Care should be taken not to put too much ink in the pen, but on the other hand there must be enough to draw the next line as it is difficult to continue a line after re-filling the pen. The only way to draw fine lines well is to frequently clean and re-fill the pen. If the amount of ink in the pen is small it is quite likely to thicken in the point and cause clogging. When this occurs, draw a small strip of paper between the nibs to clean out the clogged ink.

When drawing, the pen should be held with the thumb screw out and should be inclined slightly in the direction in which it is moved. Be careful, however, not to incline it too much, as the best of pens when incorrectly held will produce poor lines. It is therefore advisable at the start to acquire the correct method of holding the pen. Do not press the sides of the pen point too heavily against the ruling edge as this will vary the width of the line; after a little practice the pen can be lightly and firmly brought in contact with the paper and ruling edge at the same time. The pen should be drawn from left to right, the hand being steadied by sliding it on the end of the little finger.

Always try to get into the easiest position when inking a line, even if it becomes necessary to walk around the drawing. The average draftsman prefers the standing position while inking as he can usually obtain much better results. Keep the ruling edge between the line and the body so that the pen will be drawn against the ruling edge, for if this is not done, the pen is liable to be pulled off at an angle, making a crooked line. Be careful after inking a line to draw the ruling edge toward the body away from the line in order to avoid blotting. Where lines meet at a point, always ink towards the point, being sure to allow one line to dry before inking another. Always ink in the top and left-hand lines first, gradually working down to the right, thus saving time that otherwise would be lost in waiting for the lines to dry. When the pen is set at the proper width, draw all the lines of that width before making a change. Never push

the pen backward over a line. If a good line is not drawn the first time, it is better to go over it again in the same direction, taking great care not to widen the original line.

Ink dries very quickly and should not be left in the pen on account of its corrosive effects. The celluloid triangles should be washed frequently in water and all ink spots removed.

In using the compass, bend both legs so that each will be perpendicular to the paper or cloth when the arc or circle is drawn. When the pen attachment is used special care must be exercised on this point for in no other way can the nibs of the pen be made to bear evenly on the surface. In drawing arcs, hold the cylindrical handle at the top of the compass loosely between the thumb and the forefinger and let it roll between the two during rotation; allow the compass to lean slightly in the direction of rotation, pressing down the pen point slightly but not the needle point. Be sure to fix the needle point firmly in its proper place on the paper before touching the pen to the paper, as otherwise a slip is likely to occur. In setting the needle down on any particular center, guide it with a finger of the left hand. Avoid making a noticeable hole in the paper.

Ink in the circumference of a circle with one continuous motion, giving an even pressure to the pen throughout the operation and stopping it sharply at the end of one revolution. Since straight lines can be more easily drawn tangent to curves than the reverse, it is always advisable to ink in all arcs or circles first. When a number of circles are to be drawn from one center, the smaller should be inked first while the center is in the best possible condition.

PLATE I

Penciling. To draw *Plate I*,* take a sheet of drawing paper at least 11 inches by 15 inches and fasten it to the drawing board as already explained. Find the center of the sheet and draw fine pencil lines to represent the lines *DE* and *HK* of Fig. 38. Also draw the border lines *L*, *M*, *N*, and *P*.

Now measure $\frac{3}{8}$ inch above and below the horizontal center line and, with the T-square, draw lines through these points. These lines will form the lower lines *DC* of Fig. 1 and Fig. 2 and the top lines *AB* of Fig. 3 and Fig. 4. Measure $\frac{3}{8}$ inch to the right and left

*Note Instructions, pages 22 to 25, inclusive.

TRIM THE SHEET TO THE SIZE SHOWN BY DASH LINES



FIG. 1

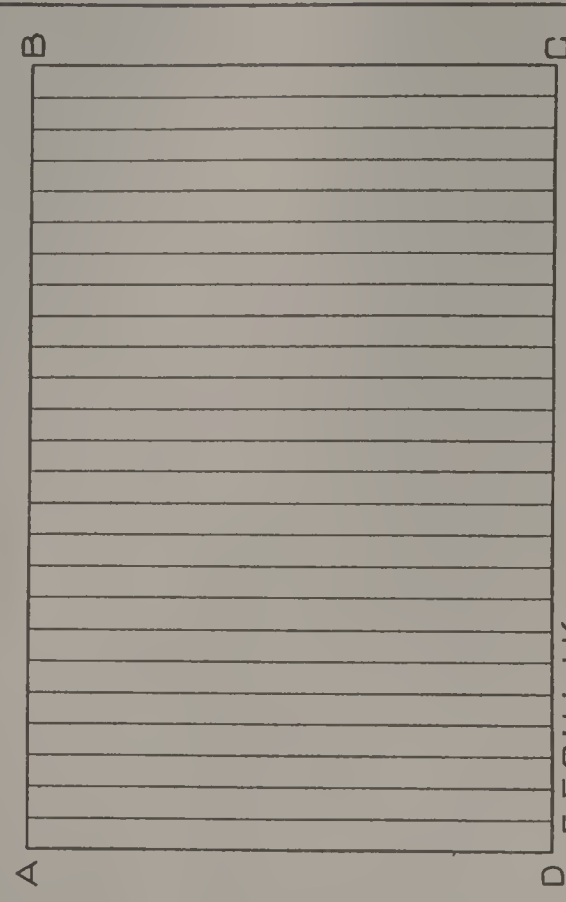


FIG. 2

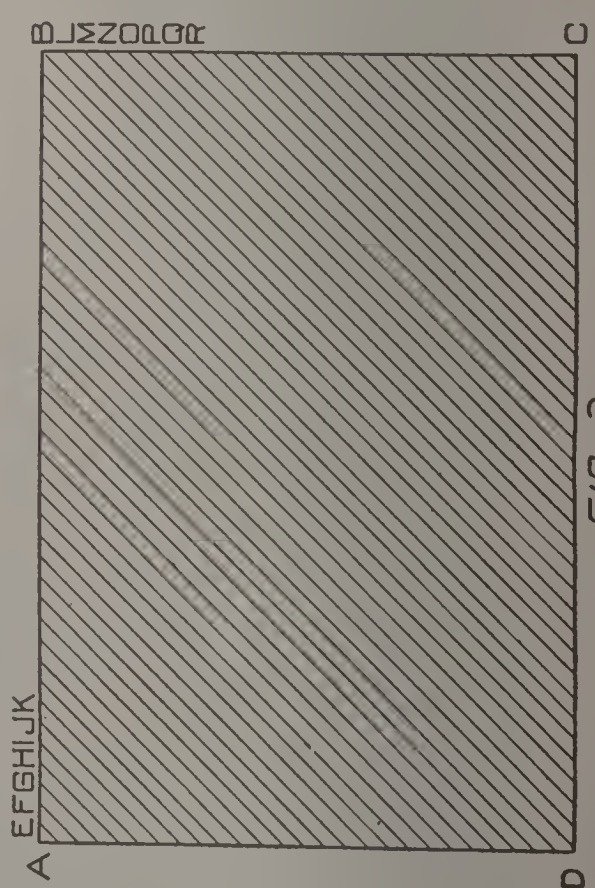


FIG. 3

LETTERING

THE SUBJECT OF LETTERING IS OF GREAT IMPORTANCE TO THE MECHANICAL DRAFTSMAN. MANY WELL EXECUTED DRAWINGS HAVE BEEN DISFIGURED BY POOR LETTERING.

Proficiency can be acquired only by practice. Practice lettering. Practice.

ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
1234567890
I II III IV V VI VII VIII IX X

FIG. 4

of the vertical center line; and through these points, draw lines parallel to the center line. These lines should be drawn by placing the triangle on the T-square as shown in Fig. 38. The lines thus drawn, form the sides BC of Fig. 1 and Fig. 3 and the sides AD of Fig. 2 and Fig. 4. Next draw, with the T-square, the line AB AB $4\frac{5}{8}$ inches above the horizontal center line, and the line DC DC $4\frac{5}{8}$ inches below the horizontal center line. The rectangles of the four figures may now be completed by drawing vertical lines $6\frac{5}{8}$ inches on each side of the vertical center line; these rectangles are each $6\frac{1}{4}$ inches long and $4\frac{1}{4}$ inches wide.

Fig. 1. *Exercise with Line Pen and T-square.* Divide the line AD into divisions each $\frac{1}{4}$ inch long, making a fine pencil point or *slight* puncture at each division such as E, F, G, H, I , etc. Now place the T-square with its head at the left-hand edge of the drawing board and through these points draw light pencil lines extending to the line BC . In drawing these lines the pencil point must pass *exactly* through the division marks so that the lines will be the same distance apart. Start each line in the line AD and do not fall short of the line BC or run over it. Accuracy and neatness in penciling insure an accurate drawing. Some beginners think that they can correct inaccuracies while inking; but experience soon teaches them that they cannot do so.

Fig. 2. *Exercise with Line Pen, T-square and Triangle.* Divide the lower line DC of the rectangle into divisions each $\frac{1}{4}$ inch long and mark the points E, F, G, H, I, J, K , etc., as in Fig. 1. Place the T-square about as shown in Fig. 38, and either triangle in position with its 90-degree angle at the left. Now draw fine pencil lines from the line DC to the line AB passing through the points E, F, G, H, I, J, K , etc., keeping the T-square rigid and sliding the triangle toward the right.

Fig. 3. *Exercise with Line Pen T-square and 45-degree Triangle.* Lay off the distances AE, BL , etc., each $\frac{1}{4}$ inch long on AB and BC , respectively. Place the T-square so that the upper edge will be below the line DC , and, with the 45-degree triangle, draw the diagonal lines through the points laid off. In drawing these lines move the pencil away from the body, *i. e.*, from AD to AB and from DC to BC .

Fig. 4. *Exercise in Free-Hand Lettering.* Draw the center line EF , Fig. 39, and light pencil lines YZ and TX , $\frac{3}{8}$ inch from the

border lines. With the T-square, draw the line *G*, $\frac{1}{4}$ inch from the top line and the line *H*, $\frac{5}{32}$ inch below *G*. The word "*LETTERING*" is to be placed between these two lines. Draw the line *I*, $\frac{3}{16}$ inch below *H*, and space the lines included between *I* and *K*, $\frac{5}{32}$ inch apart.

The next style of letters to be discussed is lower-case letters. Draw the line *L* $\frac{3}{16}$ inch below *K* and to limit the height of the small letters draw a light line $\frac{1}{8}$ inch above *L*.

Make the space between *L* and *M*, $\frac{5}{32}$ inch and draw *M* and *N* in the same manner as *K* and *L*. Now draw *O*, $\frac{3}{16}$ inch below *N*,

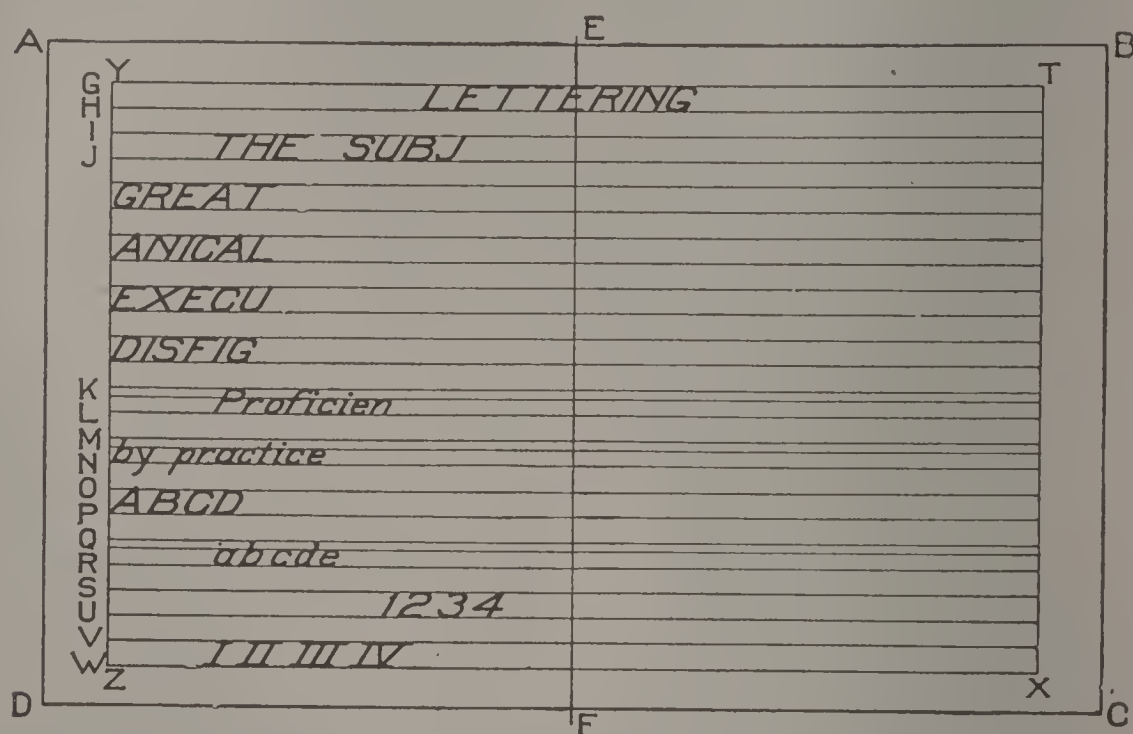


Fig. 39. Sample Lettering Plate—Fig. 4., Plate I

P, $\frac{5}{32}$ inch below *O*, and *Q*, $\frac{5}{32}$ inch below *P*. Space *Q* and *R* as *K* and *L*, and draw *S*, *U*, *V*, and *W*, $\frac{5}{32}$ inch apart.

The center line is a great aid in centering the word "*LETTERING*," the alphabets, numerals, etc. Indent the words "*THE*" and "*Proficiency*" about $\frac{3}{8}$ inch, as they are the first words of paragraphs. To draw the guide lines, mark off distances of $\frac{1}{4}$ inch on any line such as *J* and with the 60-degree triangle draw light pencil lines cutting the parallel lines. Sketch the letters in pencil making the width of the ordinary letters such as *E*, *F*, *H*, *N*, *R*, etc., about $\frac{3}{4}$ their height. Letters like *A*, *M*, and *W*, are wider. The space between the letters depends upon the draftsman's taste, but the beginner should remember that letters next to an *A* or an *L* should be placed nearer to them than to letters whose sides are parallel: for

instance there should be more space between an *N* and *E* than between an *E* and *H*. Similarly a greater space should be left on either side of an *I*. On account of the space above the lower line of the *L*, a letter following an *L* should be close to it. If a *T* follows a *T* or an *L* follows an *L* place them near together. In all lettering place the letters so that the general effect is pleasing. After the four figures are completed, pencil in the lettering for name, address, and date. With the T-square draw a pencil line $\frac{5}{32}$ inch above the top border line at the right-hand end, and about 3 inches long. At a distance of $\frac{5}{32}$ inch above this line draw another line of about the same length. These are the guide lines for the word *Plate I*. Pencil the letters free-hand using the 60-degree guide lines if desired.

Draw in a similar manner the guide lines of the date, name, and address in the lower margin, the date of completing the drawing placed under Fig. 3, and the name and address at the right, under Fig. 4. The street address is unnecessary. It is a good plan to draw lines $\frac{5}{32}$ inch apart on a separate sheet of paper and pencil the letters in order to know just how much space each word will require. The insertion of the words "Fig. 1," "Fig. 2," etc., is optional with the student, but it is advised that he do this extra lettering for the practice as well as for convenience in reference. First draw with the T-square two parallel lines $\frac{5}{32}$ inch apart under each exercise, the lower line being $\frac{1}{16}$ inch above the horizontal center line or above the lower border line.

Inking. After all of the penciling of *Plate I* has been completed the exercises should be inked. Before doing this, however, see that the pen is in proper condition, and after filling try it on a separate piece of paper in order that the proper width of line may be drawn. In the first work where no shading is done, use a firm, distinct line. The beginner should avoid the extremes; a very light line makes the drawing appear weak and indistinct, while a very heavy line detracts from its artistic appearance.

Ink in all the horizontal lines of Fig. 1 first, moving the T-square from *A* to *D*, and take great care to start and stop the lines exactly on the vertical boundary lines. It is necessary to use both triangle and T-square for inking *A D* and *B C*. In inking Fig. 2 and Fig. 3, follow the same directions as for penciling, inking in the vertical and oblique lines first and then the border lines. Ink the border lines

of Fig. 4 first and then the border lines of the plate, making the latter very heavy and the intersections accurate. The lettering in Fig. 4 should be done free-hand, using a steel pen not finer than a Gillott 404. Now ink in the four figure numbers, plate number, date, and name also free-hand, and then erase the pencil lines. **In the finished drawing there should be no center lines, construction lines, or letters other than those in the name, date, etc.**

Cut the sheet 11" $\times$ 15", the dash line outside the border line of *Plate I* indicating the edge.

PLATE II

Penciling. The horizontal and vertical center lines and the border lines for *Plate II* are laid out in the same manner as were those of *Plate I*. To draw the squares for the six figures, proceed as follows:

Measure off two inches on either side of the vertical center line and draw light pencil lines through these points parallel to the vertical center line. These lines will form the sides AD and BC of Fig. 2 and Fig. 5. Parallel to these lines and at a distance of $\frac{1}{2}$ inch draw similar lines to form the sides BC of Fig. 1 and Fig. 4 and AD of Fig. 3 and Fig. 6. The vertical sides AD of Fig. 1 and Fig. 4 and BC of Fig. 3 and Fig. 6 are formed by drawing lines perpendicular to the horizontal center line at a distance of $6\frac{1}{2}$ inches from the center.

Complete the figures by laying off lines $\frac{1}{2}$ inch and $4\frac{1}{2}$ inches above and below the horizontal center line respectively, thus forming six 4-inch squares.

In drawing Fig. 1, divide AD and AB into 4 equal parts, then draw horizontal lines through E , F , and G and vertical lines through L , M , and N . Draw lines from A and B to the intersection O of lines E and M , and from A and D to the intersection P of lines F and L . Similarly draw DJ , $J C$, $C I$, and $I B$. Also connect the points O , P , J , and I , thus forming a square. The four diamond-shaped areas are formed by drawing lines from the middle points of AD , AB , BC , and DC to the middle points of lines AP , AO , OB , IB , etc., as shown in Fig. 1.

Fig. 2 is an exercise of straight lines. Divide AD and AB into four equal parts and draw horizontal and vertical lines as in Fig. 1. Now divide these dimensions, AL , MN , etc., and EF ,

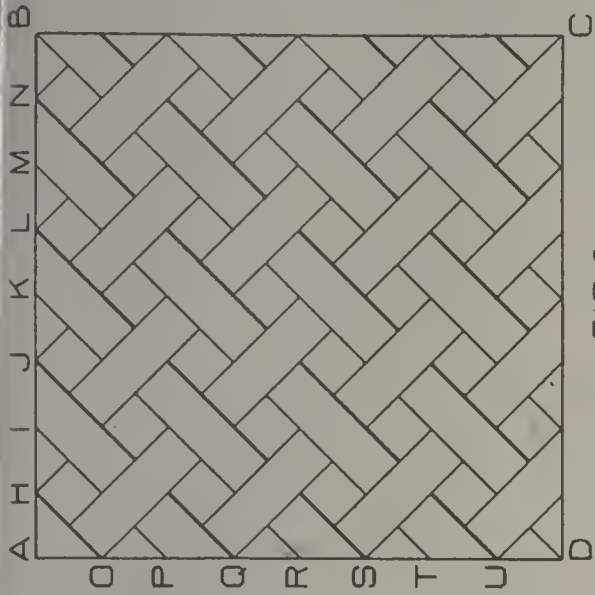


FIG. 3

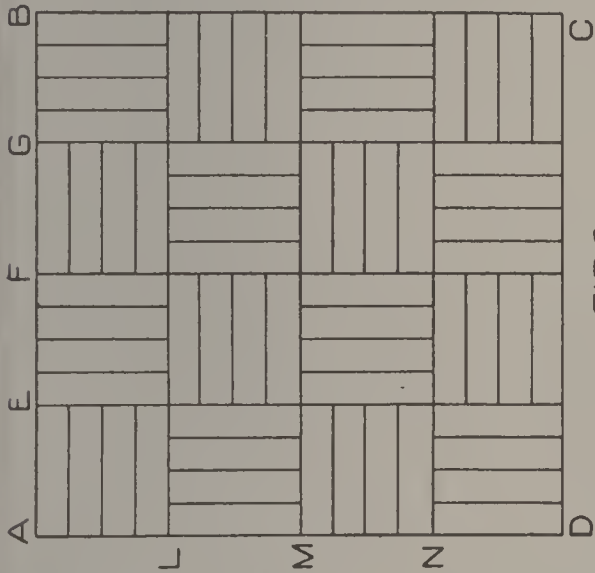


FIG. 2

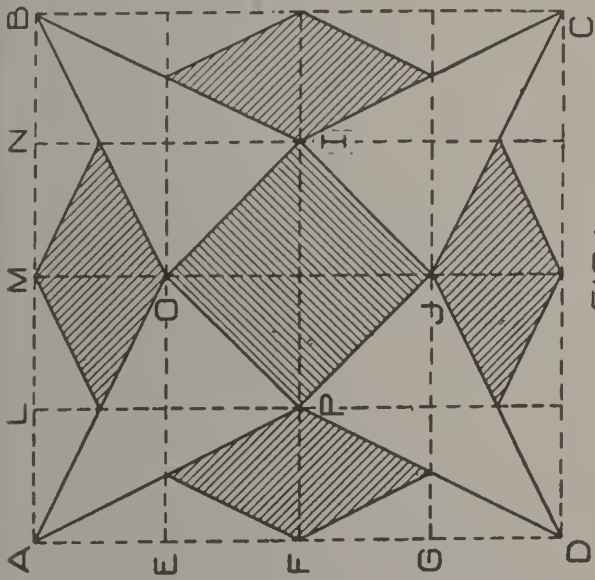


FIG. 1

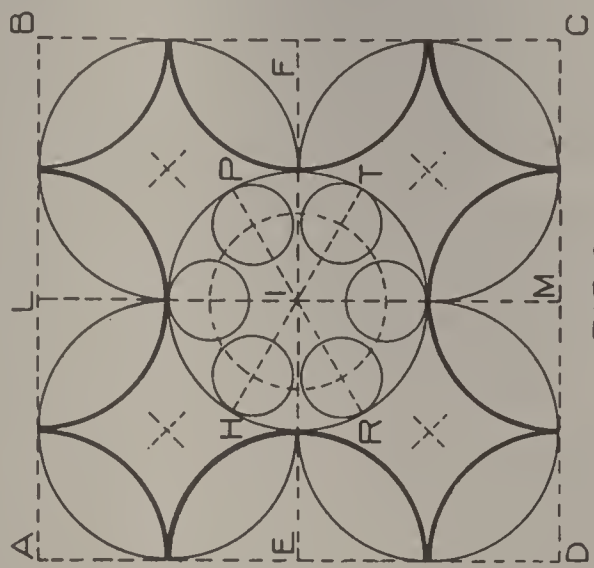


FIG. 6

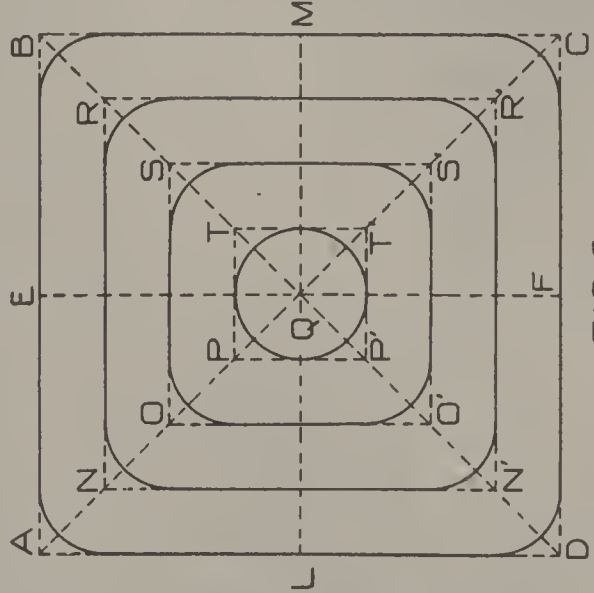


FIG. 5

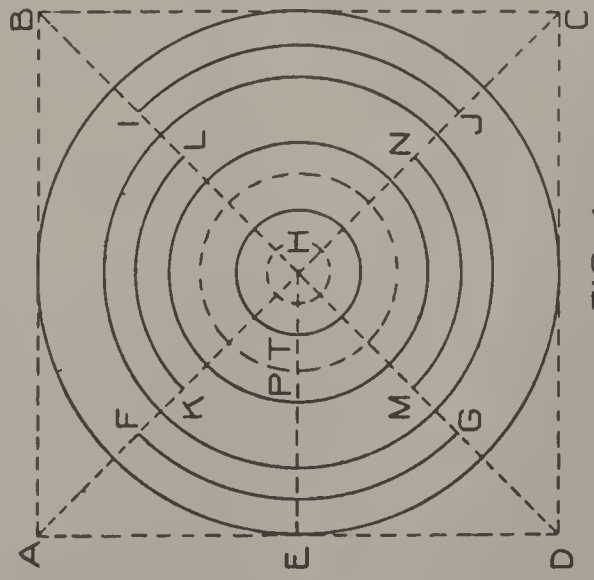


FIG. 4

$G B$, etc., into four equal parts—each $\frac{1}{4}$ inch—and draw light pencil lines with the T-square and triangle as shown.

In Fig. 3, divide $A D$ and $A B$ into eight equal parts, and through the points O, P, Q, H, I, J , etc., draw horizontal and vertical lines. Now draw lines connecting O and H, P and I, Q and J , etc. As these lines form an angle of 45 degrees with the horizontal, a 45-degree triangle may be used. Similarly from each one of the given points on $A B$ and $A D$, draw lines at an angle of 45 degrees to $B C$ and $D C$ respectively.

Fig. 4 is drawn with the compasses. Draw the diagonals $A C$ and $D B$, and with the T-square draw the line $E H$. Now mark off on $E H$ distances of $\frac{1}{4}$ inch, and with H as a center describe, by means of the compasses, circles having radii respectively 2 inches, $1\frac{1}{2}$ inches, 1 inch, $\frac{3}{4}$ inch, $\frac{1}{2}$ inch, and $\frac{1}{4}$ inch. Similarly with H as a center and a radius of $1\frac{3}{4}$ inches and $1\frac{1}{4}$ inches respectively draw the arcs $F G$ and $I J$ and $K L$ and $M N$, being careful to end the arcs in the diagonals.

Fig. 5 is an exercise with the line pen and compasses. Draw the diagonals $A C$ and $D B$, the horizontal line $L M$ and the vertical line $E F$ passing through the center Q . Mark off distances of $\frac{1}{2}$ inch on $L M$ and $E F$ and complete the squares $N R R' N'$, etc. With the bow pencil adjusted so that the distance between the pencil point and the needle point is $\frac{1}{2}$ inch, draw arcs having centers at the corners of the inner squares. The arc whose center is N will be tangent to the lines $A L$ and $A E$ and the arc whose center is O will be tangent to $N N'$ and $N R$. Since the smallest square has 1 inch sides, the $\frac{1}{2}$ -inch arcs drawn with Q as a center will form a circle.

In Fig. 6, draw the center lines $E F$ and $L M$, and find the centers of the four squares thus formed. Through the center I draw the construction lines $H I T$ and $R I P$ forming angles of 30 degrees with $E F$. Now adjust the compasses to draw circles having a radius of one inch, and with I as a center, draw the circle $H P T R$. With the same radius draw the arcs with centers at A, B, C , and D , and also draw the semicircles with centers at L, F, M , and E . Now draw the arcs as shown having centers at the centers of the four squares. To locate the centers of the six small circles within the circle $H P T R$, draw a circle with a radius of $\frac{11}{16}$ inch and having the center in I . The small circles each have a radius of $\frac{5}{16}$ inch.

Inking. In *Plate II* ink in only the lines shown *full* in the specimen plate. First ink the star and then the square and diamonds. As this is an exercise for practice, the cross-hatching should be done *without* measuring the distance between the lines and without the aid of any cross-hatching device. The lines should be about $\frac{1}{16}$ inch apart. After inking in the plate all construction lines should be erased.

In inking Fig. 2 first ink the principal horizontal and vertical lines and then very carefully ink in the short lines. Make these lines all of the same width.

Fig. 3 is drawn entirely with the 45-degree triangle. In inking the oblique lines make *P I*, *R K*, *T M*, etc., of the usual width, while the alternate lines *O H*, *Q J*, *S L*, etc., should be somewhat heavier. All of the lines which slope in the opposite direction are light. Now ink in the border lines and erase all other horizontal and vertical lines.

In inking Fig. 4 use only the compasses, adjusting the legs so that the pen will always be perpendicular to the paper. In inking the arcs, see that the pen stops *exactly* at the diagonals. The inner circle and the next but one should be dotted as shown in the specimen plate. After inking the circles and arcs erase the construction lines that are without the outer circles, leaving in *pencil* the diagonals inside the circles.

In Fig. 5 *draw all arcs first* and then the straight lines meeting these arcs, as it is much easier to make a straight line meet an arc or tangent to it, than the reverse. Leave all construction lines in pencil. This exercise is difficult, and as in all mechanical and machine drawing, arcs and tangents are frequently used, the beginner is advised to draw this exercise several times.

Fig. 6 is an exercise with compasses. If the laying out has been accurately done in pencil, the inked arcs will be tangent to each other and the finished exercise will have a good appearance. If, however, the distances were not accurately measured and the lines carefully drawn, the inked arcs will not be tangent. The arcs whose centers are *L*, *F*, *M*, and *E*, and *A*, *B*, *C*, and *D* should be heavier than the rest. The small circles may be drawn with the bow pen. After inking the arcs all construction lines should be erased.

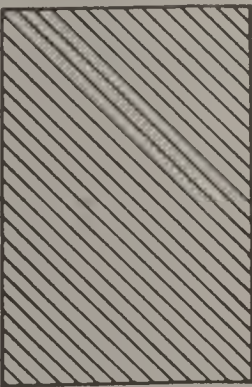
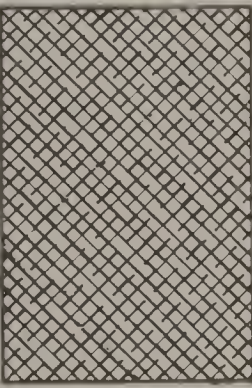
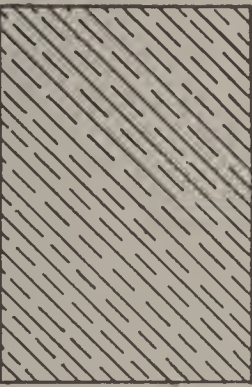
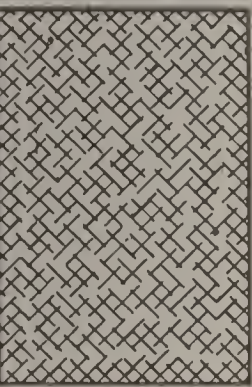
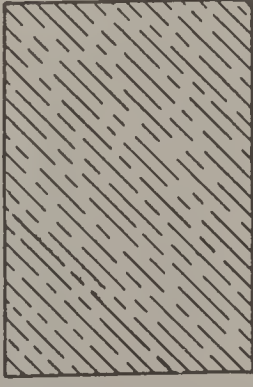
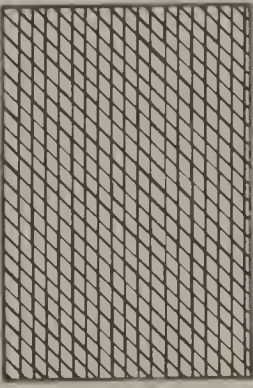
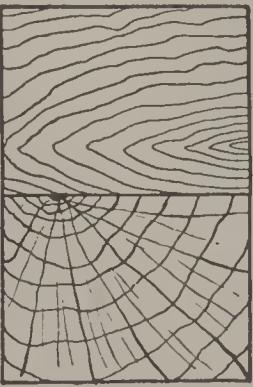
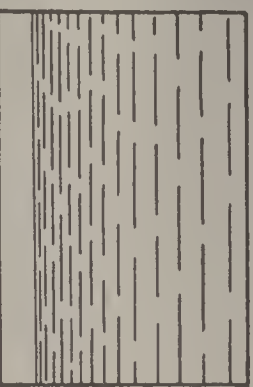
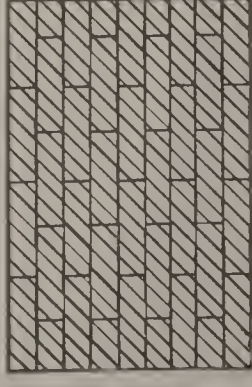
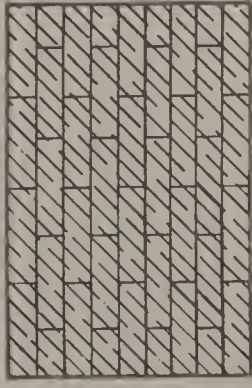
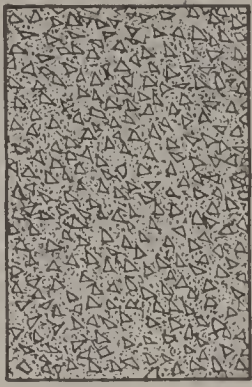
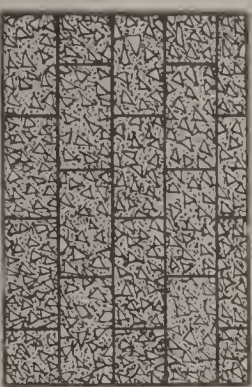
Finally ink in the figure numbers, the border lines of the plate, name, address, and plate number as in *Plate I*.

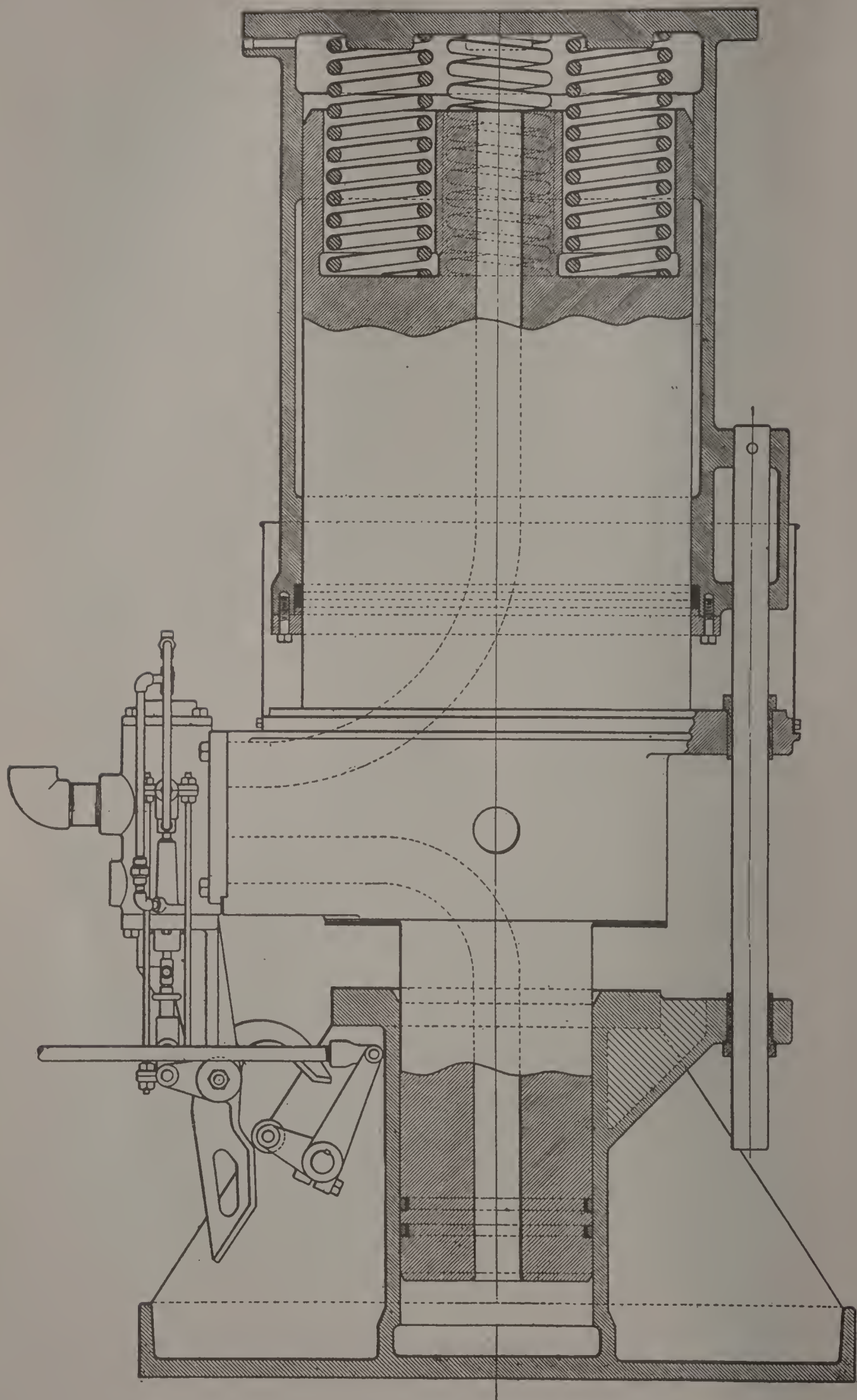
PLATE III

Penciling. *Plate III* should be laid out in the same manner as *Plate II*, that is, for size and border lines. In laying out the sixteen rectangles, however, the space between the center lines and rectangles must in every case be made $\frac{1}{2}$ inch. Each rectangle is to be filled in with what is called *section lining*, illustrating the material of which the object is composed, and, therefore, differing accordingly. The conventions here shown are standard, and some of them will be used by the student in later work in Machine Drawing. Familiarity with them is of value to any draftsman. In drawing section lines of this character, the closeness of the lines should be governed by the area being sectioned. For large areas use a rather wide spacing; for small areas use a narrow spacing. In showing a section of any machine, the different parts are distinguished by altering the slope of the section lines, whether of the same material or not.

Draw the sixteen figures in full and then draw the border lines of the plate. Make the lettering conform to that in *Plate I* and *Plate II*.

Inking. After all the penciling of *Plate III* has been completed, the exercise should be inked, including the titles.

CAST IRON  FIG. 1	WROUGHT IRON  FIG. 2	MALLEABLE IRON  FIG. 3	CAST STEEL  FIG. 4
WROUGHT STEEL  FIG. 5	COPPER  FIG. 6	COMPOSITION  FIG. 7	ZINC  FIG. 8
ALUMINUM  FIG. 9	INSULATING MATERIAL  FIG. 10	WOOD  FIG. 11	WATER  FIG. 12
BRICK  FIG. 13	FIRE BRICK  FIG. 14	CONCRETE  FIG. 15	CONCRETE BLOCKS  FIG. 16



SECTION OF SHOCKLESS JARRING MACHINE

Courtesy of Tabor Manufacturing Company, Philadelphia, Pennsylvania

MECHANICAL DRAWING

PART II

In Part I the instructions and the problems worked out have been designed to teach the student the elementary operations of Mechanical Drawing, giving him a knowledge of the instruments, an ability to draw a straight and true line, and to make up simple figures. A fair degree of drawing ability is now assumed and we can pass on to more complicated problems. Wherever we turn for subjects, however, we find a knowledge of geometrical figures and their properties is absolutely essential to a clear understanding of the problems chosen and we will therefore turn to a discussion of these geometrical figures and the problems which involve them.

GEOMETRICAL DEFINITIONS

A *point* is used for marking position; it has neither length, breadth, nor thickness.

LINES

A *line* has length only; it is produced by the motion of a point.

A *straight line* or *right line* is one that has the same direction throughout. It is the shortest distance between two points.

A *curved line* is one that is constantly changing in direction. It is sometimes called a curve.

A *broken line* is one made up of several straight lines.

Parallel lines are lines which lie in the same plane and are equally distant from each other at all points.

A *horizontal line* is one having the direction of a line drawn upon the surface of water that is at rest. It is a line parallel to the horizon.

A *vertical line* is one that lies in the direction of a thread suspended from its upper end and having a weight at the lower end. It is a line that is perpendicular to a horizontal plane.

An *oblique line* is one that is neither vertical nor horizontal.

In Mechanical Drawing, lines drawn along the edge of the T-square, when the head of the T-square is resting against the left-hand edge of the board, are called *horizontal* lines. Those drawn at right angles or perpendicular to the edge of the T-square are called *vertical* lines.

If two lines cut each other, they are called *intersecting lines*, and the point at which they cross is called the *point of intersection*.

ANGLES

An *angle* is the measure of the difference in direction of two lines. The lines are called *sides*, and the point of meeting, the



Fig. 40. Right Angle

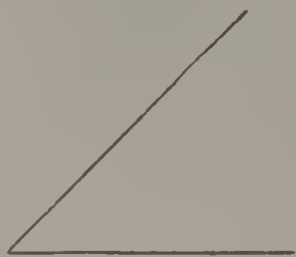


Fig. 41. Acute Angle



Fig. 42. Obtuse Angle

vertex. The size of an angle is independent of the length of the lines.

If one straight line meets another (extended if necessary), Fig. 40, so that the two angles thus formed are equal, the lines are said to be *perpendicular* to each other and the angles formed are called *right angles*.

An *acute angle* is less than a right angle, Fig. 41.

An *obtuse angle* is greater than a right angle, Fig. 42.

SURFACES

A *surface* is produced by the motion of a line; it has two dimensions—length and breadth.

A *plane figure* is a plane bounded on all sides by lines; the space included within these lines (if they are straight lines) is called a *polygon* or a *rectilinear figure*.

POLYGONS

A *polygon* is a plane figure bounded by straight lines. The boundary lines are called the *sides* and the sum of the sides is called the *perimeter*.

Polygons are classified according to the number of sides.

A *triangle* is a polygon of *three* sides.

A *quadrilateral* is a polygon of *four* sides.

A *pentagon* is a polygon of *five* sides, Fig. 43.

A *hexagon* is a polygon of *six* sides, Fig. 44.

A *heptagon* is a polygon of *seven* sides.

An *octagon* is a polygon of *eight* sides, Fig. 45.

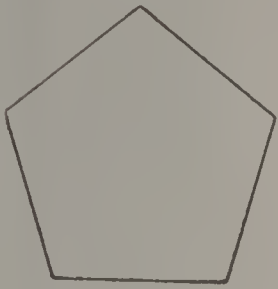


Fig. 43. Pentagon

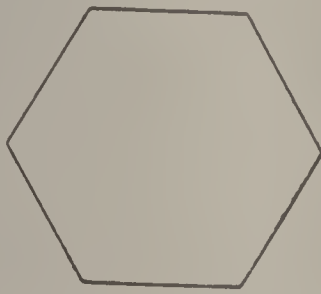


Fig. 44. Hexagon

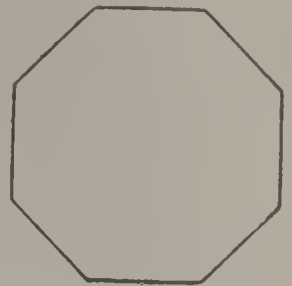


Fig. 45. Octagon

A *decagon* is a polygon of *ten* sides.

A *dodecagon* is a polygon of *twelve* sides.

An *equilateral* polygon is one all of whose sides are equal.

An *equiangular* polygon is one all of whose angles are equal.

A *regular* polygon is one all of whose angles and all of whose sides are equal.

Triangles. A triangle is a polygon enclosed by three straight lines called *sides*. The *angles* of a triangle are the angles formed by the sides.

A *right-angled* triangle, often called a *right* triangle, Fig. 46, is one that has a right angle. The longest side (the one opposite

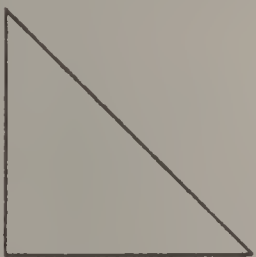


Fig. 46. Right-Angled Triangle



Fig. 47. Acute Angled Triangle



Fig. 48. Obtuse-Angled Triangle

the right angle) is called the *hypotenuse*, and the other sides are sometimes called *legs*.

An *acute-angled* triangle is one that has all of its angles acute, Fig. 47.

An *obtuse-angled* triangle is one that has an obtuse angle, Fig. 48.

An *equilateral* triangle is one having all of its sides equal, Fig. 49.

An *equiangular* triangle is one having all of its angles equal.

An *isosceles* triangle, Fig. 50, is one, two of whose sides are equal. A *scalene* triangle, Fig. 51, is one, no two of whose sides are equal.



Fig. 49. Equilateral Triangle



Fig. 50. Isosceles Triangle



Fig. 51. Scalene Triangle

The *base* of a triangle is the lowest side; it is the side upon which the triangle is supposed to stand. Any side may, however, be taken as the base. In an isosceles triangle, the side which is not one of the equal sides is usually considered as the base.

The *altitude* of a triangle is the perpendicular drawn from the vertex to the base.

Quadrilaterals. A quadrilateral is a polygon bounded by four straight lines, as Fig. 52.

The *diagonal* of a quadrilateral is a straight line joining two opposite vertices.

Trapezium. A trapezium is a quadrilateral, no two of whose sides are parallel.

Trapezoid. A trapezoid is a quadrilateral having two sides



Fig. 52. Quadrilateral



Fig. 53. Trapezoid

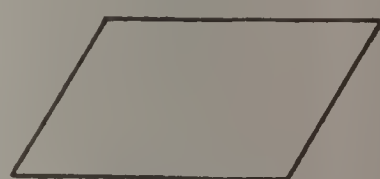


Fig. 54. Parallelogram

parallel, Fig. 53. The parallel sides are called the *bases* and the perpendicular distance between the bases is called the *altitude*.

Parallelogram. A parallelogram is a quadrilateral whose opposite sides are parallel, Fig. 54.

There are four kinds of parallelograms: rectangle, square, rhombus, and rhomboid.

The *rectangle*, Fig. 55, is a parallelogram whose angles are right angles.

The *square*, Fig. 56, is a parallelogram all of whose sides are equal and whose angles are right angles.

The *rhombus*, Fig. 57, is a parallelogram whose sides are equal but whose angles are not right angles.

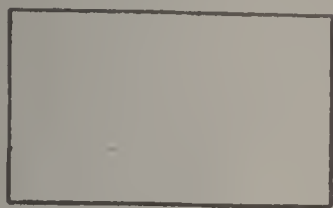


Fig. 55. Rectangle



Fig. 56. Square



Fig. 57. Rhombus

The *rhomboid* is a parallelogram whose adjacent sides are unequal, and whose angles are not right angles.

CIRCLES

A *circle* is a plane figure bounded by a curved line called the *circumference*, every point of which is equally distant from a point within called the *center*, Fig. 58.

A *diameter* of a circle is a straight line drawn through the center, terminating at both ends in the circumference, Fig. 59.

A *radius* of a circle is a straight line joining the center with the



Fig. 58. Circle

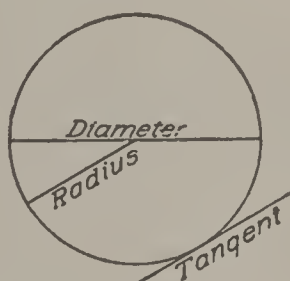
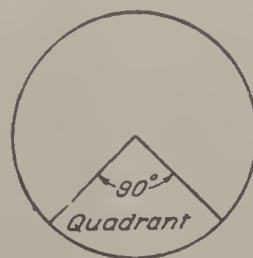
Fig. 59. Diameter,
Radius, Tangent

Fig. 60. Quadrant

circumference. All radii of the same circle are equal and their length is always one-half that of the diameter.

An *arc* is any part of the circumference of a circle. An arc equal to one-half the circumference is called a *semi-circumference*, and an arc equal to one-quarter of the circumference is called a *quadrant*, Fig. 60. A quadrant may mean the arc or angle.

A *chord*, Fig. 61, is a straight line which joins the extremities of an arc but does not pass through the center of the circle.

A *secant* is a straight line which intersects the circumference in two points, Fig. 61.

A *segment* of a circle, Fig. 62, is the area included between an arc and a chord.

A *sector* is the area included between an arc and two radii drawn to the extremities of the arc, Fig. 62.

A *tangent* is a straight line which touches the circumference at only one point, called the *point of tangency* or *contact*, Fig. 59.

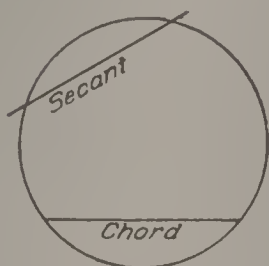


Fig. 61. Chord and Secant

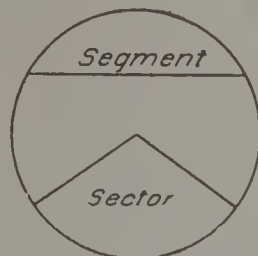


Fig. 62. Segment and Sector

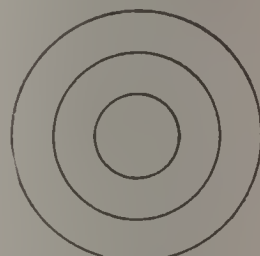


Fig. 63. Concentric Circles

Concentric circles are circles having the same center, Fig. 63.

An *inscribed angle* is an angle whose vertex lies in the circumference and whose sides are chords. It is measured by one-half the intercepted arc, Fig. 64.

A *central angle* is an angle whose vertex is at the center of the circle and whose sides are radii, Fig. 65.

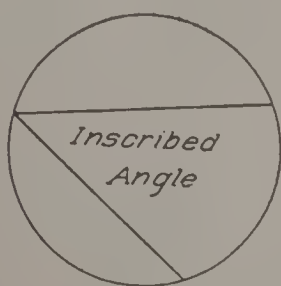


Fig. 64. Inscribed Angle

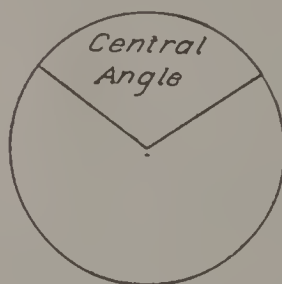


Fig. 65. Central Angle

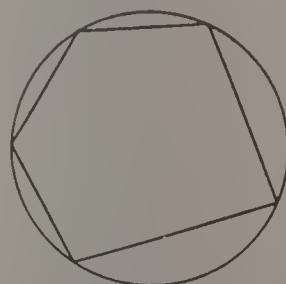


Fig. 66. Inscribed Polygon

An *inscribed polygon* is one whose vertices lie in the circumference and whose sides are chords, Fig. 66.

MEASUREMENT OF ANGLES

To measure an angle, take any convenient radius and describe an arc with the center at the vertex of the angle. The portion of the arc included between the sides of the angle is the *measure of the angle*. If the arc has a constant radius, the greater the divergence of the sides, the longer will be the arc. If there are several arcs drawn with the same center, the intercepted arcs will have different lengths but they will all be the *same fraction* of the entire circumference.

In order that the size of an angle or arc may be stated without saying that it is a certain fraction of a circumference, the circumference is divided into 360 equal parts called *degrees*, Fig. 67. Thus, it may be said that a certain angle contains 45 degrees, *i.e.*, it is $\frac{45}{360} = \frac{1}{8}$ of a circumference. In order to obtain accurate measurements each degree is divided into 60 equal parts called *minutes* and each minute into 60 equal parts called *seconds*.

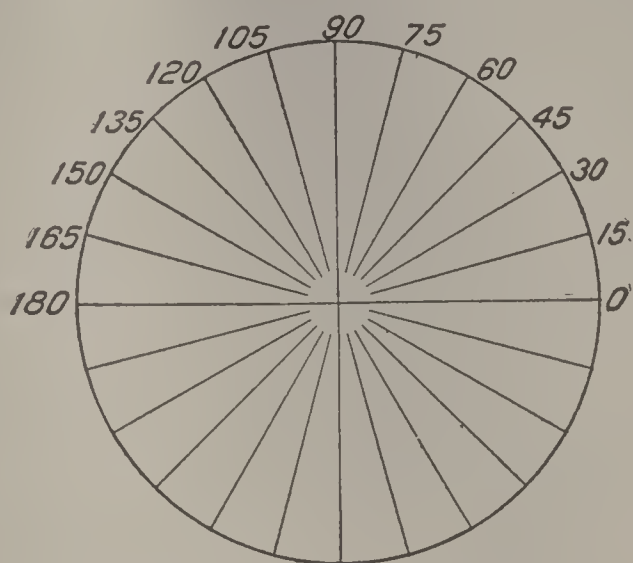


Fig. 67. Angular Measurement

SOLIDS

A *solid* has three dimensions—length, breadth, and thickness. The most common forms of solids are *polyhedrons*, *cylinders*, *cones*, and *spheres*.

POLYHEDRONS

A *polyhedron* is a solid bounded by planes. The bounding planes are called *faces* and their intersections are called *edges*. The intersections of the edges are called *vertices*.

A polyhedron having four faces is called a *tetrahedron*; one having six faces, a *hexahedron*; one having eight faces, and *octahedron*, Fig. 68; one having twelve faces, a *dodecahedron*, etc.

Prisms. A prism is a polyhedron having two opposite faces, called *bases*, which are equal and parallel, and other faces, called

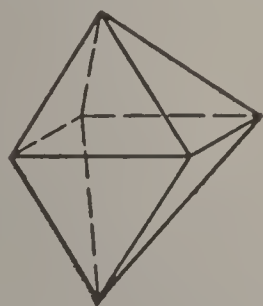


Fig. 68. Octahedron

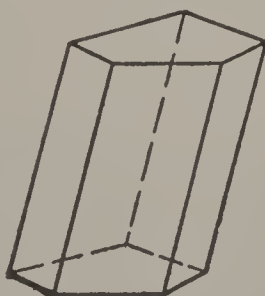


Fig. 69. Prism

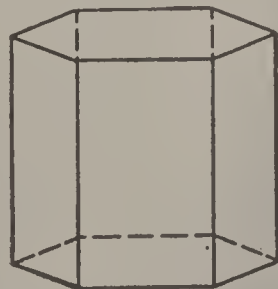


Fig. 70. Right Prism

lateral faces, which are parallelograms, Fig. 69. The *altitude* of a prism is the perpendicular distance between the bases. The area of the lateral faces is called the *lateral area*.

Prisms are called *triangular*, *rectangular*, *hexagonal*, etc., according to the shape of the bases. Further classifications are as follows:

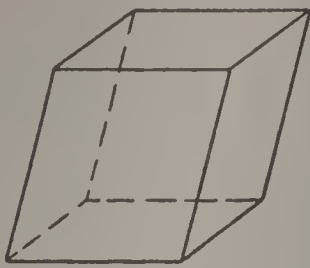


Fig. 71. Parallelopiped

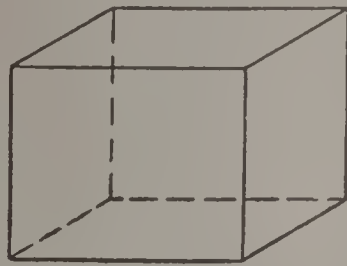


Fig. 72. Rectangular Parallelopiped

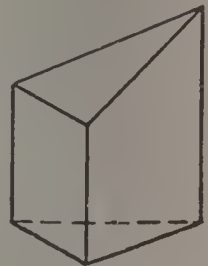


Fig. 73. Truncated Prism

A *right prism* is one whose lateral faces are perpendicular to the bases, Fig. 70.

A *regular prism* is a right prism having regular polygons for bases.

Parallelopiped. A parallelopiped is a prism whose bases are parallelograms, Fig. 71. If all the edges are perpendicular to the bases, it is called a *right parallelopiped*.

A *rectangular parallelopiped* is a right parallelopiped whose bases and lateral faces are rectangles, Fig. 72.

A *cube* is a rectangular parallelopiped all of whose faces are squares.

A *truncated prism* is the portion of a prism included between the base and a plane not parallel to the base, Fig. 73.

Pyramids. A pyramid is a polyhedron whose base is a polygon and whose lateral faces are triangles having a common vertex called the *vertex* of the pyramid.

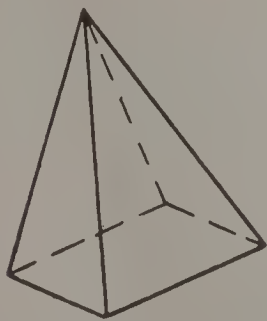


Fig. 74. Pyramid

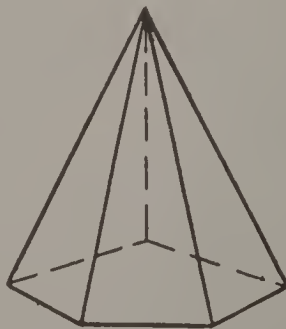


Fig. 75. Regular Pyramid

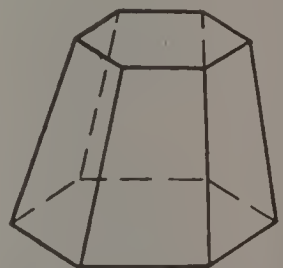


Fig. 76. Frustum of Pyramid

The *altitude* of the pyramid is the perpendicular distance from the vertex to the base.

Pyramids are named according to the kind of polygon forming the base, viz, *triangular*, *quadriangular*, Fig. 74. *pentagonal*, Fig. 75, *hexagonal*.

A *regular pyramid* is one whose base is a regular polygon and whose vertex lies in a perpendicular erected at the center of the base, Fig. 75.

A *truncated pyramid* is the portion of a pyramid included between the base and a plane not parallel to the base.

A *frustum* of a pyramid is the solid included between the base and a plane parallel to the base, Fig. 76; its *altitude* is the perpendicular distance between the bases.

CYLINDERS

A *cylinder* is a solid having as bases two equal parallel surfaces bounded by curved lines, and as its lateral face the continuous

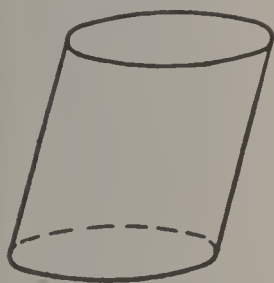


Fig. 77. Cylinder

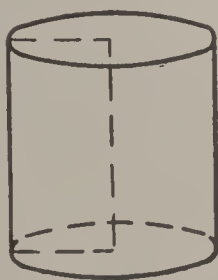


Fig. 78. Right Cylinder

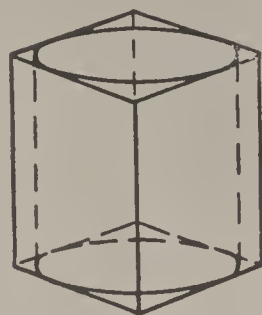


Fig. 79. Inscribed Cylinder

surface generated by a straight line connecting the bases and moving along their circumferences. The bases are usually circles and such a cylinder is called a *circular cylinder*, Fig. 77.

A *right cylinder*, Fig. 78, is one whose side is perpendicular to the bases.

The *altitude* of a cylinder is the perpendicular distance between the bases.

A prism whose base is a regular polygon may be inscribed in or circumscribed about a circular cylinder, Fig. 79.

CONES

A *cone* is a solid bounded by a conical surface and a plane which cuts the conical surface. It may be considered as a pyramid with an infinite number of sides, Fig. 80.

The conical surface is called the *lateral area* and it tapers to a point called the *vertex*; the plane is called the *base*.

The *altitude* of a cone is the perpendicular distance from the vertex to the base.

An *element* of a cone is any straight line from the vertex to the circumference of the base.

A *circular cone* is a cone whose base is a circle.

A *right circular cone*, or *cone of revolution*, Fig. 81, is a cone



Fig. 80. Cone



Fig. 81. Right Circular Cone

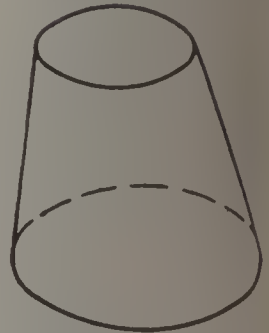


Fig. 82. Frustum of Cone

whose axis is perpendicular to the base. It may be generated by the revolution of a right triangle about one of the legs as an axis.

A *frustum* of a cone, Fig. 82, is the portion of the cone included between the base and a plane parallel to the base; its *altitude* is the perpendicular distance between the bases.

SPHERES

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

The *diameter* is a straight line drawn through the center and having its extremities in the curved surface. The *radius*— $\frac{1}{2}$ diameter—is the straight line from the center to a point on the surface.

A *plane* is *tangent* to a *sphere* when it touches the sphere in only

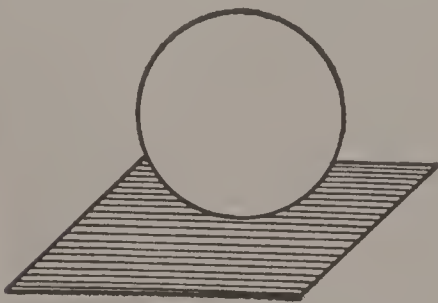


Fig. 83. Plane Tangent to Sphere

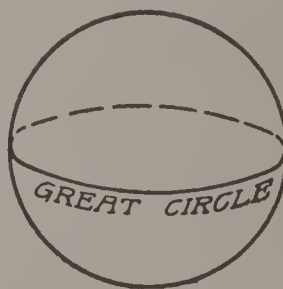


Fig. 84. Great and Small Circle

one point. A plane perpendicular to a radius at its outer extremity is tangent to the sphere, Fig. 83.

An *inscribed polyhedron* is a polyhedron whose vertices lie in the surface of the sphere.

A *circumscribed polyhedron* is a polyhedron whose faces are tangent to a sphere.

A *great circle* is the intersection of the spherical surface and a plane passing through the center of the sphere, Fig. 84.

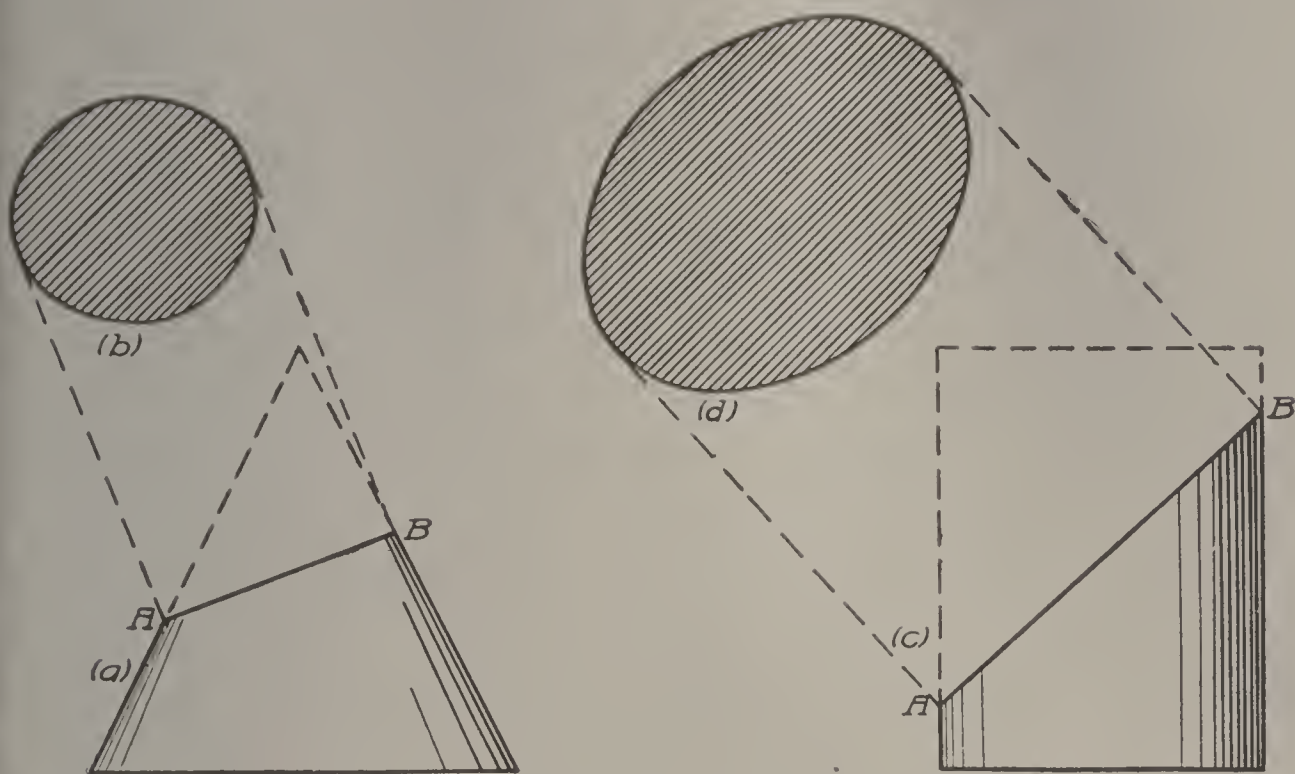


Fig. 85. Intersections of Plane with Cone and Cylinder Giving Ellipses as Shown in (b) and (d)

A *small circle* is the intersection of the spherical surface and a plane which does not pass through the center, Fig. 84.

CONIC SECTIONS

If a plane intersects a cone at various angles with the base the geometrical figures thus formed are called *conic sections*. A plane perpendicular to the base passing through the vertex of a right circular cone forms an isosceles triangle. If the plane is parallel to the base, the intersection of the plane and the conical surfaces will be the circumference of a circle.

Ellipse. If a plane AB , Fig. 85a, cuts a cone oblique to the axis of the cone, but not cutting the base, the curve formed is called an ellipse, as shown in Fig. 85b, this view being taken perpendicular to the plane AB . If the plane cuts a cylinder as shown in Fig. 85c, the ellipse shown in Fig. 85d is the result, this view being also taken perpendicular to the plane AB . An ellipse may be defined as a curve generated by a point



Fig. 86. Diagram Showing Constants of Ellipse

generated by a point

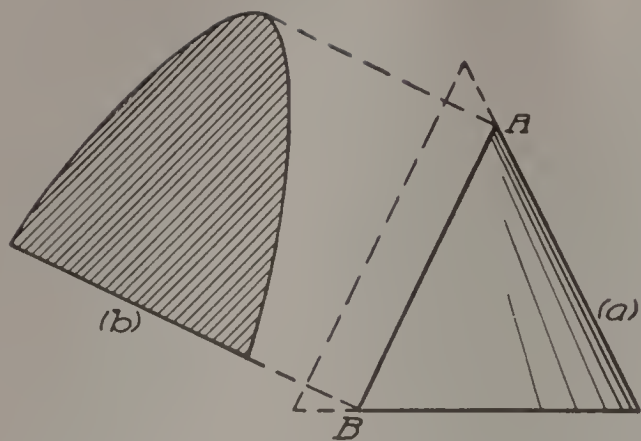


Fig. 87. Intersection of Plane with Cone, Parallel to Element of Cone and Parabolic Section Produced

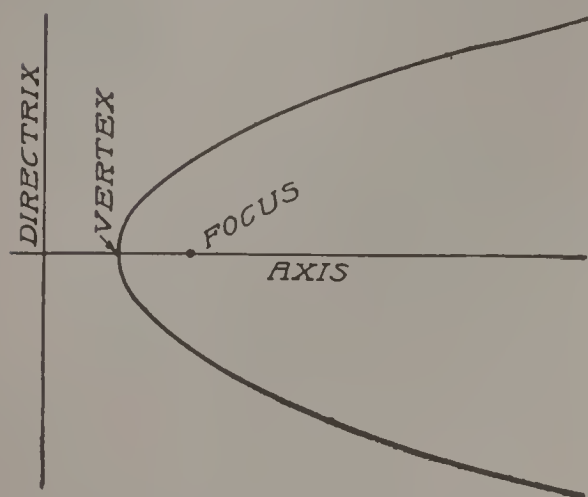


Fig. 88. Diagram Showing Constants of Parabola

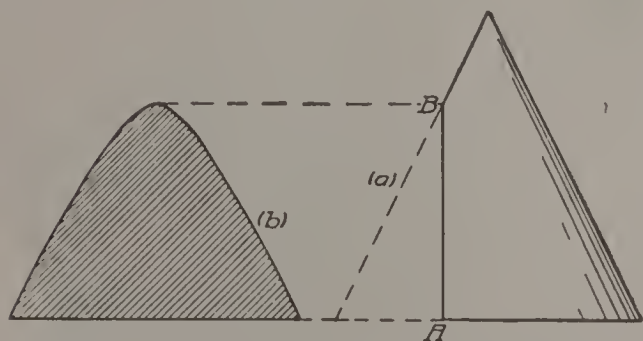


Fig. 89. Intersection of Plane with Cone, Parallel to Axis and Hyperbolic Section Produced

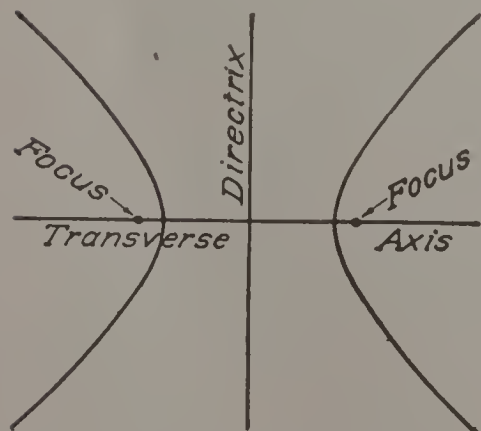


Fig. 90. Diagram Showing Constants of Hyperbola

moving in a plane in such a manner that the sum of the distances from the point to two fixed points shall always be constant.

The two fixed points are called *foci*, Fig. 86, and shall lie on the longest line that can be drawn in the ellipse which is called the *major axis*; the shortest line is called the *minor axis*; and

is perpendicular to the major axis at its middle point, called the *center*.

An ellipse may be constructed if the major and minor axes are given or if the foci and one axis are known.

Parabola. If a plane AB , Fig. 87a, cuts a cone parallel to an element of the cone, the curve resulting from this intersection is called a parabola, as shown in Fig. 87b, the view being taken perpendicular to the plane AB . This curve is not a closed curve for the branches approach parallelism.

A parabola may be defined as a curve every point of which is equally distant from a line and a point.

The point is called the *focus*, Fig. 88, and the given line, the *directrix*. The line perpendicular to the directrix and passing through the focus is the *axis*. The intersection of the axis and the curve is the *vertex*.

Hyperbola. If a plane AB , Fig. 89a, cuts a cone parallel to its axis, the resulting curve is called a hyperbola,

Fig. 89b, the view being taken perpendicular to the plane AB .

Like the parabola, the curve is not closed, the branches constantly diverging.

A hyperbola is defined as a plane curve such that the difference between the distances from any point in the curve to two fixed points is equal to a given distance.

The two fixed points are the *foci* and the line passing through them is the *transverse axis*, Fig. 90.

Rectangular Hyperbola. The form of hyperbola most used in Mechanical Engineering is called the rectangular hyperbola because it is drawn with reference to rectangular coördinates. This curve is constructed as follows:

In Fig. 91, OX and OY are the two coördinate axes drawn at right angles to each other. These lines are also called *asymptotes*. Assume A to be a known point on the curve. Draw AC parallel to OX and AD' perpendicular to OX . Mark off any convenient

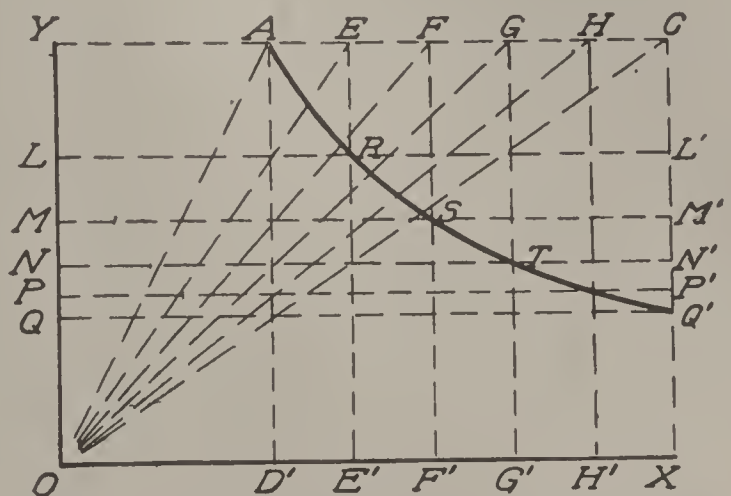


Fig. 91. Construction of Rectangular Hyperbola

points on AC such as E , F , G , and H , and through these points draw EE' , FF' , GG' , and HH' , perpendicular to OX . Connect E , F , G , H , and C with O . Through the points of intersection of the oblique lines and the vertical line AD' draw the horizontal lines LL' , MM' , NN' , PP' , and QQ' . The first point on the curve is the assumed point A , the second point is R , the intersection of LL' and EE' , the third the intersection S , and so on.

In this curve the products of the coördinates of all points are equal. Thus $LR \times RE' = MS \times SF' = NT \times TG'$.

ODONTOIDAL CURVES

Cycloidal Curves. *Cycloid.* The cycloid is a curve generated by a point on the circumference of a circle which rolls on a straight line tangent to the circle, as shown at the left, Fig. 92.

The rolling circle is called the *describing* or *generating circle*, the point on the circle, the *describing* or *generating point*, and the

tangent along which the circle rolls, the *director*. In order that the curve described by the point may be a true cycloid the circle must roll without any slipping.

Hypocycloid. In case the generating circle rolls upon the inside of an arc or circle, the curve thus generated is a hypocycloid,

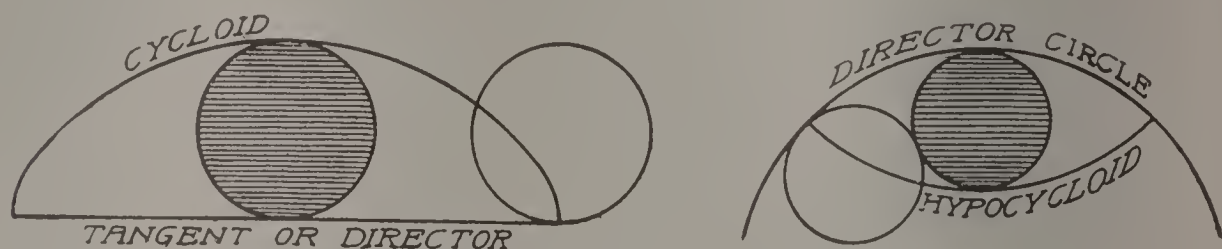


Fig. 92. Geometrical Constructions for Cycloid and Hypocycloid

Fig. 92. If the generating circle has a diameter equal to the radius of the director circle the hypocycloid becomes a straight line.

Epicycloid. If the generating circle rolls upon the *outside* of the *director circle*, the curve generated is an epicycloid, Fig. 93.

Involute Curves. If a thread of fine wire is wound around a cylinder or circle and then unwound, the end will describe an involute curve. The involute may be defined as *a curve generated by a point in a tangent rolling on a circle, known as the base circle*, Fig. 94.

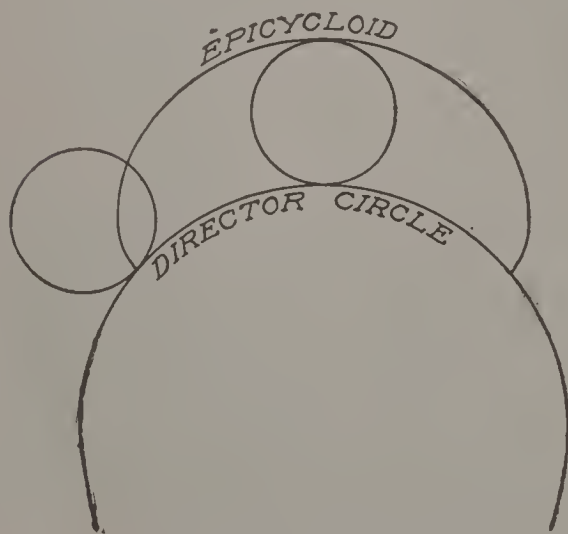


Fig. 93. Geometrical Construction for an Epicycloid

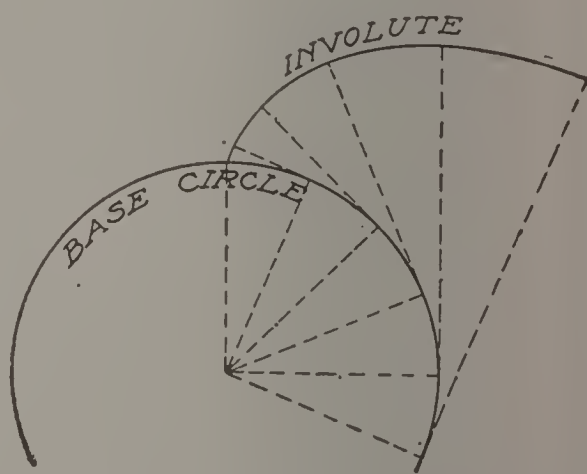


Fig. 94. Geometrical Construction for an Involute

The details of the ellipse, parabola, hyperbola, cycloid, and involute will be taken up in connection with the plates.

The most important application of the cycloidal and involute curves is in the cutting of all forms of gear teeth. It has been found that the teeth of gears when cut accurately to either of these curves will mesh with the least friction and run with exceptional smoothness. The development of these gears and of the machines for cutting them has reached a high state of perfection.

GEOMETRICAL PROBLEMS

The problems given in Plates IV to VIII inclusive have been chosen because of their particular bearing on the work of the mechanical draftsman. They should be solved with great care, as the principles involved will be used in later work.

PLATE IV

Penciling. The horizontal and vertical center lines and the border lines should be laid out in the same manner as in *Plate I*. Now measure off $2\frac{1}{4}$ inches on both sides of the vertical center line and through these points draw vertical lines as shown by the dot and dash lines, *Plate IV*. In locating the figures, place them a little above the center so that there will be room for the number of the problem.

Draw in lightly the lines of each figure with pencil and after the entire plate is completed, ink them. In penciling, all intersections must be formed with great care as the accuracy of the results depends upon it. Keep the pencil points in good order at all times and draw lines *exactly* through intersections.

Problem 1. *To bisect a given straight line.*

Draw the horizontal straight line AC about 3 inches long. With the extremity A as a center and any convenient radius—about 2 inches—describe arcs above and below the line AC . With the other extremity C as a center and with the same radius draw similar arcs intersecting the first arcs at D and E . The radius of these arcs must be greater than one-half the length of the line in order that they may intersect. Now draw the straight line DE passing through the intersections D and E . This line will cut AC at its middle point F .

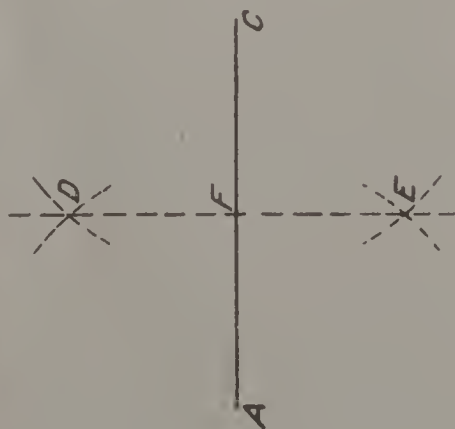
Therefore

$$AF = FC$$

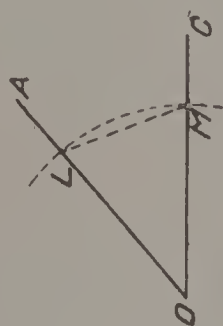
Proof. Since the points D and E are equally distant from A and C a straight line drawn through them is perpendicular to AC at its middle point F .

Problem 2. *To construct an angle equal to a given angle.*

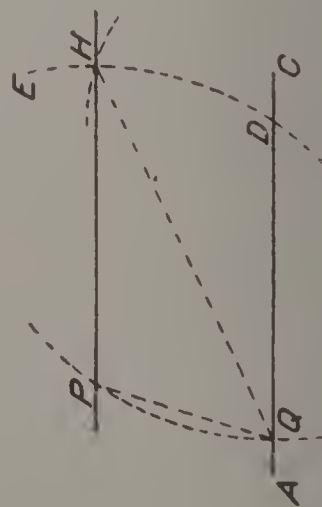
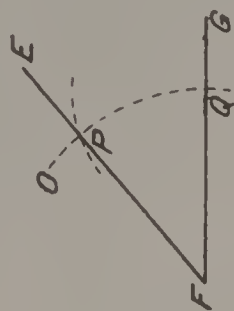
Draw the line OC about 2 inches long and the line OA of about the same length. The angle formed by these lines may be



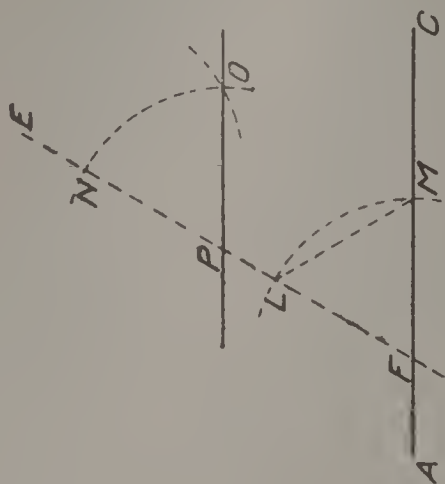
Problem 1



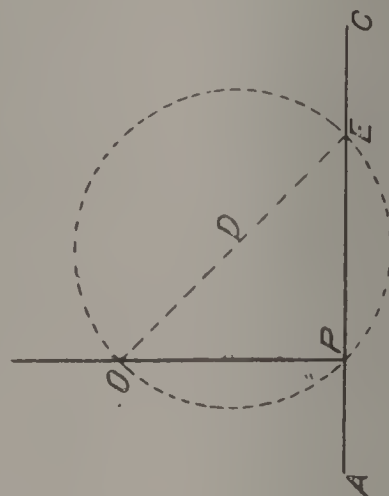
Problem 2



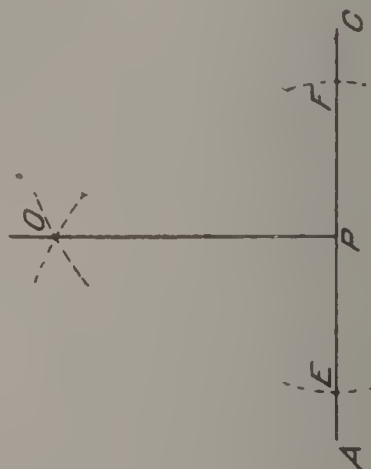
Problem 4



Problem 3



Problem 6



Problem 5

any convenient size—about 45 degrees is suitable. This angle $A O C$ is the given angle.

Now draw $F G$, a horizontal line about $2\frac{1}{4}$ inches long, and let F , the left-hand extremity, be the vertex of the angle to be constructed.

With O as a center and any convenient radius—about $1\frac{1}{2}$ inches—describe the arc $L M$ cutting both $O A$ and $O C$. With F as a center and the same radius draw the indefinite arc $O Q$. Now set the compass so that the distance between the pencil and the needle point is equal to the chord $L M$. With Q as a center and a radius equal to $L M$ draw an arc cutting the arc $O Q$ at P . Through F and P draw the straight line $F E$. The angle $E F G$ is the required angle since it is equal to $A O C$.

Proof. Since the chords of the arcs $L M$ and $P Q$ are equal, the arcs are equal. The angles are equal because with equal radii equal arcs are intercepted by equal angles.

Problems 3 and 4. *To draw through a given point a line parallel to a given line.*

First Method. Draw the straight line $A C$ about $3\frac{1}{2}$ inches long and assume the point P about $1\frac{1}{2}$ inches above $A C$. Through the point P draw an oblique line $F E$ forming any convenient angle—about 60 degrees—with $A C$. Now construct an angle equal to $P F C$ having its vertex at P and the line $E P$ as one side. (See Problem 2.) The straight line $P O$ forming the other side of the angle $E P O$ will be parallel to $A C$.

Proof. If two straight lines are cut by a third making the corresponding angles equal, the lines are parallel.

Second Method. Draw the straight line $A C$ about $3\frac{1}{4}$ inches long and assume the point P about $1\frac{1}{2}$ inches above $A C$. With P as a center and any convenient radius—about $2\frac{1}{2}$ inches—draw the indefinite arc $E D$ cutting the line $A C$. Now with the same radius and with D as a center, draw an arc $P Q$. Set the compass so that the distance between the needle point and the pencil is equal to the chord $P Q$. With D as a center and a radius equal to $P Q$, describe an arc cutting the arc $E D$ at H . A line drawn through P and H will be parallel to $A C$.

Proof. Draw the line $Q H$. Since the arcs $P Q$ and $H D$ are equal and have the same radii, the angles $P H Q$ and $H Q D$

are equal. Two lines are parallel if the alternate interior angles are equal.

Problems 5 and 6. *To draw a perpendicular to a line from a point in the line.*

First Method. WHEN THE POINT IS NEAR THE MIDDLE OF THE LINE.

Draw the line AC about $3\frac{1}{2}$ inches long and assume the point P near the middle of the line. With P as a center and any convenient radius—about $1\frac{1}{4}$ inches—draw two arcs cutting the line AC at E and F . Now with E and F as centers and any convenient radius—about $2\frac{1}{2}$ inches—describe arcs intersecting at O . The line OP will be perpendicular to AC at P .

Proof. The points P and O are both equally distant from E and F . Hence a line drawn through them is perpendicular to EF at P .

Second Method. WHEN THE POINT IS NEAR THE END OF THE LINE.

Draw the line AC about $3\frac{1}{2}$ inches long. Assume the given point P to be about $\frac{3}{4}$ inch from the end A . With any point D as a center and a radius equal to DP , describe an arc cutting AC at E . Through E and D draw the diameter EO . A line from O to P is perpendicular to AC at P .

Proof. The angle $OP E$ is inscribed in a semicircle; hence it is a right angle, and the sides OP and PE are perpendicular to each other.

Lettering. After completing these figures draw pencil lines for the lettering. Place the words “*Plate IV*” and the date and the name in the border, as in preceding plates. To letter the words “Problem 1,” “Problem 2,” etc., draw three horizontal lines $\frac{1}{4}$ inch, $\frac{3}{8}$ inch, and $1\frac{7}{8}$ inch, respectively, above the horizontal center line and the lower border line to serve as a guide for the size of the letters.

Inking. In inking *Plate IV*, ink in the figures first. Make the line AC , Problem 1, a full line as it is the given line; make the arcs and the line DE dotted as they are construction lines. Similarly in Problem 2, make the sides of the angles full lines and the chord LM and the arcs dotted. Follow the same plan in inking the lines of Problems 3, 4, 5, and 6. In Problem 6, ink in only that part of the circumference which passes through the points O , P , and E .

After inking the figures, ink in the heavy border line, and the lettering.

PLATE V

Penciling. In laying out the border lines and center lines follow the directions given for *Plate IV*. Draw the dot and dash lines in the same manner, as there are to be six problems on this plate.

Problem 7. *To draw a perpendicular to a line from a point without the line.*

Draw the straight line AC about $3\frac{1}{4}$ inches long, and assume the point P about $1\frac{1}{2}$ inches above the line. With P as a center and any convenient radius—about 2 inches—describe an arc cutting AC at E and F . The radius of this arc must always be such that it will cut AC in two points; the nearer the points E and F are to A and C , the greater will be the accuracy of the work.

Now with E and F as centers and any convenient radius—about $2\frac{1}{4}$ inches—draw the arcs intersecting below AC at T . A line through the points P and T will be perpendicular to AC . In case there is not room below AC to draw the arcs, they may be drawn intersecting above the line as shown at N . Whenever convenient draw the arcs below AC for greater accuracy.

Proof. Since P and T are both equally distant from E and F , the line PT is perpendicular to AC .

Problems 8 and 9. *To bisect a given angle.*

First Method. WHEN THE SIDES INTERSECT.

Draw the lines OC and OA —about 3 inches long—forming any angle of 45 to 60 degrees. With O as a center and any convenient radius—about 2 inches—draw an arc intersecting the sides of the angle at E and F . With E and F as centers and a radius of $1\frac{1}{2}$ or $1\frac{3}{4}$ inches, describe short arcs intersecting at I . A line OD , drawn through the points O and I , bisects the angle.

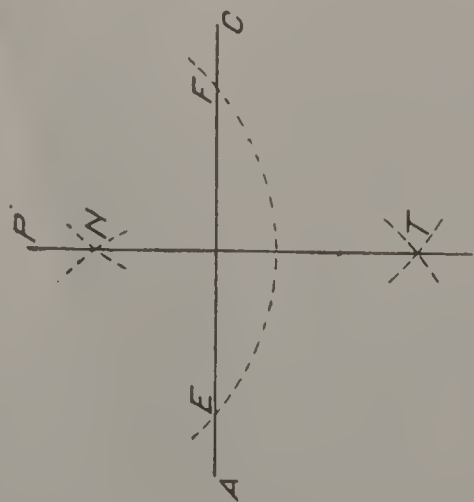
In solving this problem the arc EF should not be too near the vertex if accuracy is desired.

Proof. The central angles AOD and DOC are equal because the arc EF is bisected by the line OD . The point I is equally distant from E and F .

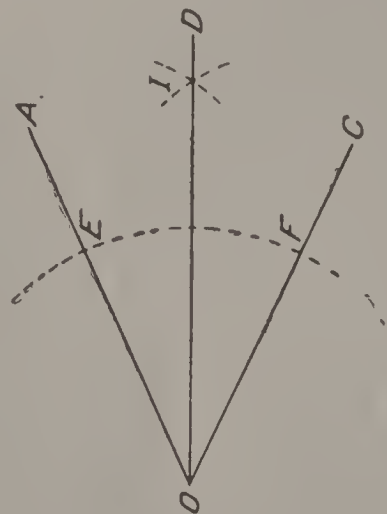
Second Method. WHEN THE LINES DO NOT INTERSECT.

Draw the lines AC and EF about 4 inches long making an

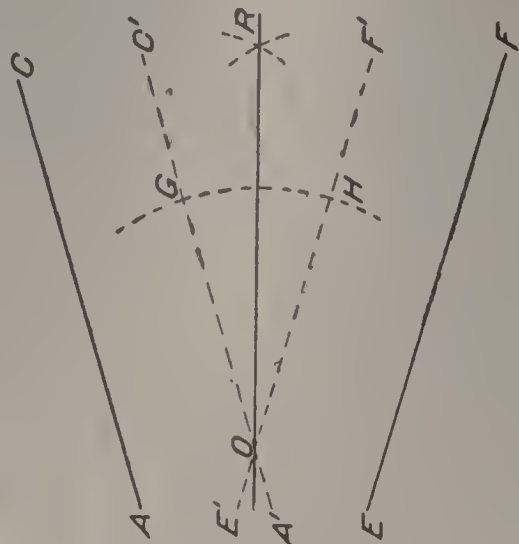
PLATE V



Problem 7



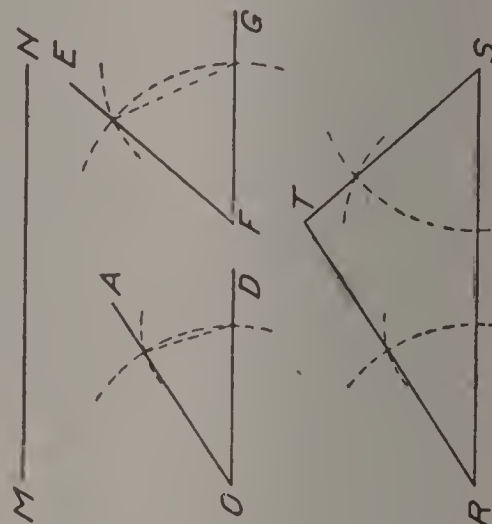
Problem 8



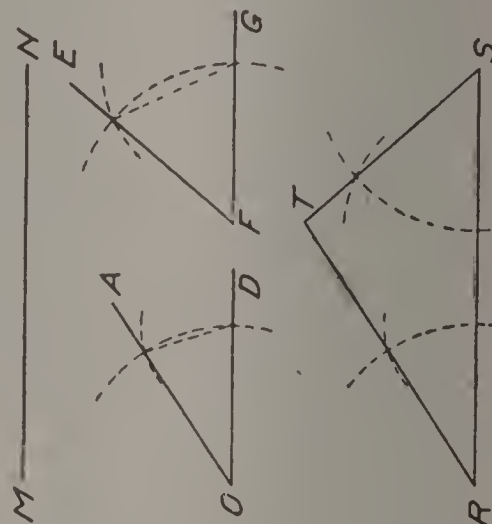
Problem 9



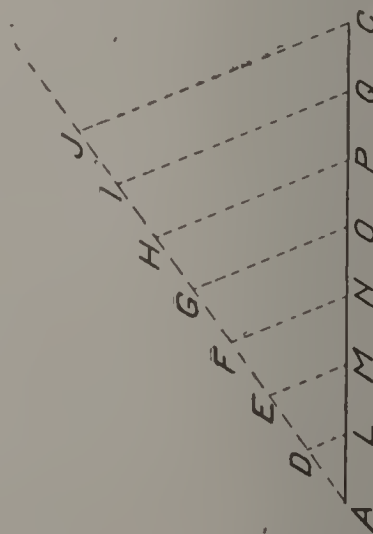
Problem 10



Problem 11



Problem 12



angle approximately as shown. Draw $A' C'$ and $E' F'$ parallel to $A C$ and $E F$ and at such equal distances from them that they will intersect at O . Now bisect the angle $C' O F'$ by the method given in Problem 8. The line $O R$ bisects the given angle.

Proof. Since $A' C'$ is parallel to $A C$ and $E' F'$ is parallel to $E F$, the angle $C' O F'$ is equal to the angle formed by the lines $A C$ and $E F$. Hence as $O R$ bisects angle $C' O F'$ it also bisects the angle formed by the lines $A C$ and $E F$.

Problem 10. *To divide a line into any number of equal parts.*

Let $A C$ —about $3\frac{3}{4}$ inches long—be a given line. Suppose it is desired to divide it into 7 equal parts. First draw the line $A J$ at least 4 inches long, forming any convenient angle with $A C$. On $A J$ lay off, by means of the dividers or scale, points D, E, F, G , etc., each $\frac{1}{2}$ inch apart. (If dividers are used, the spaces need not be exactly $\frac{1}{2}$ inch.) Draw the line $J C$ and through the points D, E, F, G , etc., draw lines parallel to $J C$. These parallels will divide the line $A C$ into 7 equal parts.

Proof. If a series of parallel lines, cutting two straight lines, intercept equal distances on one of these lines, they also intercept equal distances on the other.

Problem 11. *To construct a triangle having given the three sides.*

Draw the three sides, $A C$, $2\frac{3}{4}$ inches long; $E F$, $1\frac{1}{4}\frac{5}{8}$ inches long; and $M N$, $2\frac{3}{16}$ inches long.

Draw $R S$ equal in length to $A C$. With R as a center and a radius equal to $E F$ describe an arc. With S as a center and a radius equal to $M N$ draw an arc cutting the arc previously drawn, at T . Connect T with R and S to form the triangle.

Problem 12. *To construct a triangle having given one side and the two adjacent angles.*

Draw the line $M N$ $3\frac{1}{4}$ inches long and draw two angles $A O D$ and $E F G$ about 30 degrees and 60 degrees respectively.

Draw $R S$ equal in length to $M N$ and with R as a vertex and $R S$ as one side construct an angle equal to $A O D$. In a similar manner construct at S an angle equal to $E F G$. Draw lines from R and S through the two established points until they meet at T . The triangle $R T S$ will be the required triangle.

Lettering. Draw the pencil lines and put in the lettering as in plates already drawn.

Inking. In inking *Plate V*, follow the principles previously used and do not make certain lines dotted until sure that they should be dotted.

After inking the figures, ink in the border lines and the lettering as already explained.

PLATE VI

Penciling. Lay out this plate in the same manner as the preceding plates.

Problem 13. *To describe an arc or circumference through three given points not in the same straight line.*

Locate the three points *A*, *B*, and *C* with a distance between *A* and *B* of about 2 inches and a distance between *A* and *C* of about $2\frac{1}{4}$ inches. Connect *A* and *B* and *A* and *C*. Erect perpendiculars to the middle points of *AB* and *AC* as explained in Problem 1. Now draw light pencil lines connecting the intersections *I* and *J* and *E* and *F*. These lines will intersect at *O*.

With *O* as a center and a radius equal to the distance *OA*, describe the circumference passing through *A*, *B*, and *C*.

Proof. The point *O* is equally distant from *A*, *B*, and *C*, since it lies in the perpendiculars to the middle points of *AB* and *AC*. Hence the circumference will pass through *A*, *B*, and *C*.

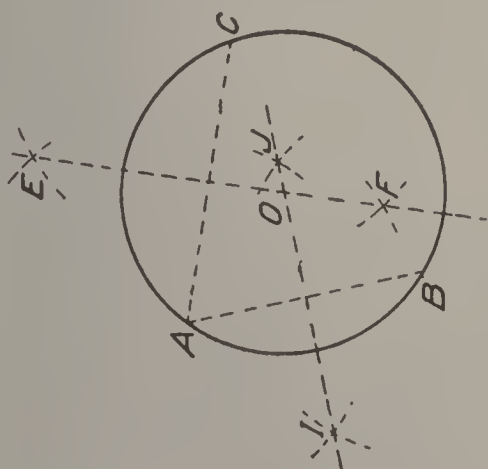
Problem 14. *To inscribe a circle in a given triangle.*

Draw the triangle *LMN* of any convenient size. *MN* may be made $3\frac{1}{4}$ inches, *LM*, $2\frac{3}{4}$ inches, and *LN*, $3\frac{1}{2}$ inches. Bisect the angles *MLN* and *LMN* by the method used in Problem 8. The bisectors *MI* and *LJ* intersect at *O*, which is the center of the inscribed circle. The radius of the circle is equal to the perpendicular distance from *O* to one of the sides.

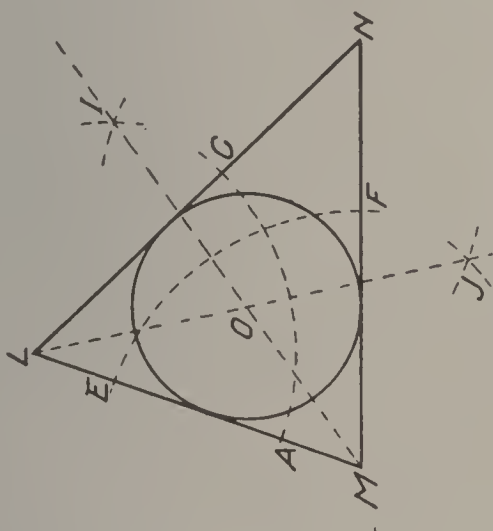
Proof. The point of intersection of the bisectors of the angles of a triangle is equally distant from the sides.

Problem 15. *To inscribe a regular pentagon in a given circle.*

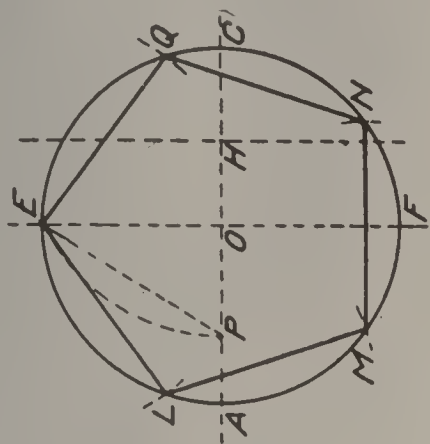
With *O* as a center and a radius of about $1\frac{1}{2}$ inches, describe the given circle. With the T-square and triangles draw the center lines *AC* and *EF* perpendicular to each other and passing through *O*. Bisect one of the radii, *OC*, at *H* and with this point as a center and a radius *HE*, describe the arc *EP*. This arc cuts the diameter *AC* at *P*. With *E* as a center and a radius *EP*, draw arcs cutting



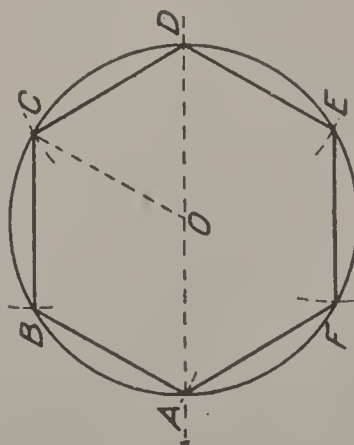
Problem 13



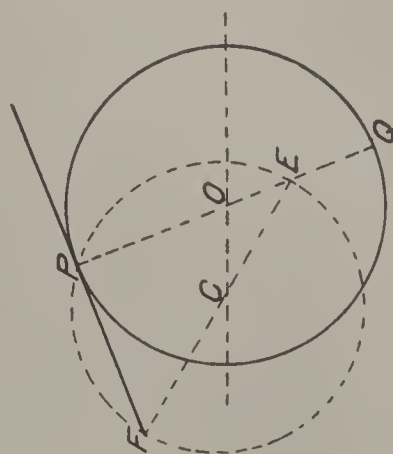
Problem 14



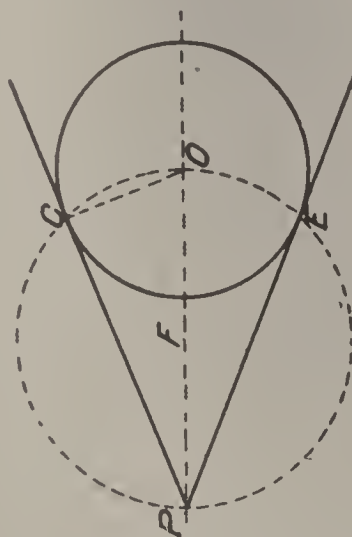
Problem 15



Problem 16



Problem 17



Problem 18

the circumference at L and Q . With the same radius and centers at L and Q , draw the arcs cutting the circumference at M and N .

The pentagon is completed by drawing the chords EL , LM , MN , NQ , and QE .

Problem 16. *To inscribe a regular hexagon in a given circle.*

With O as a center and a radius of $1\frac{3}{8}$ inches draw the given circle. With the T-square draw the diameter AD . With D as a center, and a radius equal to OD , describe arcs cutting the circumference at C and E . Now with C and E as centers and the same radius, draw the arcs, cutting the circumference at B and F . Draw the hexagon by joining the points thus formed.

Therefore, in order to inscribe a regular hexagon in a circle, mark off chords equal in length to the radius.

To inscribe an equilateral triangle in a circle the same method may be used, the triangle being formed by joining the opposite vertices of the hexagon.

Proof. Since the triangle OCD is an equilateral triangle by construction, the angle COD is one-third of two right angles and one-sixth of four right angles. Hence arc CD is one-sixth of the circumference and the chord is a side of a regular hexagon.

Problem 17. *To draw a line tangent to a circle at a given point on the circumference.*

With O as a center and a radius of about $1\frac{1}{4}$ inches draw the given circle. Assume some point P on the circumference and join the point P with the center O . By the method given in Problem 6, Plate IV, construct a perpendicular to PO , which perpendicular will be the desired tangent to the circle at the point P .

Proof. A line perpendicular to a radius at its extremity is tangent to the circle.

Problem 18. *To draw a line tangent to a circle from a point outside the circle.*

With O as a center and a radius of about 1 inch draw the given circle. Assume P some point outside of the circle about $2\frac{1}{2}$ inches from the center. Draw a straight line passing through P and O . Bisect PO and with the middle point F as a center describe the circle passing through P and O . Draw a line from P through the intersection of the two circumferences C . The line PC is tangent to the given circle. Similarly PE is tangent to the circle.

Proof. The angle $P C O$ is inscribed in a semicircle and hence is a right angle. Since $P C O$ is a right angle, $P C$ is perpendicular to $C O$. The perpendicular to a radius at its extremity is tangent to the circumference.

Inking. In inking *Plate VI*, the same method should be followed as in previous plates.

PLATE VII

Penciling. Lay out this plate in the same manner as the preceding plates.

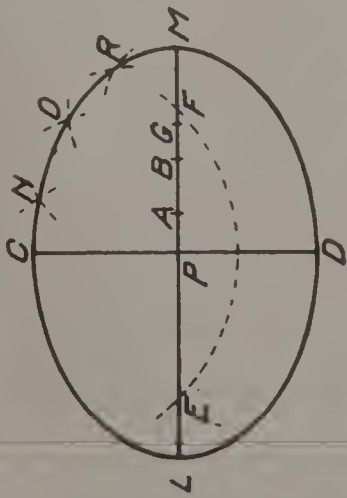
Problems 19 and 20. *To draw an ellipse when the axes are given.*

First Method. Draw the lines $L M$ and $C D$ about $3\frac{1}{4}$ and $2\frac{1}{4}$ inches long respectively, making $C D$ perpendicular to $L M$ at its middle point P and having $C P = P D$. The two lines, $L M$ and $C D$, are the axes. With C as a center and a radius $L P$ equal to one-half the major axis, draw the arc, cutting the major axis at E and F . These two points are the foci.

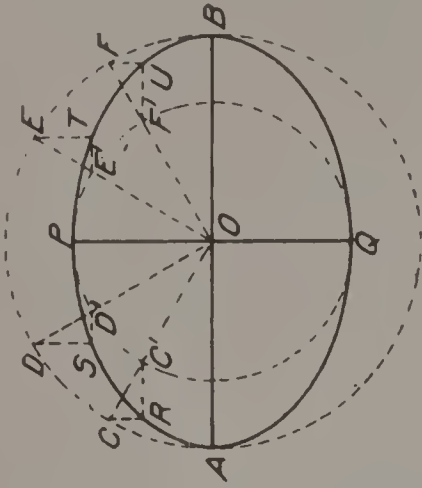
Now locate several points on $P M$, such as A , B , and G . With E as a center and a radius equal to $L A$, draw arcs above and below $L M$. With F as a center and a radius equal to $A M$ describe short arcs cutting those already drawn as shown at N . With E as a center and a radius equal to $L B$ draw arcs above and below $L M$ as before. With F as a center and a radius equal to $B M$, draw arcs intersecting those already drawn as shown at O . The point R and others are found by repeating the process. The student is advised to find at least 12 points on the curve—6 above and 6 below $L M$. These 12 points with L , C , M , and D will enable him to draw the curve.

After locating these points, draw a free-hand curve passing through them.

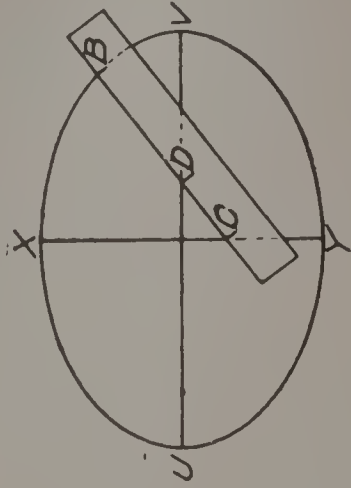
Second Method. Draw the two axes $A B$ and $P Q$ in the same manner as in the first method. With O as a center and a radius equal to one-half the major axis, describe a circle. Similarly with the same center and a radius equal to one-half the minor axis, describe another circle. Draw any radii such as $O C$, $O D$, $O E$, $O F$, etc., cutting both circumferences. These radii may be drawn with the 60 and 45 degree triangles. From C , D , E , and F , the points of intersection of the radii with the large circle, draw *vertical* lines and from C' , D' , E' , and F' , the points of intersection of the radii with



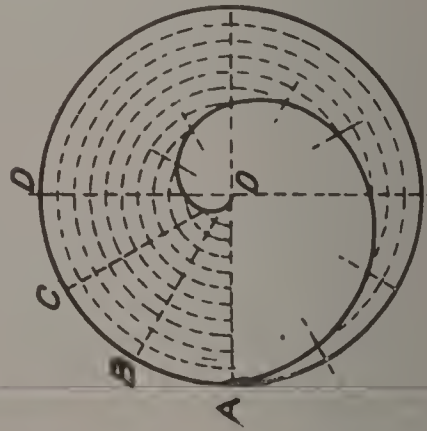
Problem 19



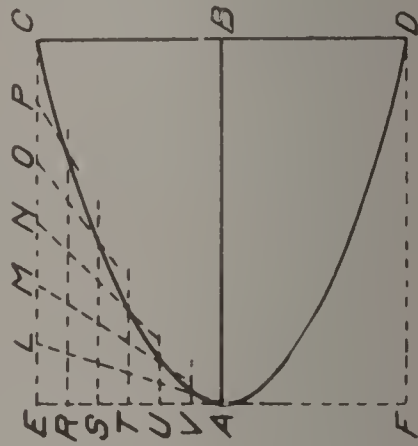
Problem 20



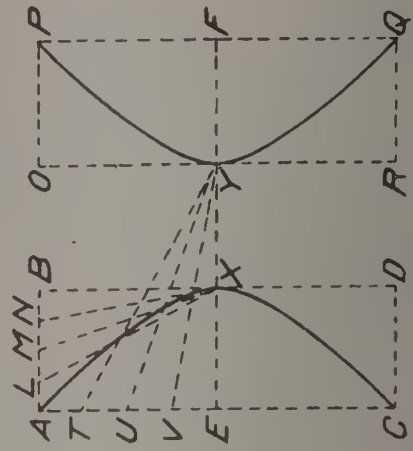
Problem 21



Problem 22



Problem 23



Problem 24

the small circle, draw *horizontal* lines. The intersections of these lines are points on the ellipse.

Draw a free-hand curve* passing through these points; about five points in each quadrant will be sufficient.

Problem 21. *To draw an ellipse by means of a trammel.*

As in Problems 19 and 20, draw the major and minor axes, UV and XY . Take a slip of paper having a straight edge and mark off CB equal to one-half the major axis, and DB equal to one-half the minor axis. Place the slip of paper in various positions keeping the point D on the major axis and the point C on the minor axis. If this is done, the point B will mark various points on the curve. Find as many points as necessary and sketch the ellipse.

Problem 22. *To draw a spiral of one turn in a circle.*

Draw a circle with the center at O and a radius of $1\frac{1}{2}$ inches. Locate twelve points, $\frac{1}{8}$ inch apart on the radius OA and draw circles through these points. With the 30-degree triangle, draw radii OB, OC, OD , etc., 30 degrees apart, thus forming 12 equal parts.

The points on the spiral are now located; the first is at the center O ; the next is at the intersection of the line OB and the first circle; the third is at the intersection of OC and the second circle; the other points are located in the same way. Sketch in pencil a smooth curve passing through these points.

Problem 23. *To draw a parabola when the abscissa and ordinate are given.*

Draw the straight line AB —about three inches long—as the axis, or *abscissa* of the parabola. At A and B draw the lines EF and CD perpendicular to AB , and with the T-square draw EC and FD , $1\frac{1}{2}$ inches above and below AB , respectively. Let A be the vertex of the parabola. Divide AE and EC into the same number of equal parts. Through R, S, T, U , and V , draw horizontal lines and connect L, M, N, O , and P , with A . The intersections of the horizontal lines with the oblique lines are points on the curve. For instance, the intersection of AL and the line V is one point and the intersection of AM and the line U is another.

The lower part of the curve AD is drawn in a similar manner.

Problem 24. *To draw a hyperbola when the abscissa EX , the ordinate AE , and the diameter XY are given.*

*See Page 16, Mechanical Drawing, Part I.

Draw EF about 3 inches long and mark the point X , 1 inch from E and the point Y , 1 inch from X . With the triangle and T-square, draw the rectangles $ABDC$ and $OPQR$ such that AB is 1 inch in length and AC , 3 inches in length. Divide AE and AB into the same number of equal parts. Connect Y with the points T , U , and V , on AE , and connect X with L , M , and N , on AB . The first point on the curve is at A ; the next is at the intersection of TY and LX ; the third is at the intersection of UY and MX . The remaining points are found in the same manner. Repeat the process for XC and the right-hand curve PYQ .

Inking. In inking the figures on this plate, use the French or irregular curve and make full lines for the curves and their axes. Dot the construction lines as usual. Ink in all the construction lines used in finding one-half of a curve, and in Problems 19, 20, 23, and 24 leave all construction lines in *pencil* except those inked. In Problems 21 and 22 erase all construction lines not inked. The trammel used in Problem 21 may be drawn in the position shown, or outside of the ellipse in any convenient place.

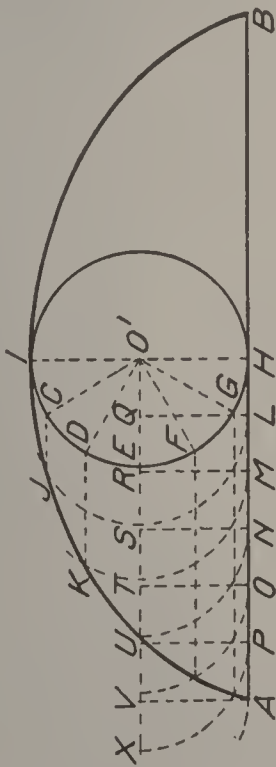
The same lettering should be done on this plate as on previous plates

PLATE VIII

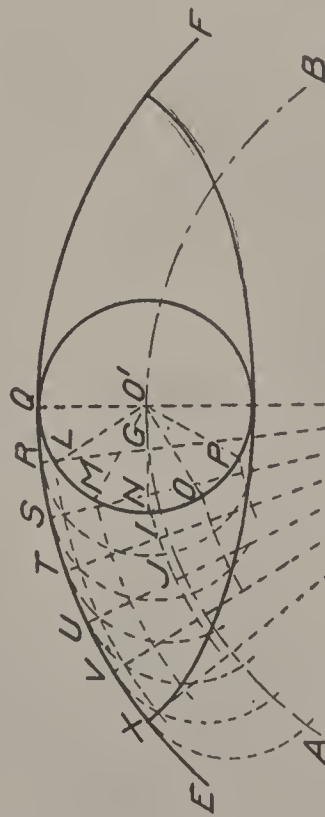
Penciling. In laying out *Plate VIII*, draw the border lines and horizontal and vertical center lines as in previous plates, dividing the plate into four spaces.

Problem 25. *To construct a cycloid when the diameter of the generating circle is given.*

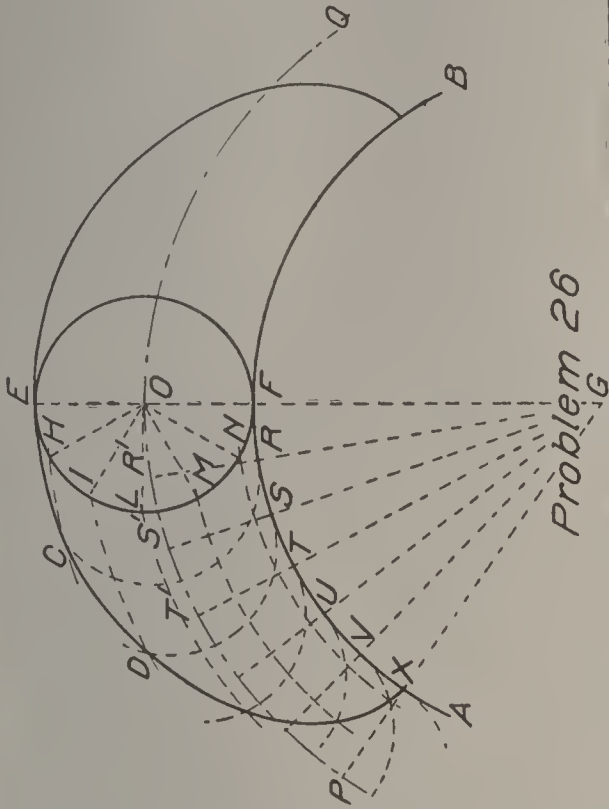
With O' as a center and a radius of $\frac{7}{8}$ inch draw a circle, and, tangent to it, draw the indefinite horizontal straight line AB . Divide the circle into any number of equal parts—12 for instance—and through these points of division C , D , E , F , etc.; draw horizontal lines. Now with the dividers set so that the distance between the points is equal to the chord of the arc CD , mark off the points L , M , N , O , P , on the line AB , commencing at the point H . At these points erect perpendiculars to the center line XO' which is the line of centers of the generating circle as it rolls along the line AB . With the intersections Q , R , S , T , etc., as centers describe arcs of circles as shown. The points on the cycloid will be the intersections of



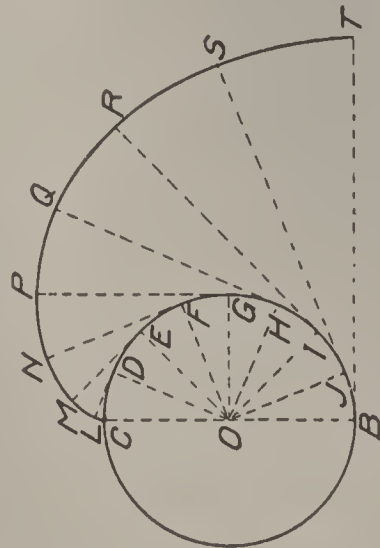
Problem 25



Problem 27



Problem 26



Problem 28

these arcs and the horizontal lines drawn through the points C, D, E, F , etc. Thus the intersection of the arc whose center is Q and the horizontal line through C is a point J on the curve. Similarly, the intersection of the arc whose center is R and the horizontal line through D is the point K on the curve. The remaining points on the left, as well as those on the right, are found in the same manner. To obtain great accuracy in this curve, the circle should be divided into a large number of equal parts, because the greater the number of divisions the less the error due to the difference in length between a chord and its arc.

Problem 26. *To construct an epicycloid when the diameter of the generating circle and the diameter of the director circle are given.*

The epicycloid and the hypocycloid may be drawn in the same manner as the cycloid if arcs of circles are used in place of the horizontal lines. With O as a center and a radius of $\frac{3}{4}$ inch describe a circle. Draw the diameter EF of this circle and produce EF to G such that the line FG is $2\frac{3}{4}$ inches long. With G as a center and a radius FG , describe the arc AB of the director circle. With the same center G , draw the arc PQ which will be the path of the center of the generating circle as it rolls along the arc AB . Now divide the generating circle into any number of equal parts—twelve for instance—and through the points of division H, I, L, M , and N , draw arcs having G as a center. With the dividers set so that the distance between the points is equal to the chord HI , mark off distances on the director circle AFB . Through these points of division R, S, T, U , etc., draw radii intersecting the arc PQ in the points R', S', T' , etc., and with these points as centers describe arcs of circles as in Problem 25. The intersections of these arcs with the arcs already drawn through the points H, I, L, M , etc., are points on the epicycloid. Thus the intersection of the circle whose center is R' with the arc drawn through the point H is a point upon the curve. Also the arc whose center is S' with the arc drawn through the point I is another point on the curve. The remaining points are found by repeating this process.

Problem 27. *To draw an hypocycloid when the diameter of the generating circle and the radius of the director circle are given.*

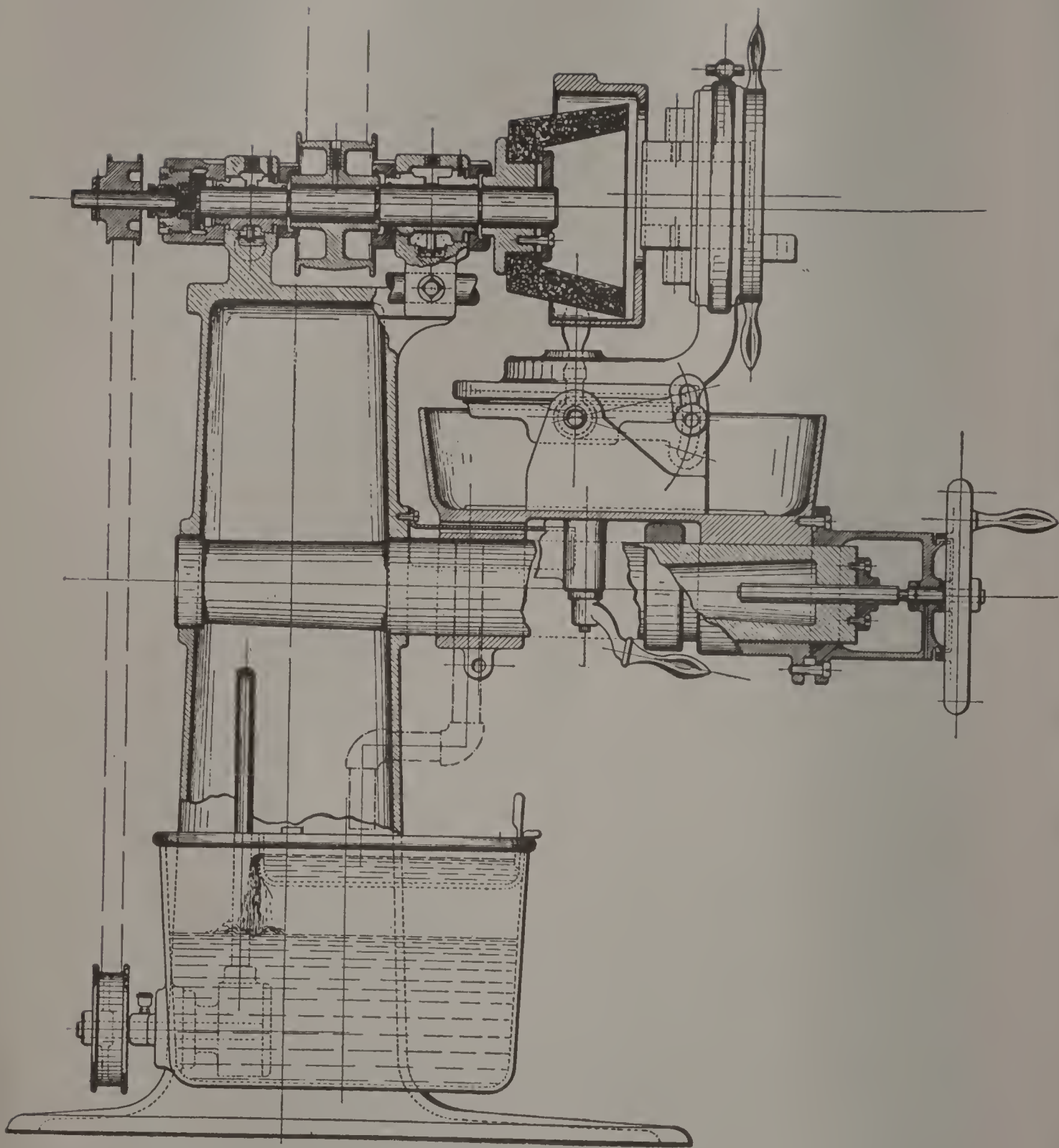
With C as a center and a radius of 4 inches describe the arc EF , which is the arc of the director circle. Now with the same

center and a radius of $3\frac{1}{4}$ inches, describe the arc $A B$, which is the line of centers of the generating circle as it rolls on the director circle. With O' as a center and a radius of $\frac{3}{4}$ inch describe the generating circle. As before, divide the generating circle into any number of equal parts—12, for instance—and with these points of division L, M, N, O , etc., draw arcs having C as a center. Upon the arc $E F$, lay off distances $Q R, R S, S T$, etc., equal to the chord $Q L$. Draw radii from the points R, S, T , etc., to the center of the director circle C and describe arcs of circles having a radius equal to the radius of the generating circle, using the points G, I, J , etc., as centers. As in Problem 26, the intersections of the arcs are the points on the hypocycloid. By repeating this process, the right-hand portion of the curve may be drawn.

Problem 28. *To draw the involute of a circle when the diameter of the base circle is known.*

With the point O as a center and a radius of 1 inch, describe the base circle. Divide the circle into any number of equal parts—16, for instance—and draw radii to the points of division. At the point D , draw a light pencil line perpendicular to $O D$. This line will be tangent to the circle. Similarly at the points E, F, G, H , etc., draw tangents to the circle. Set the dividers so that the distance between the points will be equal to the chord of the arc $C D$, and measure this distance from D along the tangent. From the point E , measure on the tangent a distance equal to two of these chords; from the point F , three divisions; and from the point G , four divisions. Similarly, measure distances on the remaining tangents, each time adding the length of the chord. This will give the points L, M, N, P , etc., to T . The curve drawn through these points will be the involute of the circle.

Inking. Observe the same rules in inking *Plate VIII* as were given for *Plate VII*. In Problems 25 and 26 the arcs and lines used in locating the points of the other half of the curve may be left in pencil. In Problem 28, all construction lines should be inked. After completing the problems the same lettering should be done on this plate as on previous plates.



GISHOLT TOOL GRINDER

Courtesy of Gisholt Machine Company, Madison, Wisconsin

MECHANICAL DRAWING

PART III

PROJECTIONS

ORTHOGRAPHIC PROJECTION

Definitions. *Projection.* The word projection means *to throw forward*. In mechanical drawing, the significance is *to throw forward in straight lines*. Projection really means, therefore, either the act or the result of projecting parallel rays from the surface of a body and of cutting these rays with a plane, so as to obtain on the

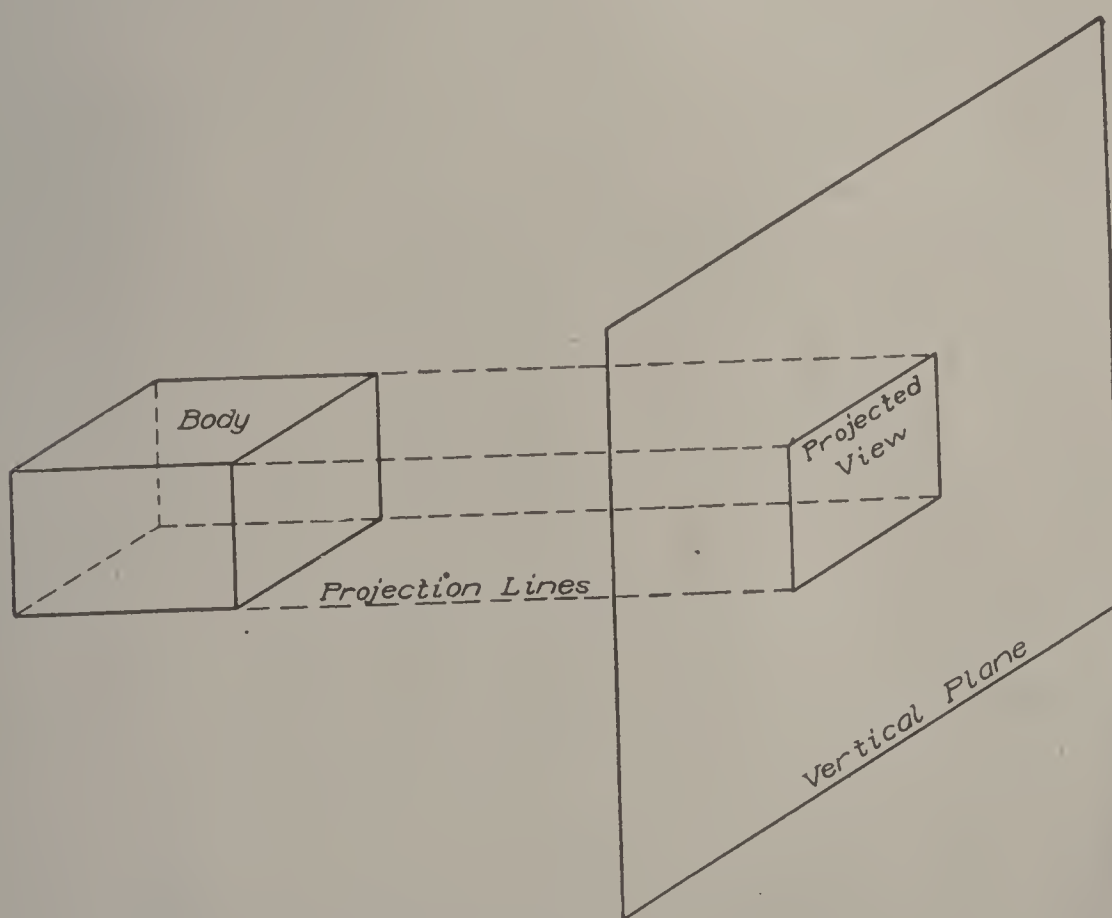


Fig. 95. Body and Its Projection

plane a shape corresponding point for point with that of the body. The rays are called *projecting lines*. A plane may be considered transparent, since it is a flat surface having no thickness.

View. In Fig. 95 a body is shown as projecting from its surface projection lines, and these lines are cut by a plane. By connecting the points on the plane made by the projection lines the

projection of the body is formed, and it corresponds in shape with the body itself. A projection of this kind is called a *view*, this name being given it on account of the fact that an observer on the same side of the body as the projection plane would get this view.

It can readily be seen that one view only will not give a complete picture of a solid object. Usually two or more views are necessary, according to the complication of the object or body. When two or three views are shown, they are pictured on two or

three planes at right angles to each other. In this way views of two or three sides are shown, and this is usually sufficient to give the idea of the complete form of the object.

Orthographic. The word *orthographic* means at right angles, and in mechanical drawing, in connection with the word projection, it means that two or more views are projected on planes at

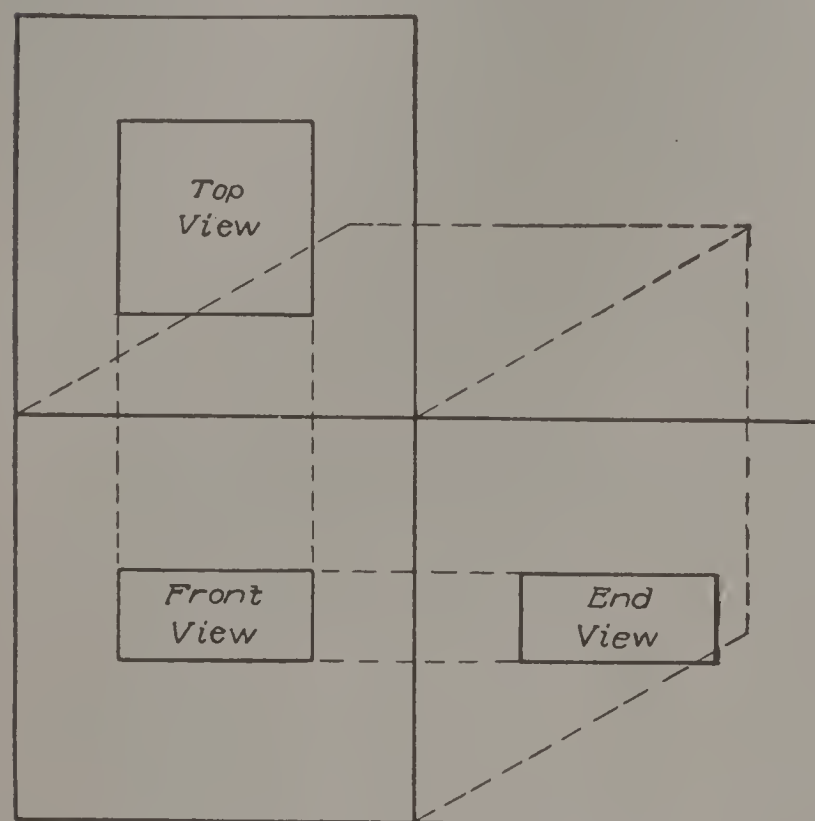


Fig. 96. Projections of Top, Front, and End of Body

right angles with each other. The various views of a body have special names—those showing vertical faces are called *elevations*, such as front, side, end or rear elevation; a view of the top of a body is called a *plan* or *plan view*; and a view of the under side, a *bottom view*.

Third-Angle Projection. In Fig. 96 is shown three faces of a body projected on three planes—the top view on the top plane, the front view on the front plane, and the end view on the end plane. It will be seen that the same body is represented as projecting rays in three directions, and thus the three projections, or views, are obtained. It will also be seen that the three planes with their views have been brought into one plane, that is, the surface of the paper. This brings the top view directly above the front view, and the end view to the right of the front view. The above is a definition of

true projection, usually called *third-angle projection*, and is the method used by practically all draftsmen in this country.

First-Angle Projection. There is, however, a method called first-angle projection, used but little now in this country, although formerly in almost general use. Because draftsmen may have to do at times with old drawings or drawings made in foreign countries, it is well for them to understand first-angle projection. This method

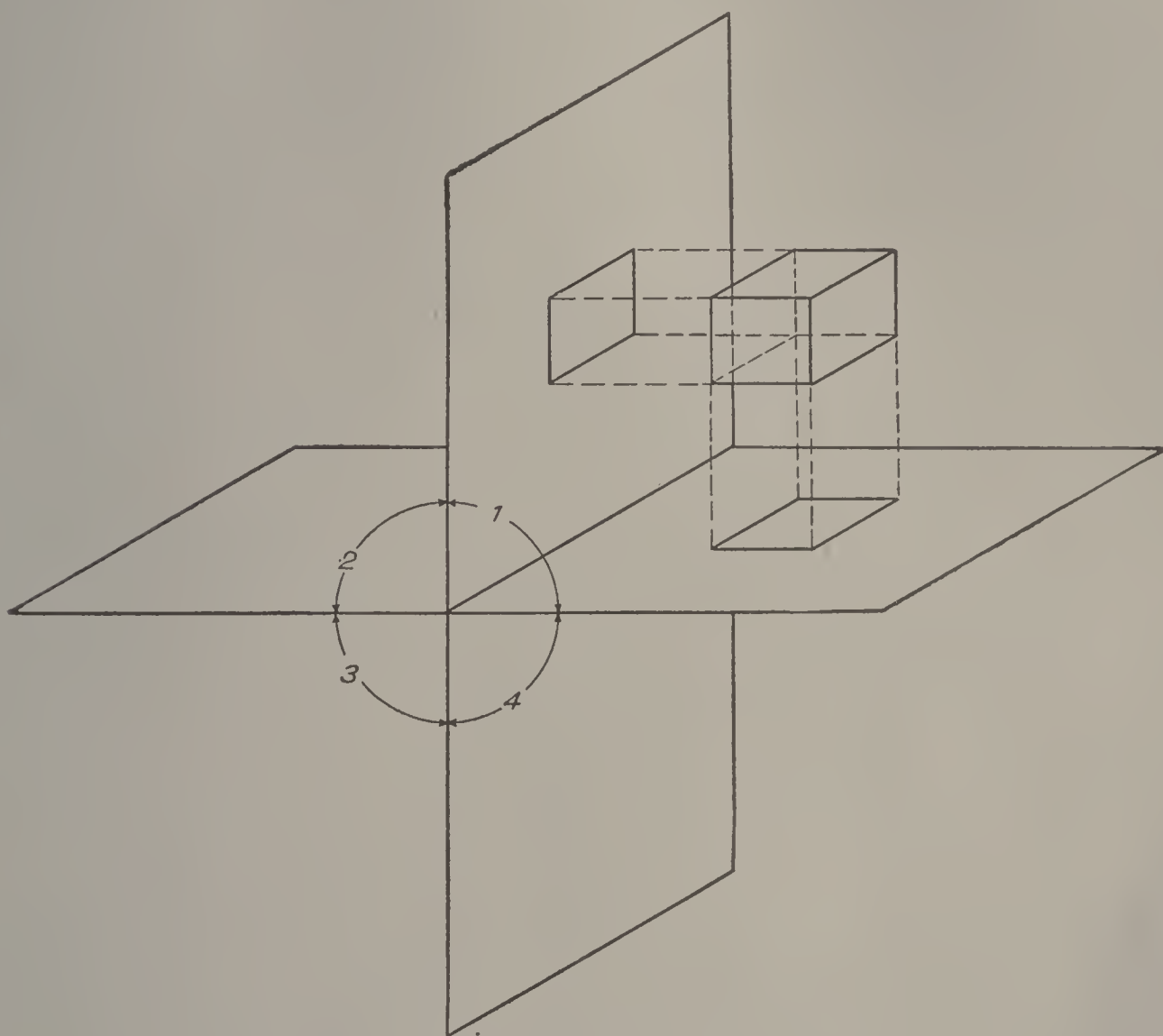


Fig. 97. Body and Its First-Angle Projections

brings the front view, or elevation, above the top view, or plan, the end view being at the right of the front view. Fig. 97 shows this method of first-angle projection.

Comparison of Third- and First-Angle Projection. Perhaps a short explanation will make clear the meaning of third- and first-angle projection. In geometry, when two planes intersect at right angles, the angles are designated as first, second, third, and fourth, as numbered in Fig. 97. In first-angle projection, the body is placed in angle 1, and a top view is projected on a plane under the body.

This passes the projection lines back through the body, instead of throwing them out from the surface. In fact, by this method, the body is supposed to turn itself inside out, an absurdity which led to the general abandonment of the method in this country. Third-angle projection places a body in angle 3, and projects a top view on to the plane above it, and a front view on to the plane in front of it. This is true projection.

Projection Methods. When a drawing is made by projection, an object is represented just as it would be seen if one eye were closed and the other were directly over each point of the object at the same time. As an illustration of this, place a box on a table and a piece of ground glass a few inches in front of it. Now, stand

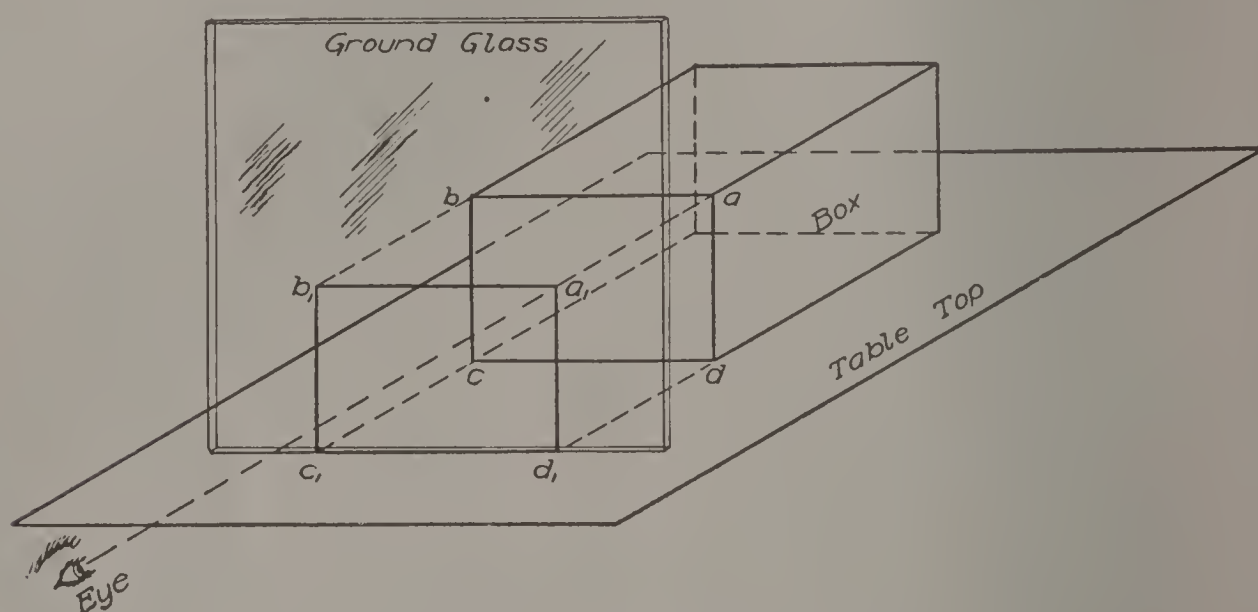


Fig. 98. Visual Method of Finding Projection

so that one eye will come directly in line with one corner *a*, Fig. 98. Make a dot at *a*₁ where the line from the eye to the corner *a* passes through the glass. Next, move the eye until it is directly in line with the corner *b* of the box, and put a dot at *b*₁ where the line from the eye to the corner *b* passes through the glass. Repeat this process, putting dots on the glass at *c*₁ and *d*₁ where the lines from the eye to the corners *c* and *d* pass through the glass. Now, connect the points *a*₁, *b*₁, *c*₁, and *d*₁, and the complete projection of the front of the box will be shown by the figure on the glass. This

NOTE. The first four figures in this textbook, Figs. 95, 96, 97, and 98, are pictorial views given to show the student clearly how the views of objects are projected. The student in drawing orthographic projections does not need to draw the pictorial views, but simply the projections, as illustrated in Figs. 99 to 129, inclusive.

figure is a rectangle, and is the same shape and size as the front of the box.

It is readily seen that from this one projection drawing, or view, no idea of the depth of the box is given, although the width and height are correctly shown. A top, or plan, view must now be made to show the depth of the box. Place another piece of ground glass a few inches above the box and, with the eye directly over each separate corner of the top, repeat the process of making the four dots, representing each top corner. Connect these four dots, and the figure thus formed represents the top projection, or plan view, of the box. Now, arrange the two pieces of glass, as shown in Fig. 99. The box being removed, the upper glass is simply lowered to the table, and the front glass is turned from the bottom forward and up, and laid directly below the upper glass.

This position of the figures represents the two projections—front elevation and plan—just as they would be drawn by a draftsman on a sheet of drawing paper. The width of the box is shown in both views, and being the

same in each, the front elevation and plan are both of equal width, and therefore each point in the plan is directly over the corresponding point in the front elevation. In more complicated objects, where the complete idea cannot be obtained from the front elevation and plan views, an end view or both end views must be shown as in Fig. 100, which represents the projections of a box with a curved top. These end views are obtained by taking two or more

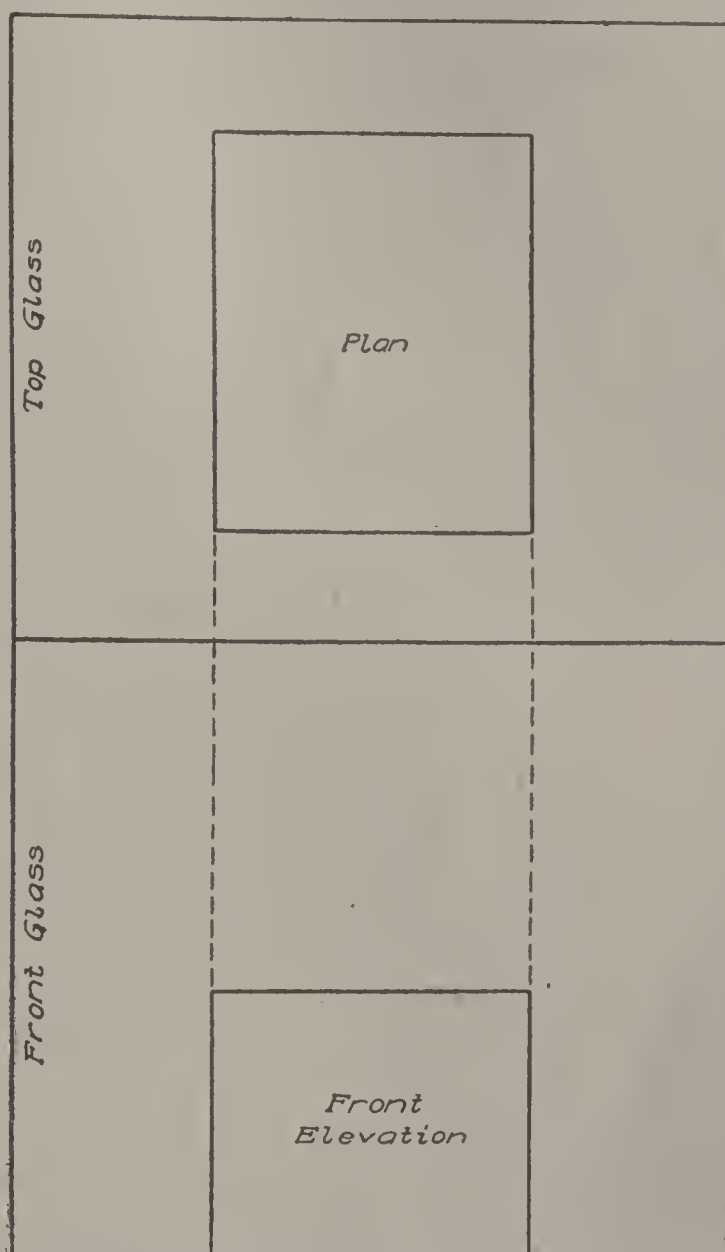


Fig. 99. Plan and Elevation of Box Shown in Fig. 98

pieces of ground glass, placing them one in front of each end, and then drawing the projections. This is done, as in the cases of the

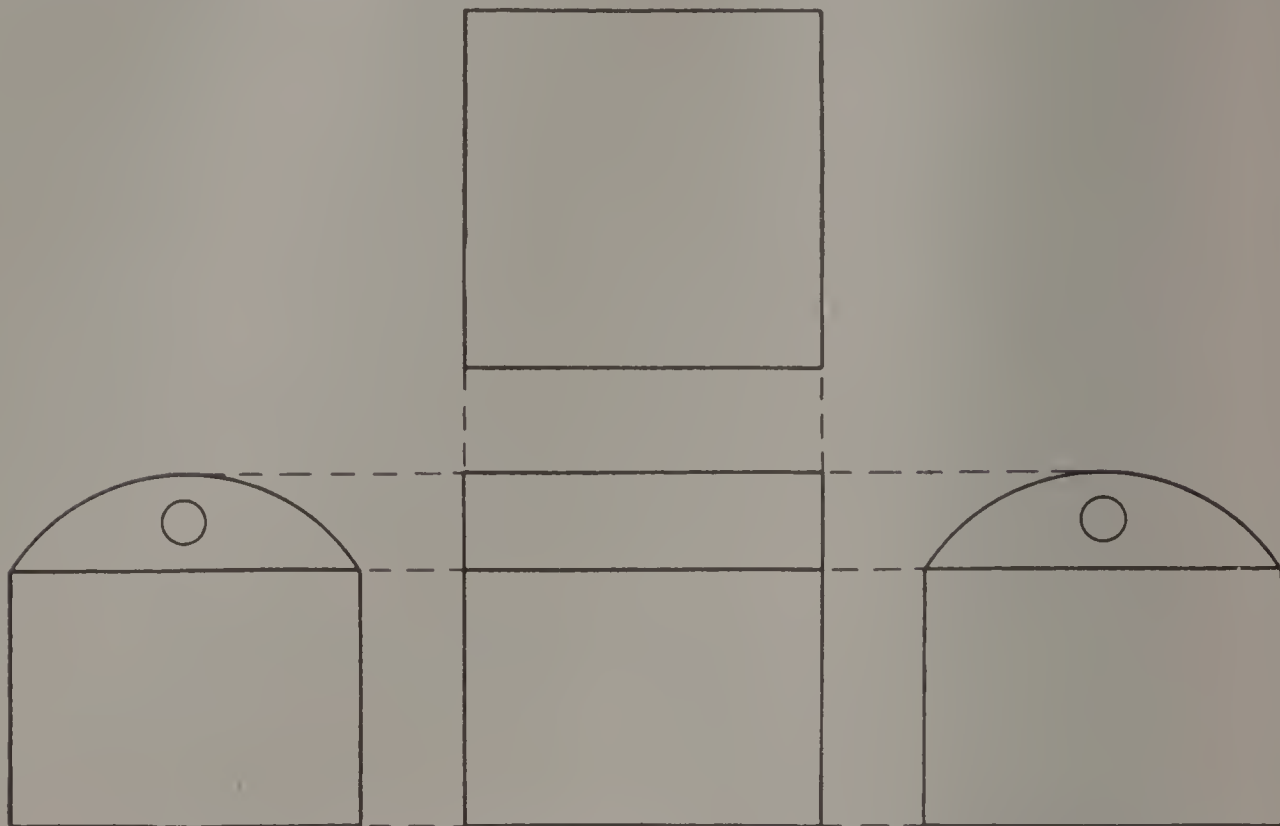


Fig. 100. Plan, Elevation, and End Views of a Box with a Curved Top

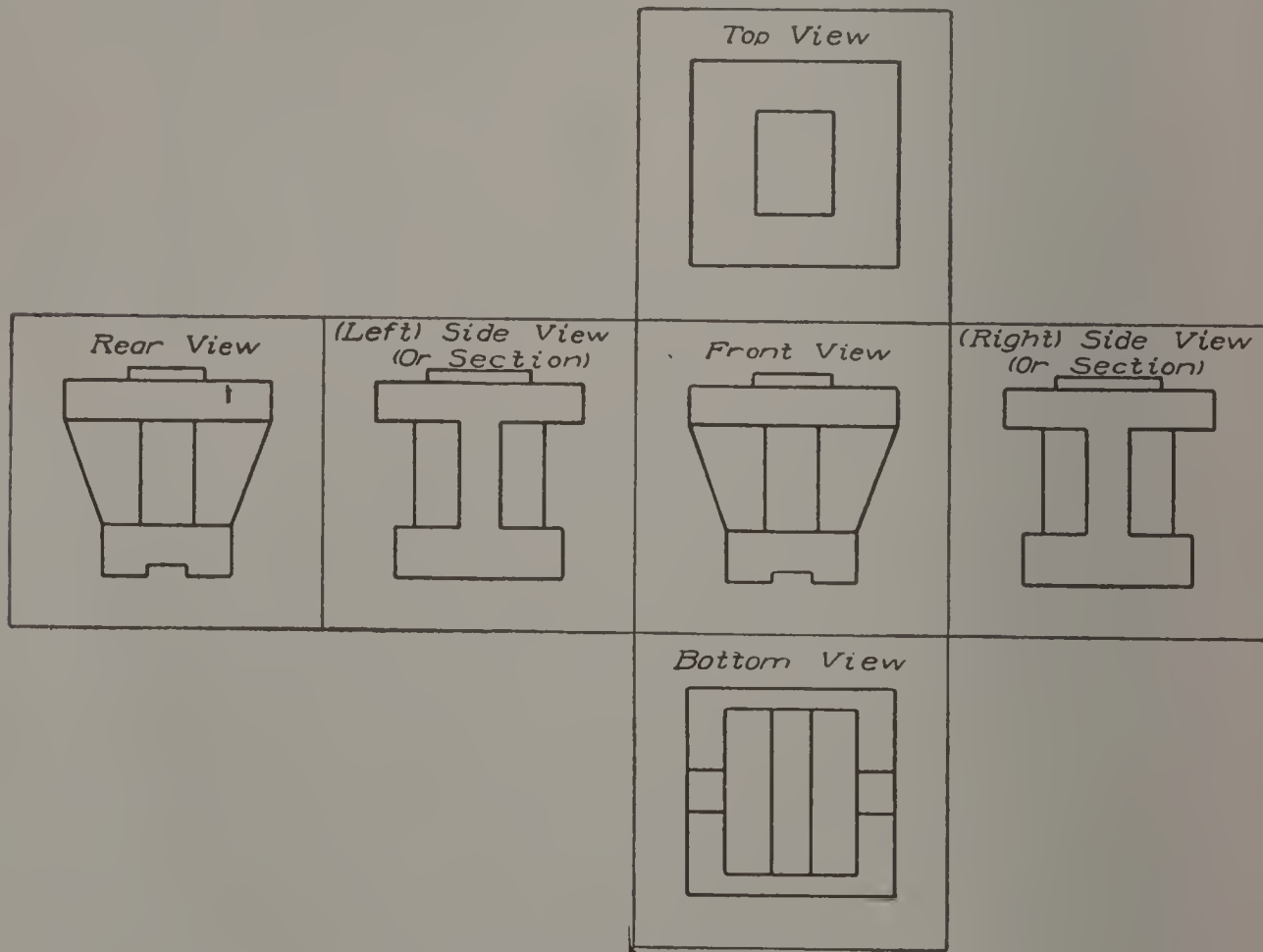


Fig. 101. Six Views of Object

Courtesy of Pennsylvania Railroad Company, Altoona, Pennsylvania

front elevation and plan, by making several dots for the shape of the top, and drawing a curved line through these dots. The two

end views are placed as shown—the right-hand view at the right of the front view, and the left-hand view at the left. This gives the proper arrangement of the views as a draftsman would work them out on paper.

In Fig. 101 is represented a practical case where the object is sufficiently complicated to require a view of each of its six faces. As will be seen in the figure, six views are shown—front, top,

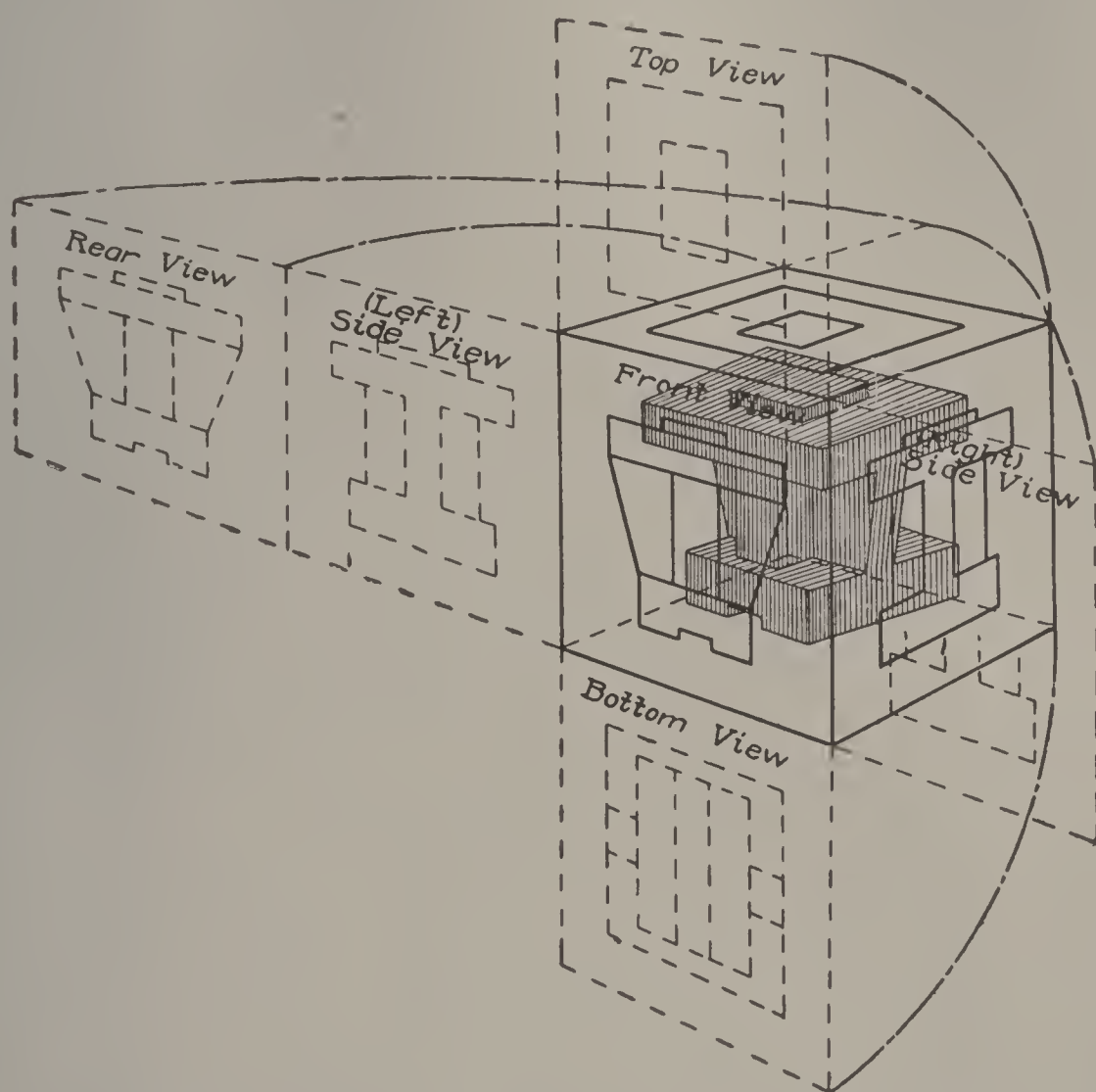


Fig. 102. Folding Out of the Projection Planes Into the Plane of the Surface of the Drawing Paper

Courtesy of Pennsylvania Railroad Company, Altoona, Pennsylvania

bottom, right side, left side, and rear. In Fig. 102 is represented the method of folding out the projection planes after the faces of the object have been projected on them, in order to have them all in one plane—that of the surface of the drawing paper, as shown in Fig. 101.

Drawing the Projection on Paper. From the explanation just given, it will be seen that the projection views are all of the same size as the faces of the object they represent. They can, therefore,

be drawn just as readily on a sheet of drawing paper without the use of the ground glass. For the front view, measure the four front edges of the object, and lay off on the paper a figure of the same shape as the front of the object. Repeat the process for the top of the object, obtaining the top view, or plan; and for each end of the object, obtaining the end view, or side views. The bottom and

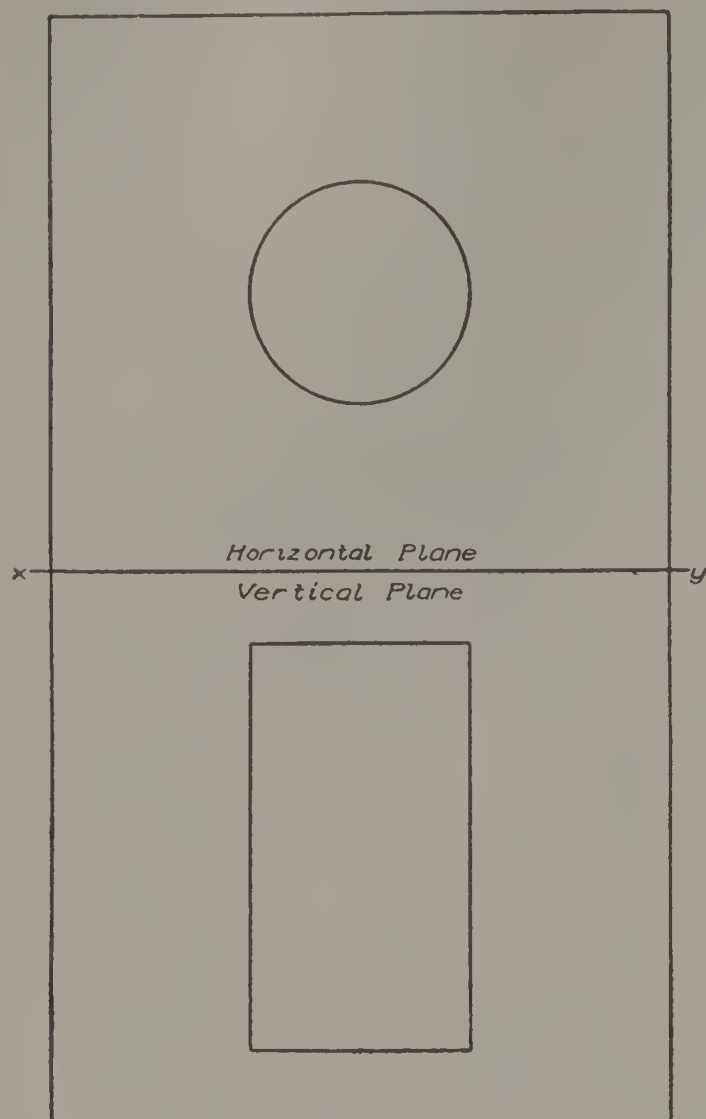


Fig. 103. Ground Line, xy , at Intersection of Horizontal and Vertical Planes

rear views can be placed in the same way. Draw the plan view with its four corners directly over the four corners of the front view, and the bottom view with its four corners directly under. Draw the right end, or side, view with its four corners directly to the right of the four corners of the front elevation, and the left end, or left side, view and rear view, with their corners directly to the left of the corners of the front view.

Projection Lines. As each projected point of an object shown in plan view must be directly over the projection of the same point in the front elevation, a vertical dotted line will connect these points,

as projected in pairs; and as each projected point in an end view must be directly opposite the projection of the same point in the front elevation, a horizontal dotted line will connect these points, as projected in pairs. These dotted lines are called projection or construction lines.

Ground Line. Having the two planes, at right angles, on which the front elevation and plan are represented, when the top plane is turned up to bring the plan above the front elevation, as represented on the surface of the drawing paper, it revolves on the intersecting line of the two planes as an axis. This intersecting line xy

in Fig. 103, is called the ground line, and this is usually abbreviated to GL . The projections may be placed at any convenient distance above or below the GL , unless these distances are given in any problem. In beginning all ordinary projection work, it is customary to show the GL as a horizontal line between the front elevation and plan views, and the projection of any pair of points in the front and plan views are always in a line perpendicular to the GL . This is evident from the fact that the points in the plan view are directly

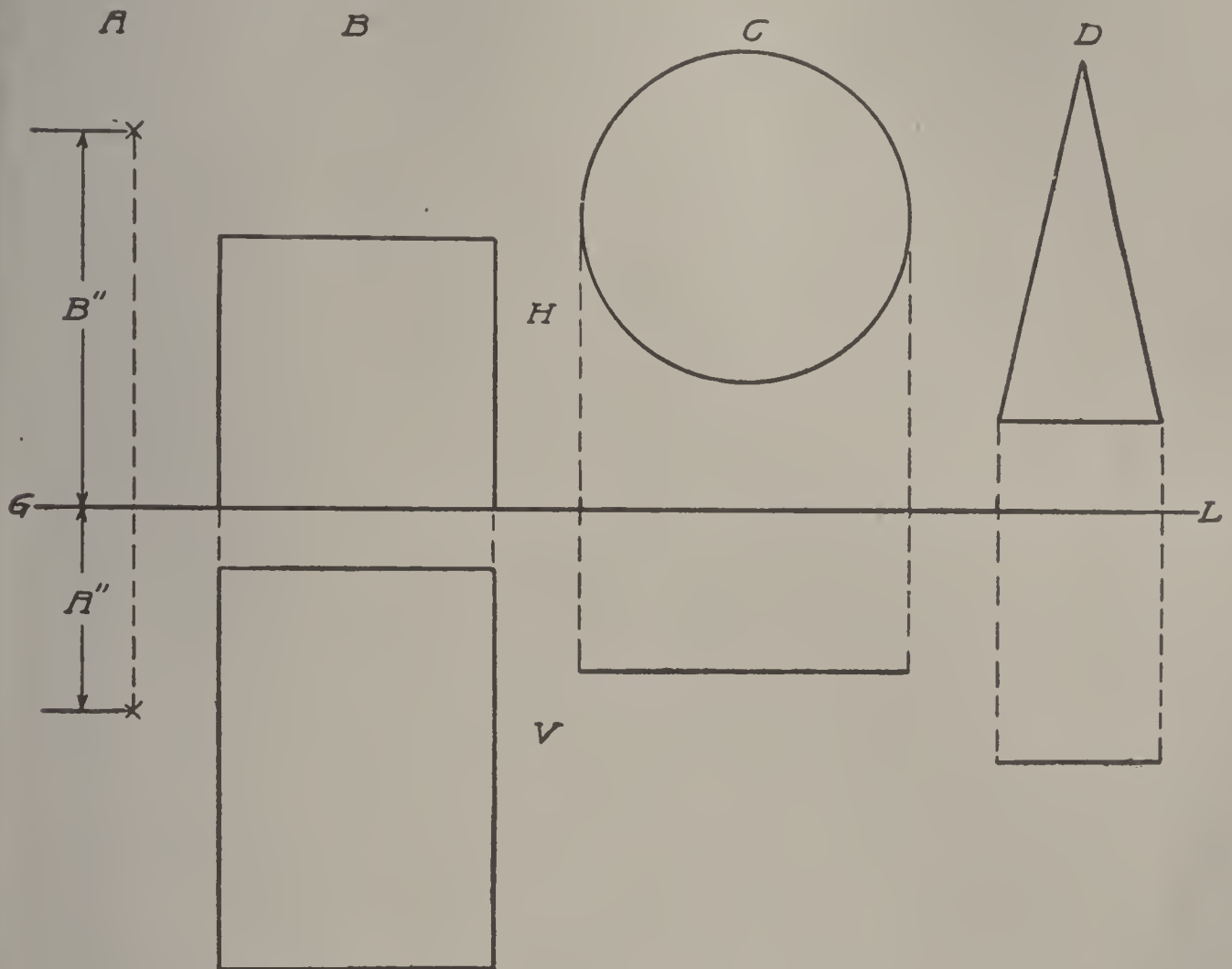


Fig. 101. Typical Projections

over the corresponding points in the front elevation. Although the ground line is usually used in learning the subject of projections, it is customary to omit it in practical work.

Rules of Projection. (1) *If a surface is perpendicular to either plane of projection, its projection on that plane is simply a line—a straight line if the surface is plane, a curved line if the surface is curved.*

(2) *The projected view of any point of any object on a plane is in a perpendicular drawn to the plane through the point of the object.*

(3) *If a straight line is perpendicular to a plane, its projection on that plane is a point; and if the straight line is parallel to the plane, the projection is a line equal in length to the line itself and makes the same angle with the ground line.*

(4) *All points on any object at the same height above its base must appear in the front elevation at the same distance below the ground line, and all points on an object at the same distance back of the front face must appear in the plan at the same distance above the ground line.*

Typical Examples of Projection. Figs. 104 and 105 show clearly several ideas of plan and elevation. In such work as this, it is

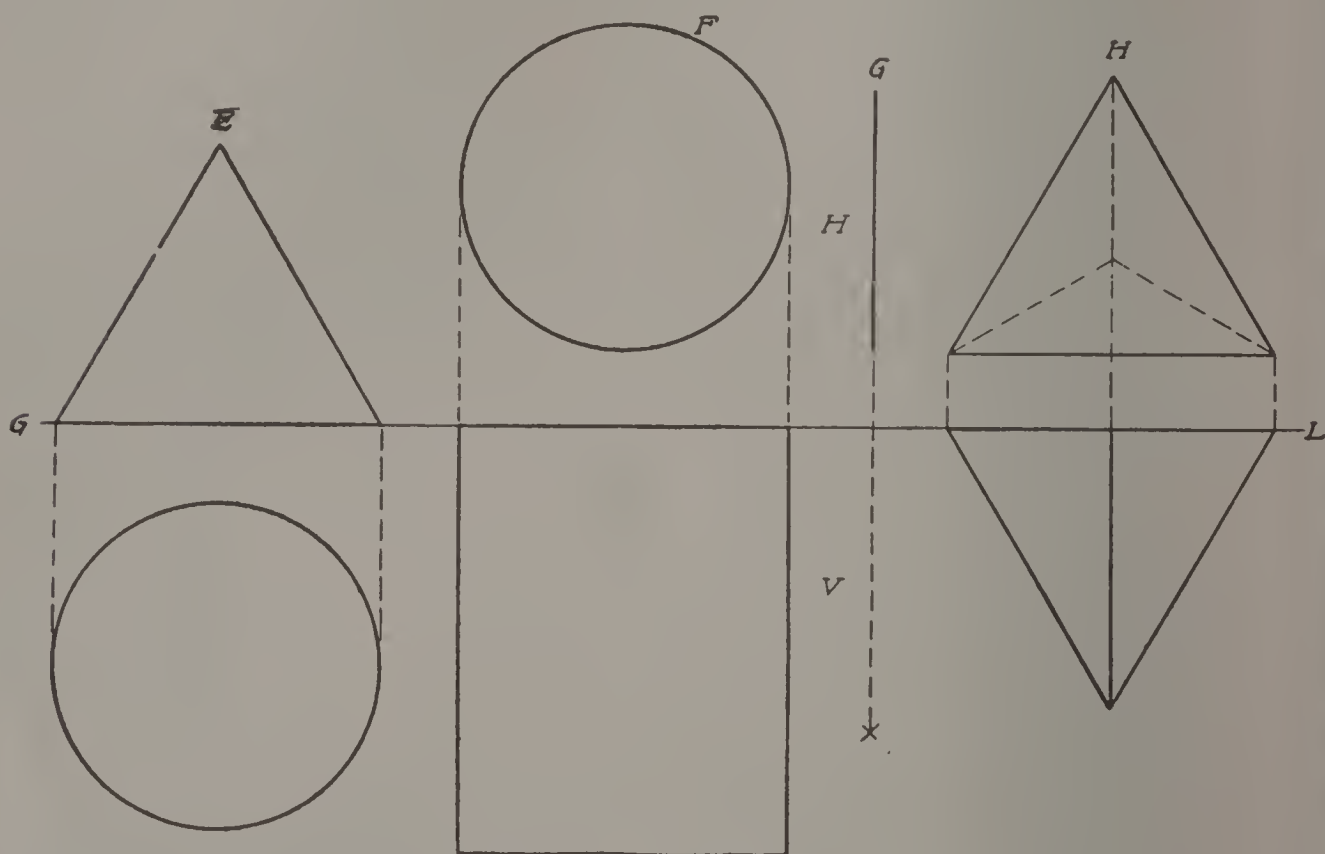


Fig. 105. Typical Projections

customary to call the vertical plane on which the front elevation is drawn V , and the horizontal plane on which the plan is drawn H .

A = a point A'' below H , and B'' in front of V

B = a square prism resting against V , two of its faces parallel to H

C = a circular disk in space parallel to H

D = a triangular card in space parallel to H

E = a cone with its base resting against V

F = a cylinder perpendicular to H , and with one end resting against H

G = a line perpendicular to V

H = a triangular pyramid back of V , with its base resting against H

PRACTICAL PROBLEMS IN PROJECTION

1. *Square Bar.* Fig. 106 represents a square bar. A is the front elevation, and shows the length and width of the bar, but not the thickness. There must then be another view. B is the plan,

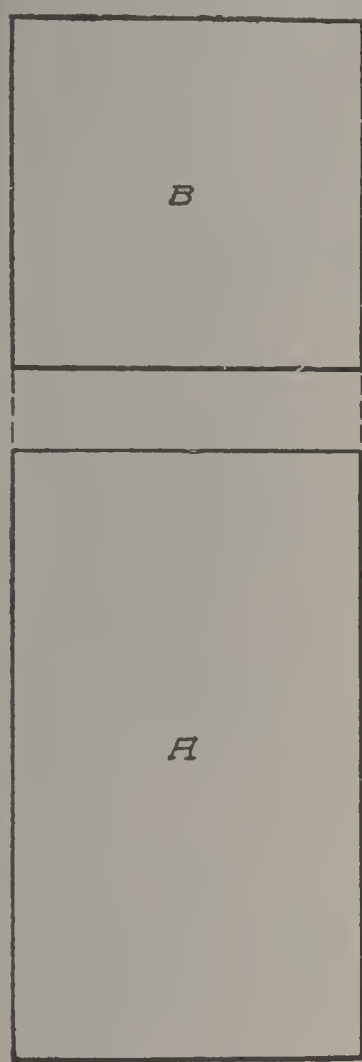


Fig. 106. Projections of Square Bar

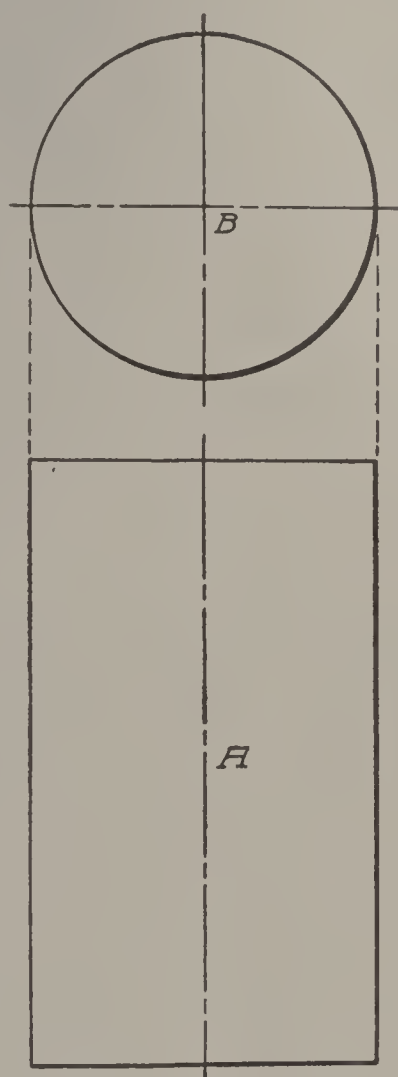


Fig. 107. Projections of Round Bar

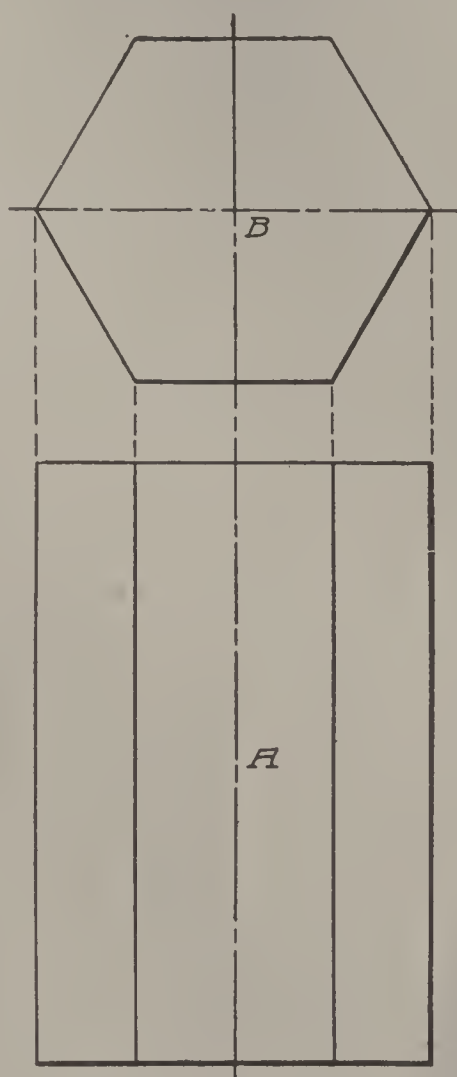


Fig. 108. Projections of Hexagonal Bar

and shows the width and thickness of the bar. From these two views the complete form of the bar is obtained and no other views are necessary when such is the case. In all working drawings, only as many views are shown as is necessary to determine the complete form of the object being drawn.

2. *Round Bar.* Fig. 107 represents a round bar. The front elevation A , shows the width and height of the bar, but does not show that it is round. The plan B , shows the circular top of the bar and of the proper diameter. In this problem, in addition to the

dotted projection lines connecting points in plan and elevation, it is advisable to put in dot and dash lines for center lines. Projection lines and center lines are construction lines, and may be erased when the drawing is finished, unless otherwise ordered.

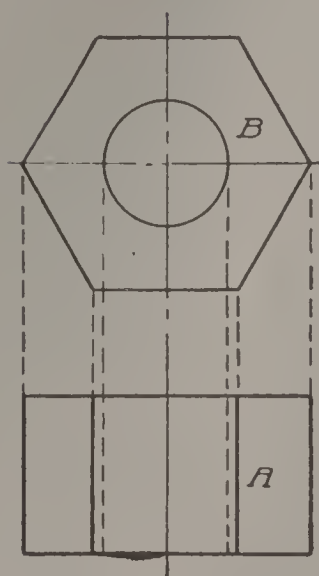


Fig. 108. Projections of Hexagonal Bar

3. *Hexagonal Bar*. Fig. 108 represents a hexagonal bar. In this case, center lines should be drawn. The front elevation *A*, shows the length of the bar, and the plan *B*, shows the form and the distance between faces. The vertical lines in the front elevation show the corners of the hexagonal form while both views show the distance from corner to corner of the hexagonal top.

4. *Hexagonal Nut*. Fig. 109 represents a hexagonal nut. Center lines should be drawn here also. The front elevation *A*, shows the thickness and width of the nut, and the cir-

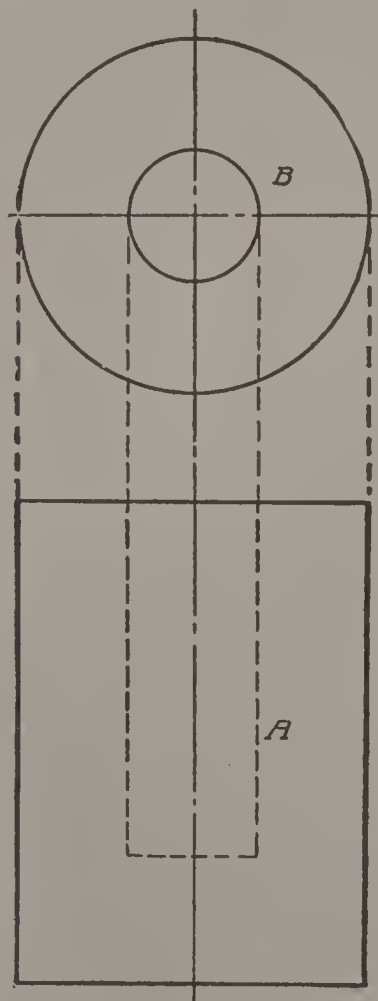


Fig. 109. Projections of Hexagonal Nut

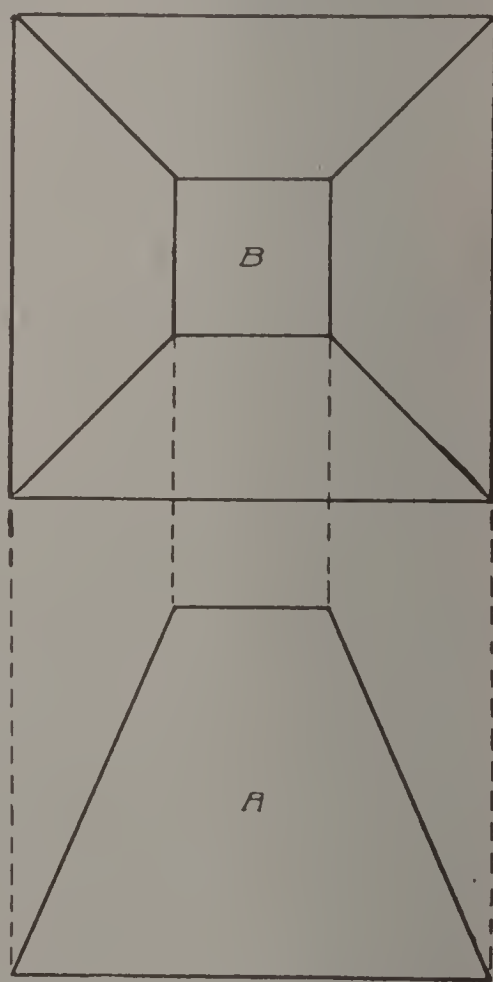


Fig. 110. Projections of Cylinder with Circular Hole

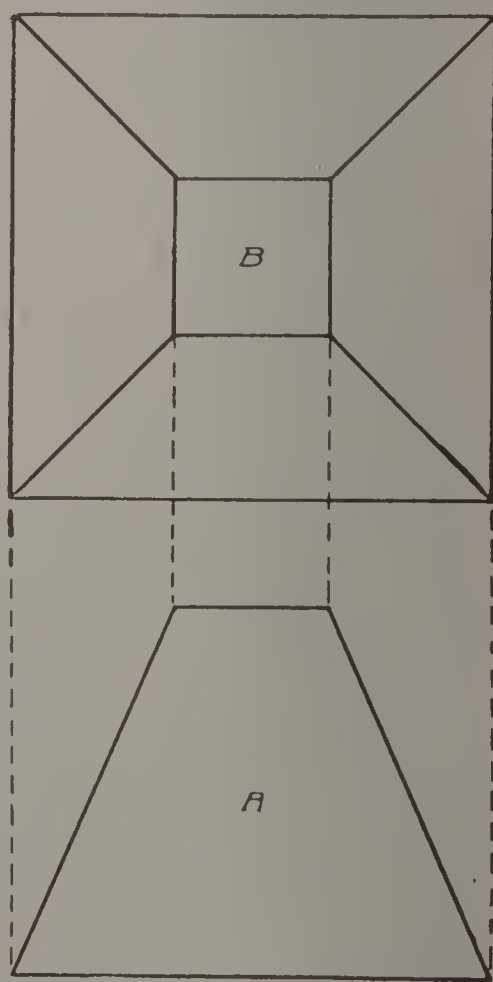


Fig. 111. Projections of Frustum of Square Pyramid

cular hole is shown by heavy dotted lines. Holes are always represented in this way. The plan *B*, shows the shape of the top of the nut, and also the shape of the hole.

5. *Cylinder with Circular Hole.* Fig. 110 represents a cylinder with a circular hole passing part way through. Center lines are needed here, and in fact where any circle, hexagon, octagon, or other shape except a square or rectangle occurs. The front elevation *A*, shows the height and width of the cylinder, and the depth and width of hole. The plan *B*, shows the top of the cylinder, its diameter, and the diameter of the hole.

6. *Frustum of Square Pyramid.* Fig. 111 represents a block in the form of a frustum of a square pyramid. The front elevation *A*, shows the height of the block, and the width of the top and bottom faces. The plan *B*, shows the width and depth of the top and bottom faces, and also the edges connecting these faces of the frustum.

7. *Square Bar with Cylindrical Portion.* Fig. 112 represents a square bar with a portion forged to a cylindrical form. The front elevation *A*, shows the length and width of the bar, and also the length and width of the cylindrical portion. The plan *B*, shows the square top, and by the dotted circle shows the shape of the cylindrical portion. The fact that this circle is dotted means that the cylindrical portion does not come clear through to the top. A bottom view *C*, is also shown here, as it gives a better idea of the complete form of the bar. Enough views should always be shown by the draftsman to give the workman a clear idea of what he is to make.

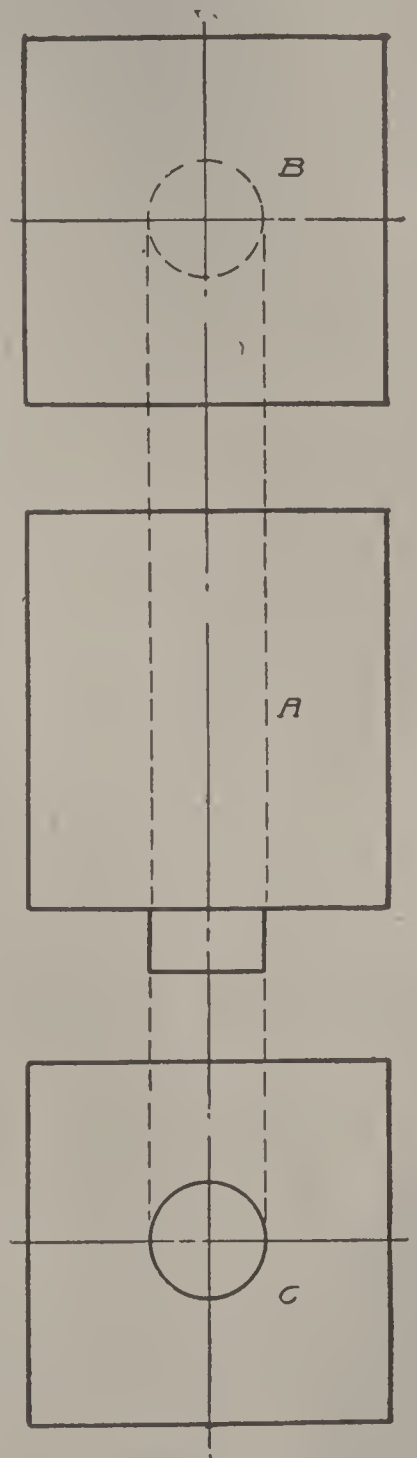


Fig. 112. Projections of Square Bar with Cylindrical Portion

8. *Circular Ring Made from Round Rod.* Fig. 113 represents a circular ring made from a round rod. The front elevation *A*, shows the thickness and the diameter of the ring, and the plan *B*, shows the circular form.

9. *Block with Number of Different Dimensions.* Fig. 114 represents a block with a number of different dimensions. The block

has been turned down in such a way that there are five different diameters, as shown. All these diameters, and the lengths between, may be shown in the front elevation *A*. From this view, only the forms of the cross-section could not be ascertained. Some might be square, some hexagonal, or some circular, but the plan *B* shows that all are circular.

Summary. The principles of projection which have been used so far, may be stated as follows:

(1) If a line is parallel to either the vertical or horizontal plane, its actual length is shown on that plane, and its other projection is parallel to the ground line.

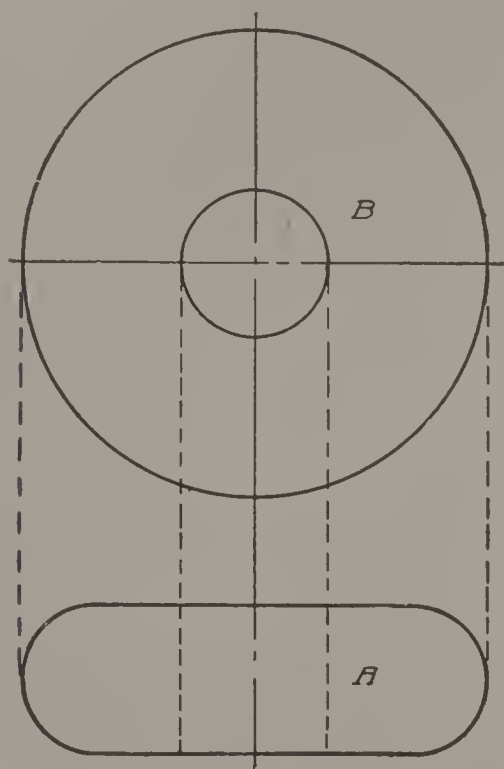


Fig. 113. Projections of Circular Ring

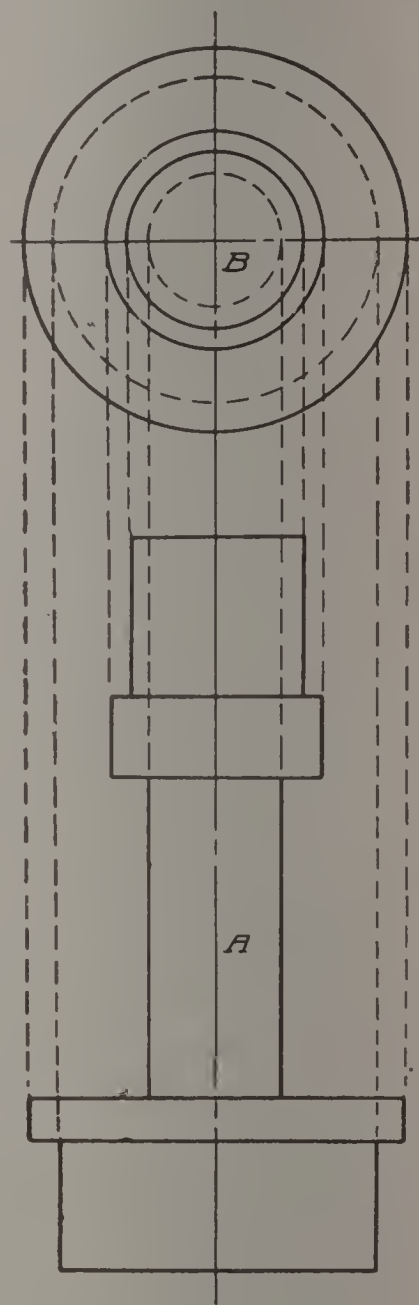


Fig. 114. Projections of Turned Block

(2) A line oblique to either plane has its projections on that plane shorter than the line itself, and its other projection oblique to the ground line.

(3) No projection can be longer than the line itself.

(4) If two lines intersect, their projections must cross, and the point of crossing in the front elevation must be directly under the point of crossing in the plan.

(5) A plane surface, if parallel to either plane, is shown on that plane in its true size and shape; if oblique, it is shown smaller than the true size, and if perpendicular it is shown as a straight line.

(6) Lines parallel in space have both their vertical and horizontal projections parallel.

TRUE LENGTH OF LINES

Principles. If a line is parallel to a plane, its projection on that plane will be equal in length to the line itself, as represented in Fig. 115. If a line is perpendicular to a plane, its projection on

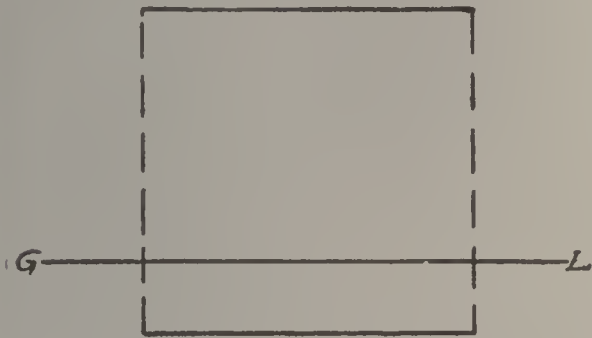


Fig. 115. Projections of a Line Parallel to Plane



Fig. 116. Projections of a Line Perpendicular to Plane

the plane will be a point, as represented by the cross in Fig. 116. If a line is inclined to a plane, its projection on that plane will be shorter than the line itself, as represented

in Fig. 117. If a line is parallel to the horizontal or vertical plane, its projection on the other plane will be parallel to the ground line, as represented in Fig. 118. A line inclined to both the horizontal

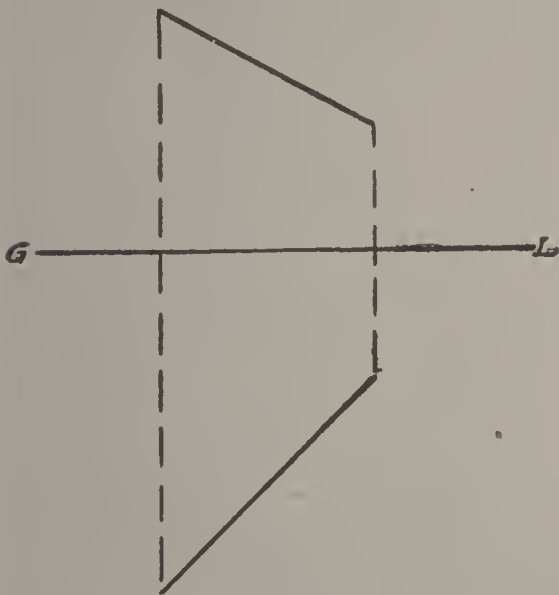


Fig. 117. Projections of a Line Inclined to Plane

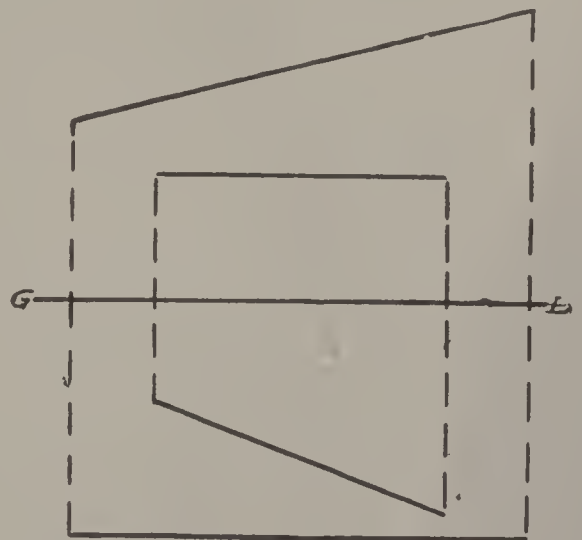


Fig. 118. Projections of Lines Parallel to Ground Line

and vertical planes will not show its true length in either projection, as represented in Fig. 119. In a case like the one last mentioned, the true length of the line is found by revolving the line until it is parallel to one of the planes. Then, its projection on that plane will be its true length.

True Length by Revolving Horizontal Projection. In Fig. 120 is shown the horizontal and vertical projections of the line AB ,

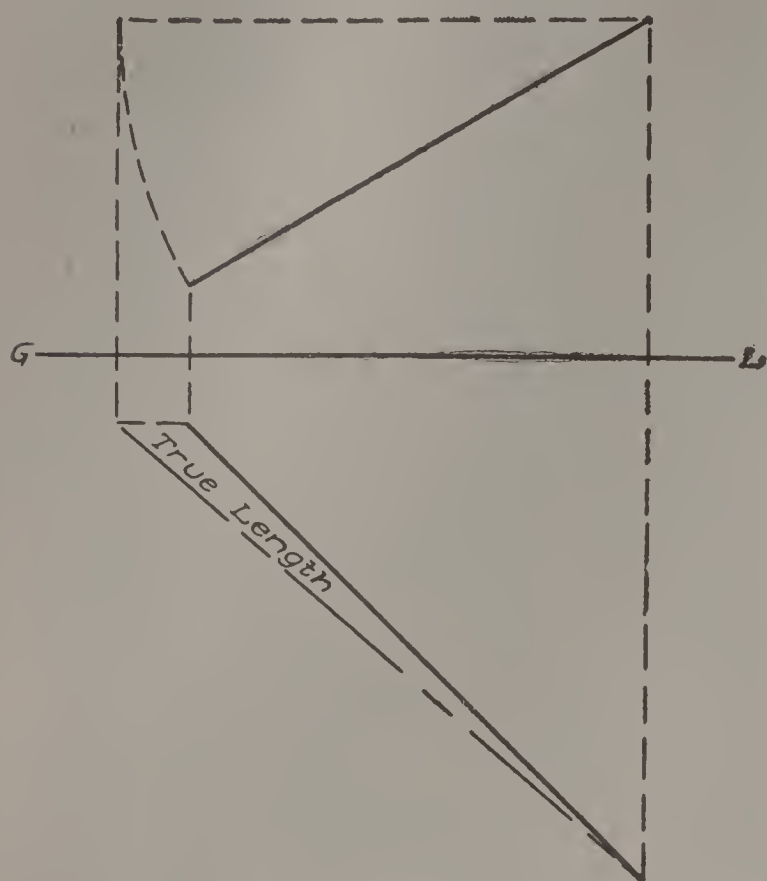


Fig. 119. True Length of Inclined Line not Shown in Its Projections

and to find the true length of the line itself proceed as follows: Swing the horizontal projection $A^h B^h$ about one end A^h as a pivot, until it is parallel to the ground line. Project the new point B_1^h downward to a point on the vertical plane to a line drawn from B^v parallel to the ground line, locating the point B_1^v . The line connecting B_1^v and A^v is the true length desired, since the true length of a line is always shown by its projection on

a plane when the line is parallel to that plane.

True Length by Revolving Vertical Projection. In Fig. 121 is shown the method of finding the true length of the same line as

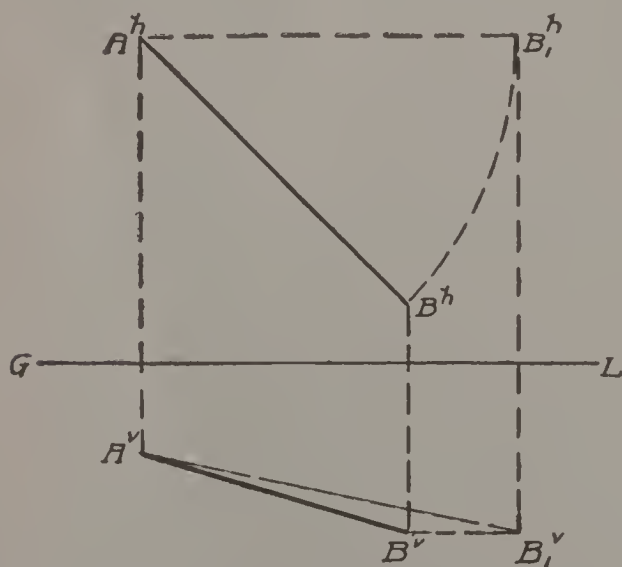


Fig. 120. True Length of a Line by Revolving Horizontal Projection

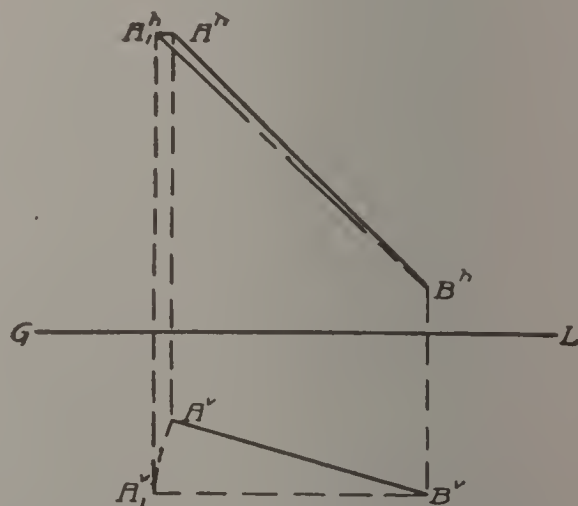


Fig. 121. True Length of a Line by Revolving Vertical Projection

in Fig. 120, but by revolving the vertical projection. The method is the same. Revolve $A^v B^v$ about the end B^v as a pivot until it is parallel to the ground line, and then project A_1^v up to A_1^h on the

horizontal plane at the same distance from the ground line as A^h . The true length is then shown on the horizontal plane by the line connecting A_1^h and B^h . Projection lines representing the true length are always shown as dot and dash lines, as in Fig. 120 and 121.

REPRESENTATION OF OBJECTS

Rectangular Prism or Block. In Fig. 122 there is represented a rectangular prism or block, whose length is twice its width. The elevation shows its height.

As the block is placed at an angle, three of the vertical edges will be visible, and the fourth, invisible. In mechanical drawing, the edges, which in projection form a part of the outline or contour of the figure, must always be visible, hence are always drawn as full lines, while the lines or edges which are invisible are drawn dotted. The plan shows what lines are visible in elevation, and the elevation determines what are visible in plan. In Fig. 122, the plan shows that the dotted edge AB is the back edge, and in Fig. 123, the elevation shows that the

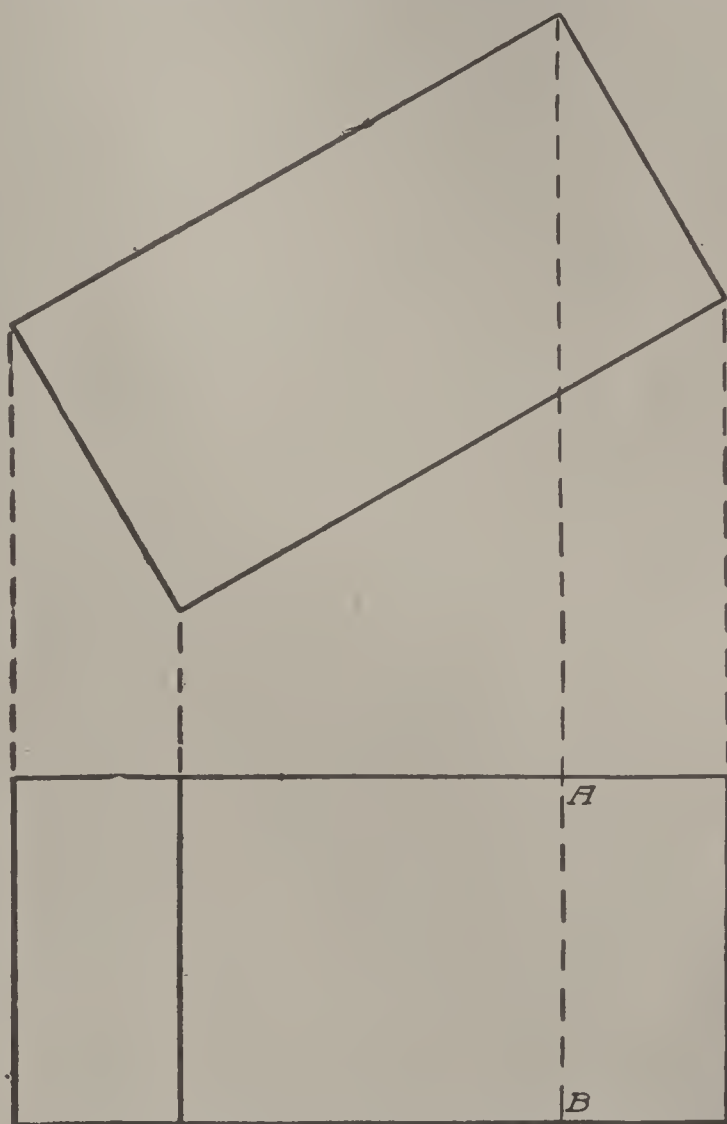


Fig. 122. Projections of a Rectangular Prism or Block

dotted edge CD is the lower edge of the triangular prism. In general, if in elevation an edge projected *within* the figure is a back edge, it must be dotted, and in plan, if an edge projected within the outline is a lower edge, it is dotted.

Triangular Prism or Block. The end view shown in Fig. 123 is obtained by projecting the points of the plan across to a plane at right angles to the horizontal and vertical planes, then revolving them down through 90 degrees and continuing the projections to meet the projection lines drawn across from

the elevation. Connecting the points thus obtained gives the end view. End or side views of any object are obtained by projection in this way.

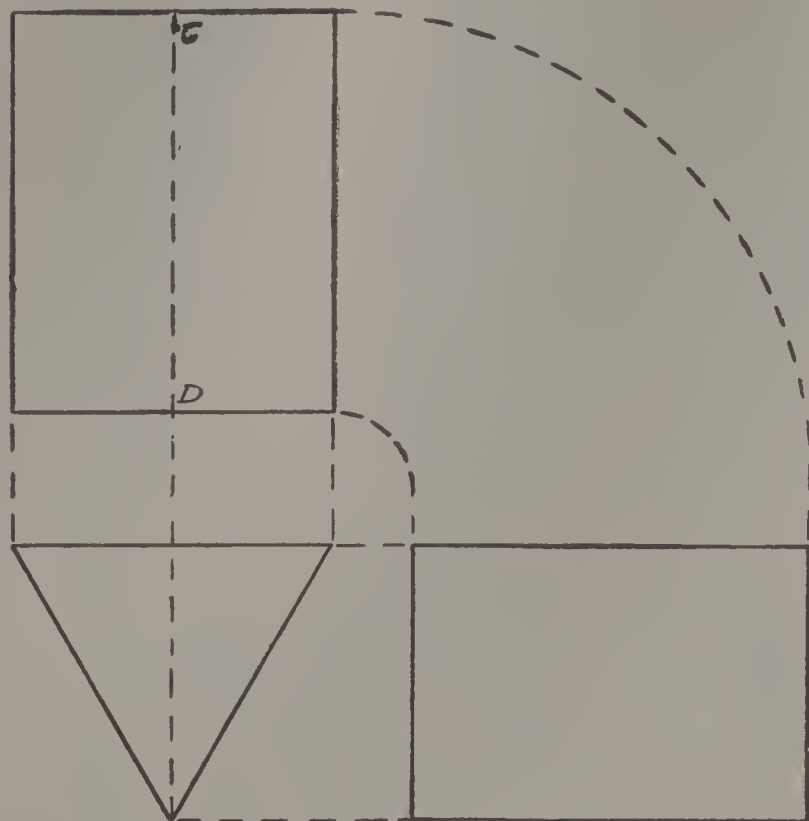


Fig. 123. Projections of a Triangular Prism or Block

Triangular Block with Square Hole. The plan, elevation, and end views of a triangular block with a square hole from end to end are shown in Fig. 124. In this case the plan and elevation alone would not be sufficient to positively determine the shape of the hole, but the end view shows at a glance that it is square.

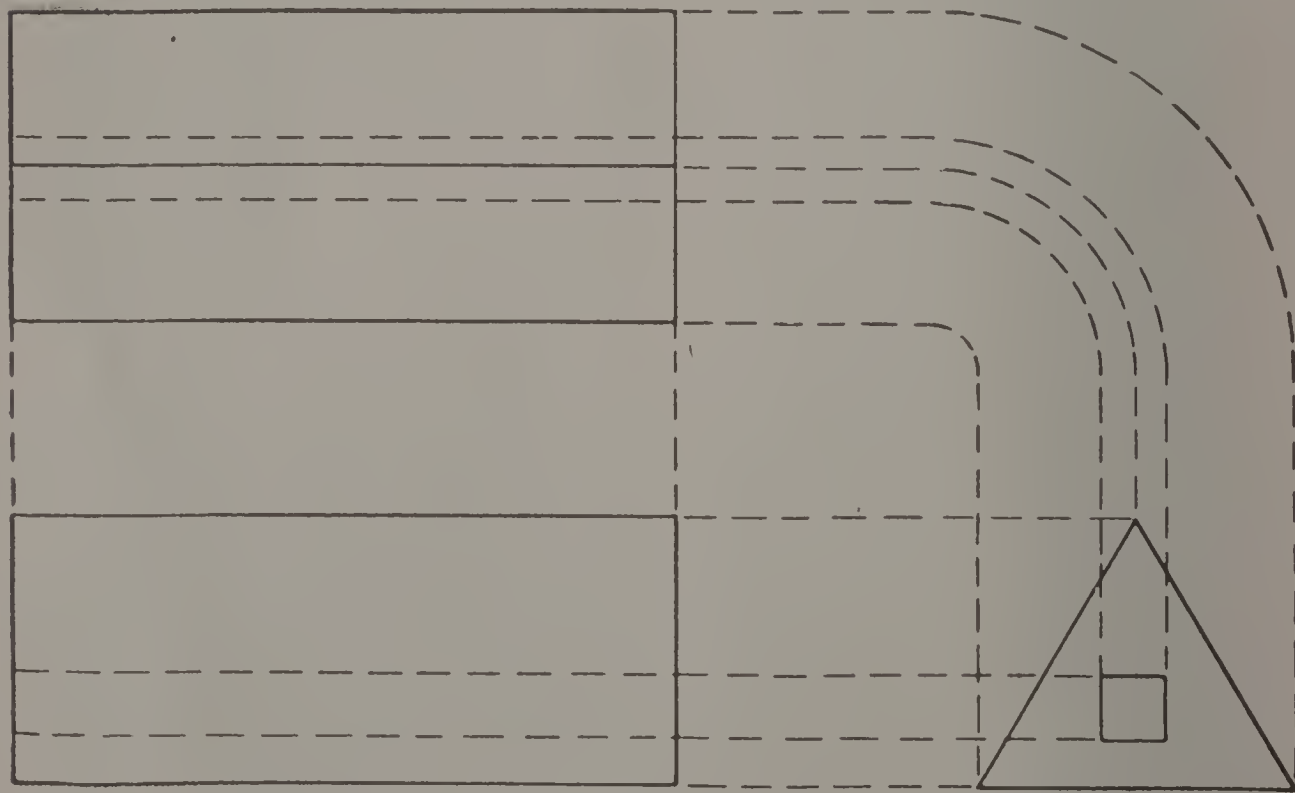


Fig. 124. Projections of a Triangular Block with Square Hole

ROTATING AND INCLINING OF OBJECTS

Method of Rotating Object. The natural way to place an object to be shown by projections would be in the simplest position; that is, with an edge or face parallel to either the horizontal or

vertical plane of projection. Sometimes it is necessary, however, to draw the views of an object in a position at an angle to the planes. In such case it is usually advisable to draw the object parallel to one of the planes, and then rotate it to the required position about an axis perpendicular to a plane of projection.

When an object is rotated in this way, about an axis perpendicular to a plane, its projection on that plane will remain unchanged

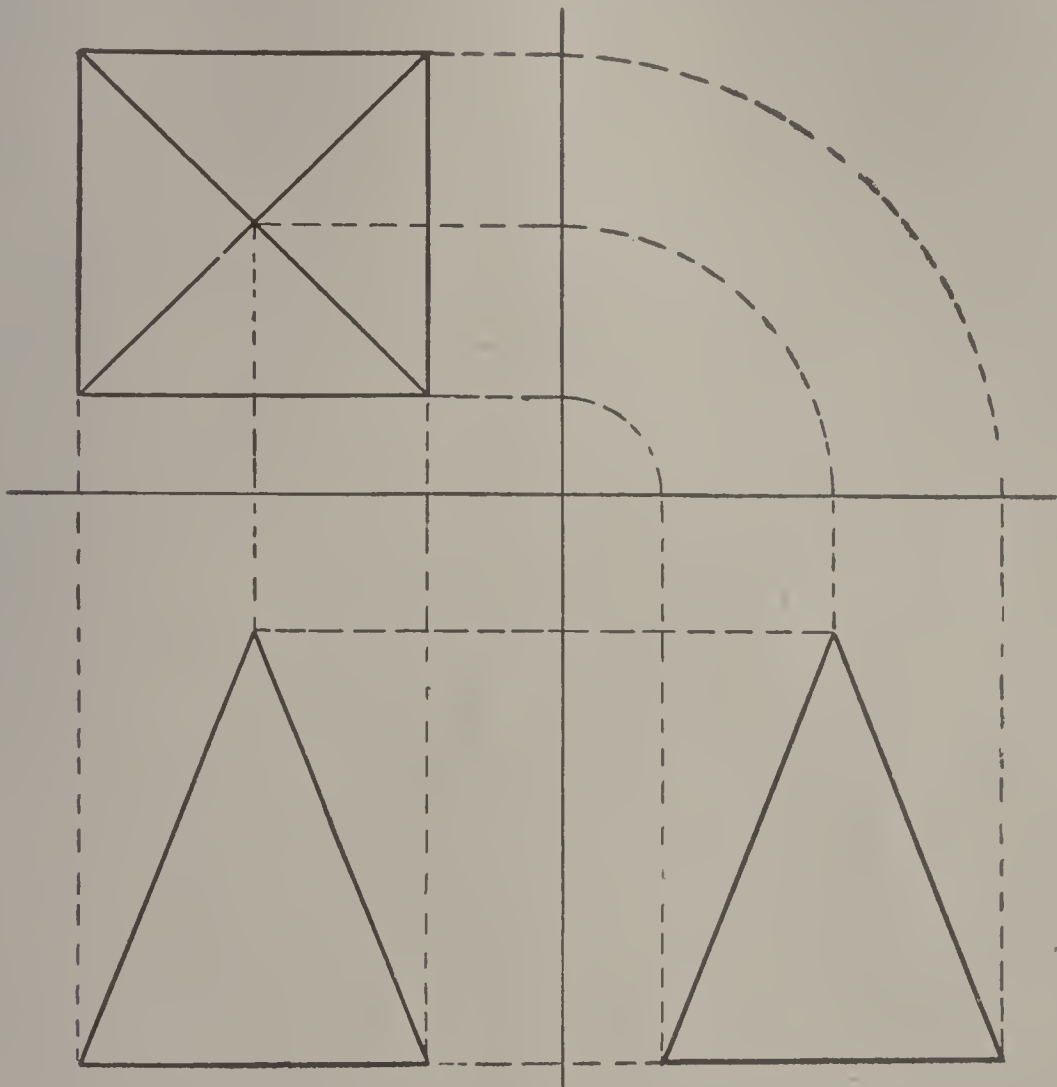


Fig. 125. Plan, Front, and Side Views of a Square Pyramid

in size and shape, and the dimensions parallel to this axis on the other planes will remain the same.

Pyramid. In Fig. 125, the plan, front, and side views of a pyramid are shown, and in Fig. 126 is shown the same pyramid after it has been rotated through 30 degrees about an axis perpendicular to the horizontal plane. The height of the pyramid has not been altered by this rotation and, therefore, the front and side views are the same height as in the original front view.

Now, if the pyramid in Fig. 125 is rotated about an axis perpendicular to the vertical plane, the front view will not be altered,

and may be copied in the new position at an angle of 30 degrees, as shown in Fig. 127. The distances above the ground line to any points in the top view are not altered, and the distances of the various points can be taken on the lines projected up from the points of the front view with a pair of dividers, or the points can be obtained by projecting across from the original top view to meet the projection lines drawn up from the front view. The side view dimensions are not altered, and this view can therefore be obtained in

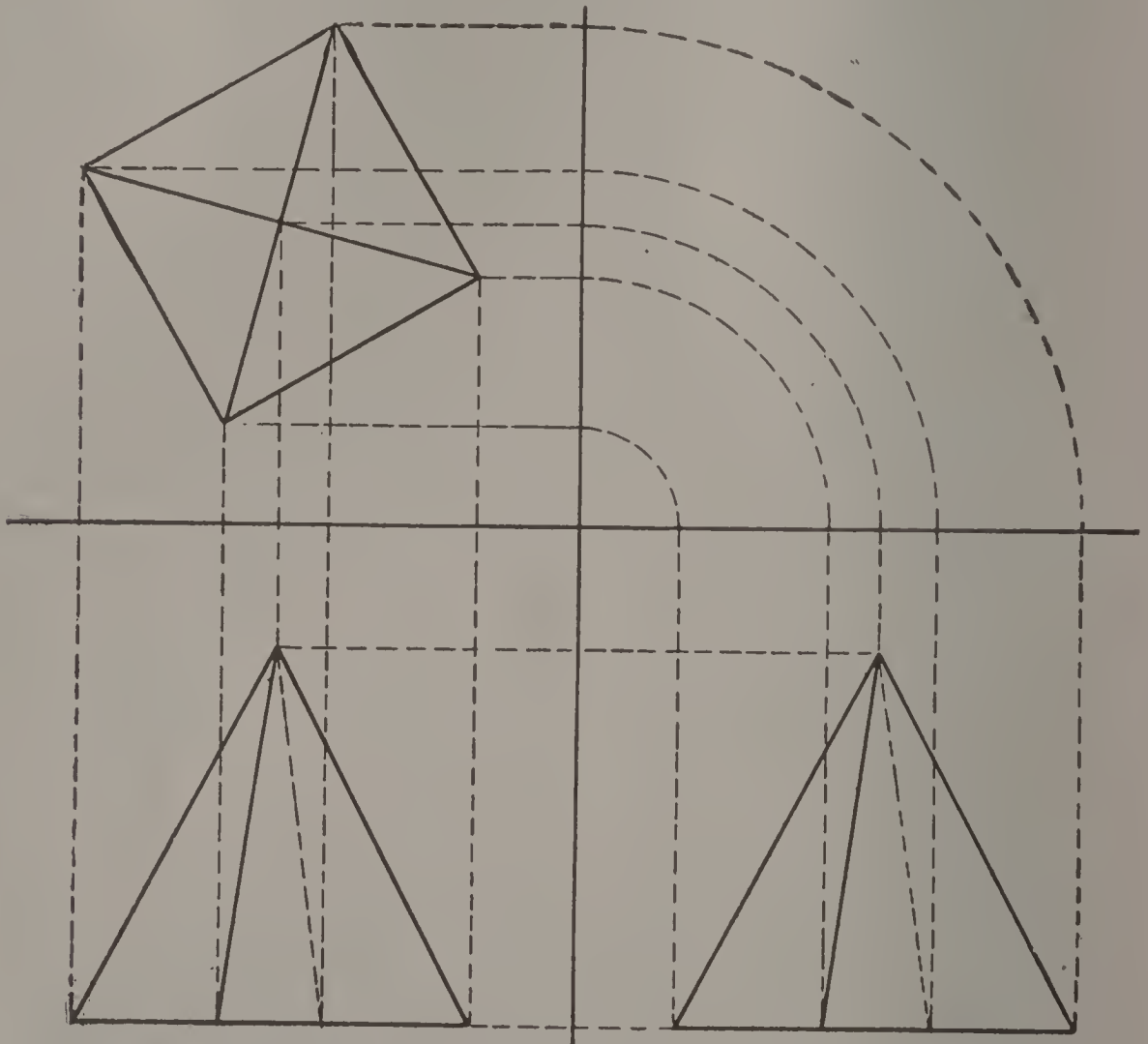


Fig. 126. Plan, Front and Side Views after Revolving Pyramid in Fig. 125 through 30 Degrees with Vertical Plane

the usual way, by projecting across from the front view, and revolving down from the plane at right angles to the horizontal and vertical planes the points projected across from the top view.

Cylinder in Inclined Position to Horizontal Plane. As shown in Fig. 128, first draw the plan, a circle, at *A*. Then draw the rectangle at *B*, representing the front view. Now, draw the rectangle at *C*, representing the front view at the desired angle. This rectangle *C* is the same size as the view at *B*, since the cylinder

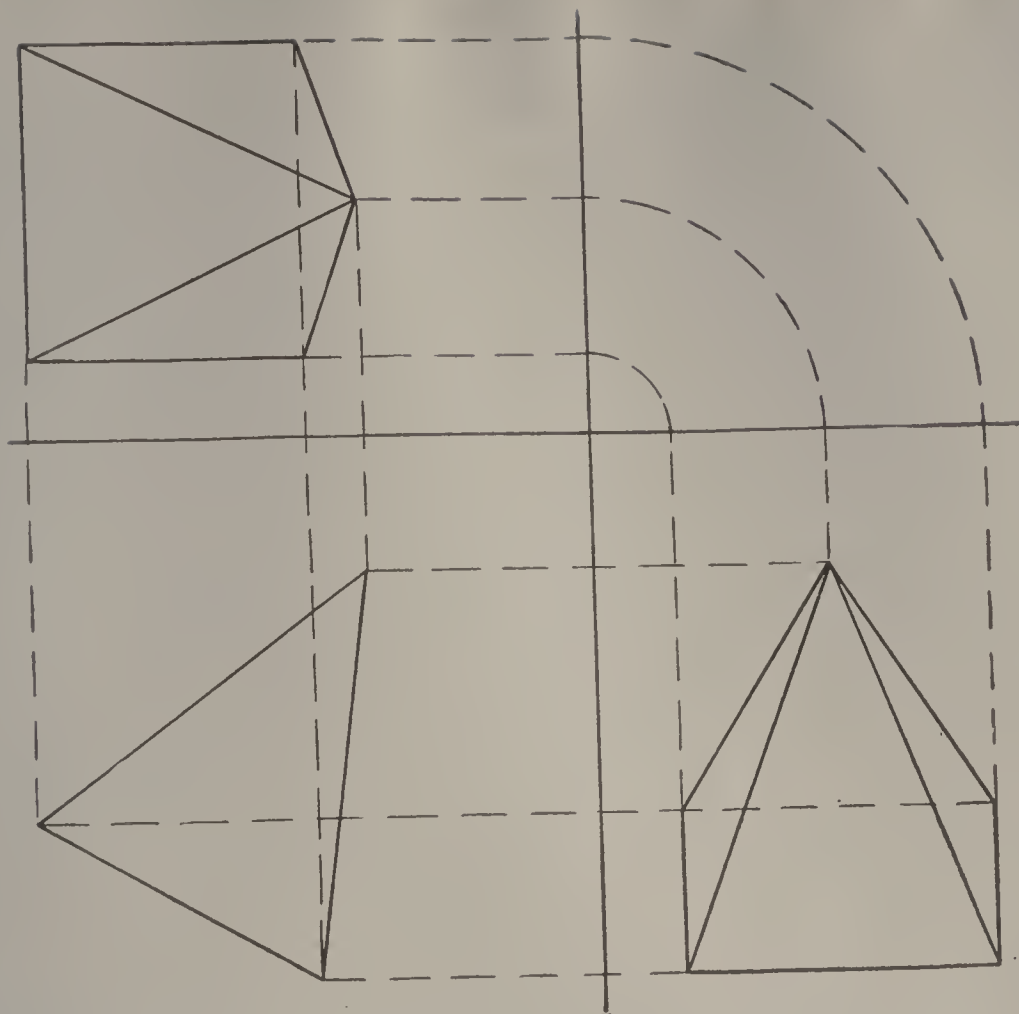


Fig. 127. Plan, Front, and Side Views after Revolving Pyramid in Fig. 125 through 30 Degrees with Horizontal Plane

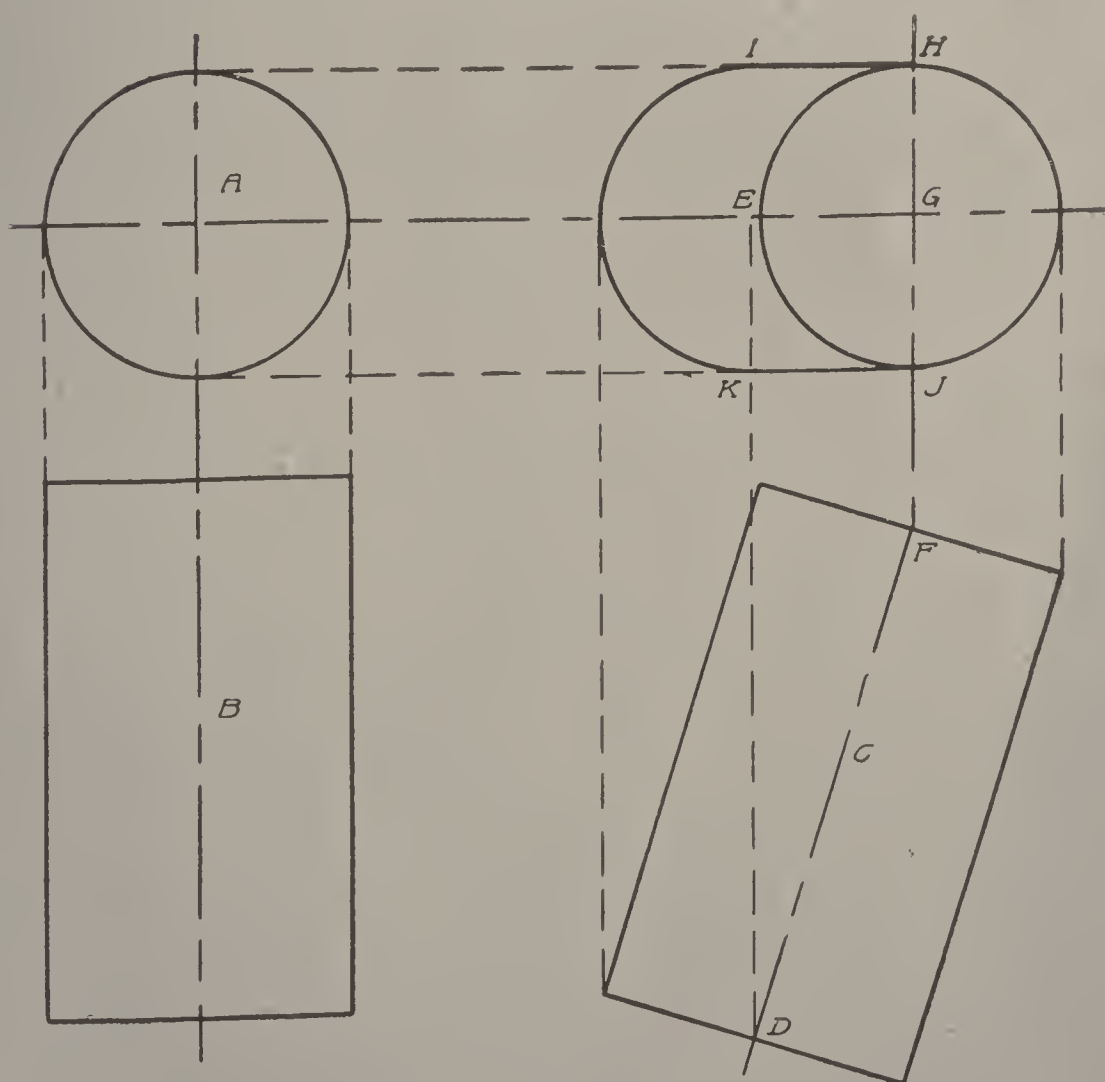


Fig. 128. Projections of Cylinder Inclined to Horizontal Plane

has simply been inclined to the horizontal plane, but kept parallel to the vertical plane. The point D , the center of the circle forming the base of the cylinder, is projected up to the point E , and with this point as a center, a circle representing the plan view of the base is drawn. Then from F project up to G , and with this point as a center draw the circle representing the plan view of the top of the

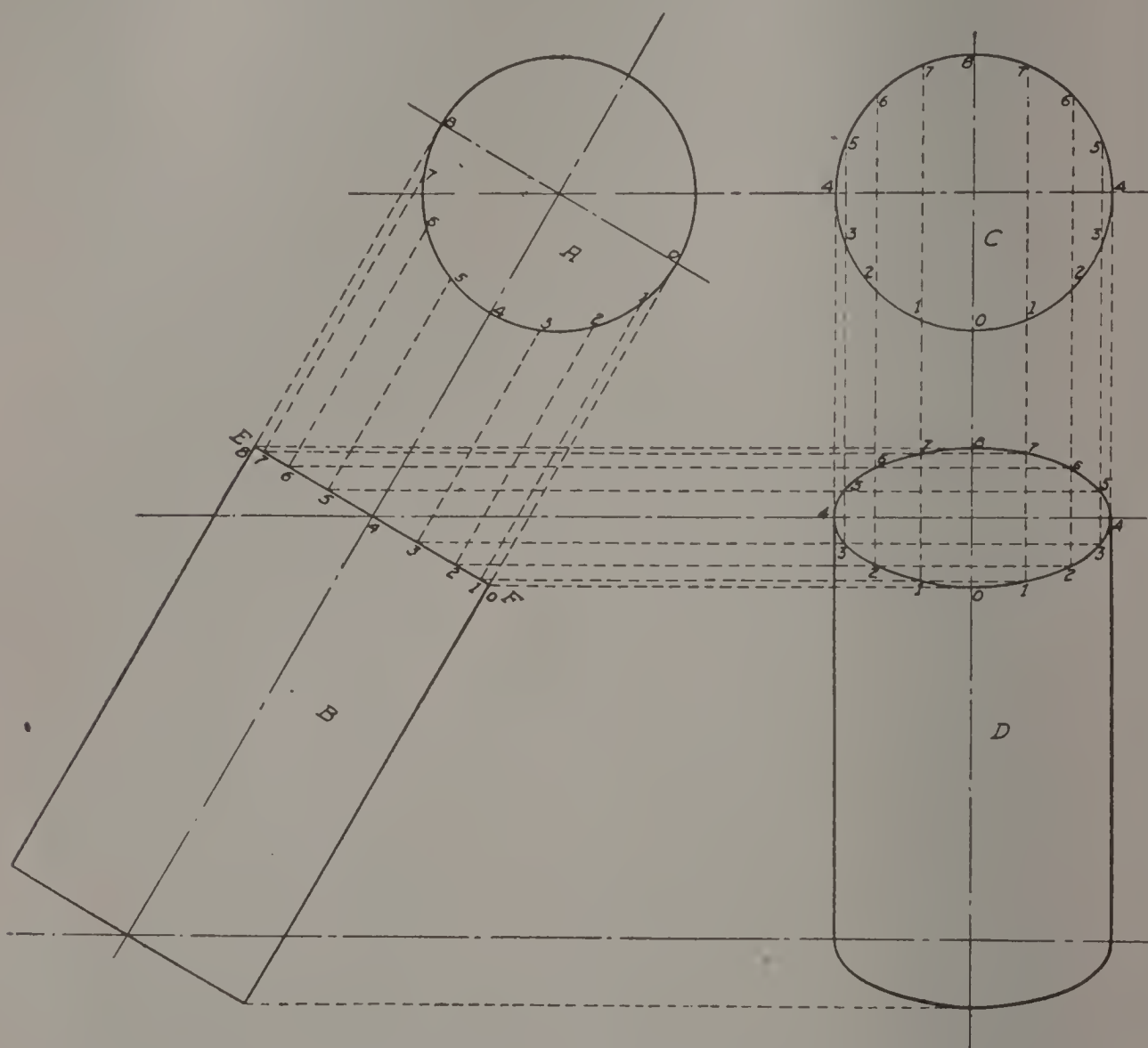


Fig. 129. Method of Finding the Projection, in the Form of an Ellipse, of the Top of a Cylinder Greatly Inclined to a Plane

cylinder. Connecting these two circles with horizontal lines HI and JK , representing the sides of the cylinder, completes the plan view, and the problem is finished.

As the cylinder is at an angle with the horizontal plane, it will be seen that the top and bottom of the cylinder in the plan view are not circles, but ellipses. It is, however, customary to draw them with the compass, as circles, when the angle of the cylinder with the plane is not great.

Cylinder Greatly Inclined to Horizontal Plane. In Fig. 129 the plan and front elevation of the top of the cylinder are drawn at the desired angle with the horizontal plane at A and B , respectively. The plan view at A is then transferred to C . In each of these plan views divide the lower semicircle into a number of equal parts, eight in this case. From the view of A , project the points 0—8, parallel to the center line, down to EF , and then project across to the projection lines drawn vertically down from the points 0—8 in C . The points of intersection of projection lines, correspondingly numbered, form the shape of the ellipse representing the top of the side view of the inclined cylinder D , and the ellipse drawn through these points completes this view. The side lines of the cylinder may now be drawn, and the curve representing the bottom of the side view may easily be copied from the lower half of the ellipse representing the top view. When the points have been located, the ellipses may be drawn through them with the aid of an irregular curve.

ILLUSTRATIVE EXAMPLES

1. *Construct plan and elevation of a regular hexagonal pyramid.* It is evident that two distinct geometrical views are necessary to convey a complete idea of the form of the object; an elevation to represent the sides of the body, and to express its height; and a plan of the upper surface to express the form horizontally.

It is to be observed that this body has an imaginary axis or center line, about which the same parts or segments of the body are equally distant; this is an essential characteristic of all symmetrical figures.

Draw a horizontal dotted line MN for the center line of the plan views, Fig. 130. Then draw a perpendicular ZZ' to MN .

In delineating the pyramid, it is necessary, in the first place, to construct the plan. The point S' , where the line ZZ' intersects the line MN , is to be taken as the center of the figure, and from this point, with a radius equal to the side of the hexagon which forms the base of the pyramid, describe a circle, cutting MN in A' and D' . From these points, with the same radius, draw four arcs of circles, cutting the primary circle in four points. These six points being joined by straight lines, will form the figure $A'B'C'D'E'F'$,

which is the base of the pyramid; and the lines $A'D'$, $B'E'$, and $C'F'$, will represent the projections of its edges foreshortened as they would appear in the plan. If this operation has been correctly performed, the opposite sides of the hexagon should be parallel to each other and to one of the diagonals; this should be tested by the application of the square or other instrument proper for the purpose.

By the help of the plan obtained as above described, the vertical

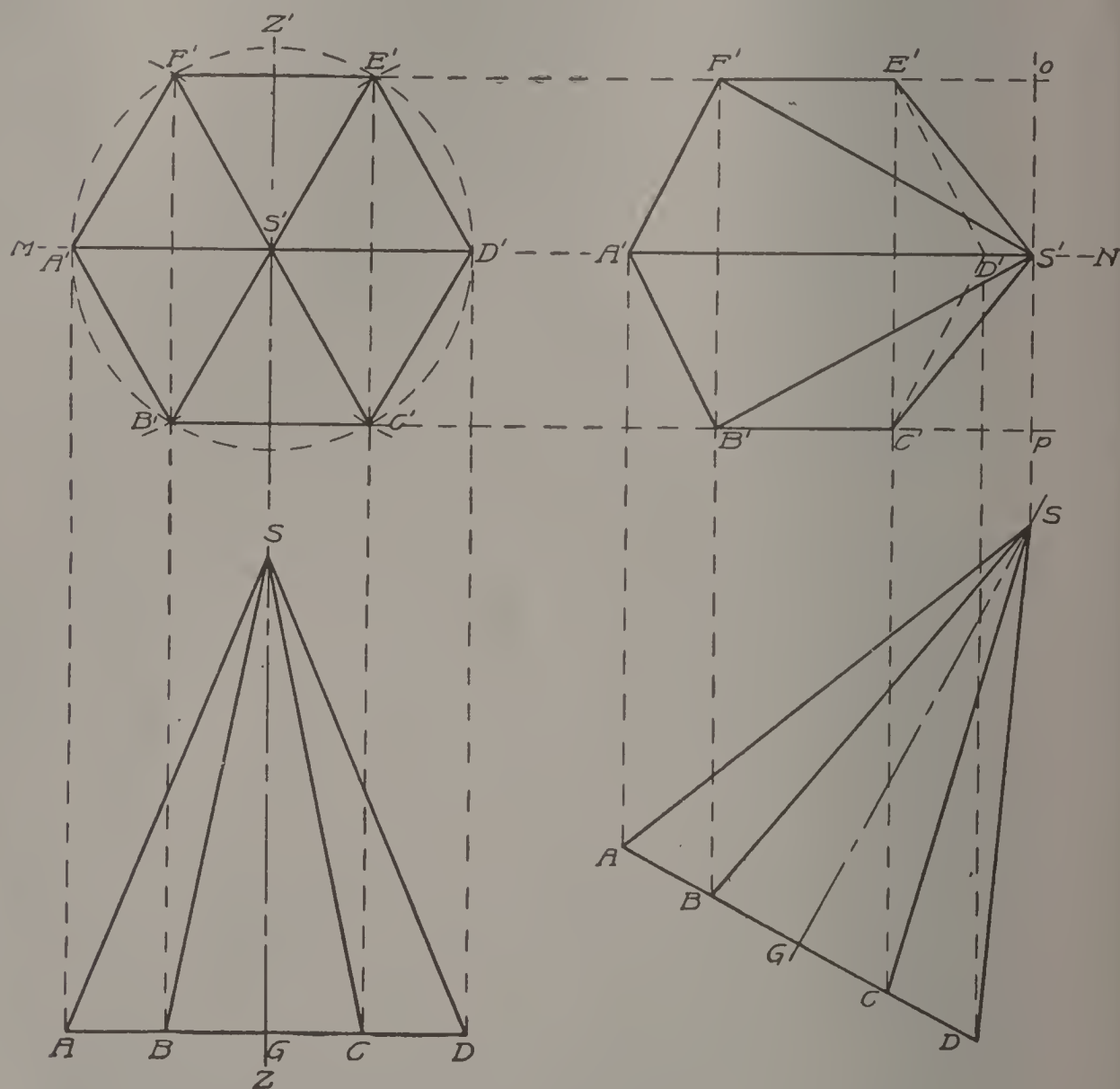


Fig. 130. Construction of Regular Hexagonal Pyramid

projection of the pyramid may be easily constructed. Since it is directly under the plan, it must be projected vertically downward; therefore, from each of points A' , B' , C' , D' , drop perpendiculars to AD , the base line of the pyramid in the elevation. The points of intersection, A , B , C , and D , are the true positions of all the angles of the base; and it only remains to determine the height of the pyramid, which is to be set off from the point G to S , and to

draw SA , SB , SC , and SD , which are the only edges of the pyramid visible in the elevation. Of these it is to be remarked that SA and SD alone, being parallel to the vertical plane, are seen in their true length; and, moreover, that from the assumed position of the solid under examination, the points F' and E' being situated in the lines BB' and CC' , the lines SB and SC are each the projections of two edges of the pyramid.

2. *Construct the projections of the pyramid, Example 1, having its base set in an inclined position, but with its edges SA and SD still parallel to the vertical plane, Fig. 130.*

It is evident, that with the exception of the inclination, the vertical projection of this solid is precisely the same as in the preceding example, and it is only necessary to show the same view of the pyramid in its new position. For this purpose, after having fixed the position of the point D , draw through this point a straight line DA , making with MN an angle equal to the desired inclination of the base of the pyramid. Then set off the distance DA , equal to that used in Example 1; erect a perpendicular on the center, and set off GS equal to the height of the pyramid. Transfer also from the first example the distance BG and CG to the corresponding points, and complete the figure by drawing the straight lines AS , BS , CS , and DS .

In constructing the plan of the pyramid in this position, it is to be remarked that since the edges SA and SD are still parallel to the vertical plane, and the point D remains unaltered, the projection of the points A , D , and S , will still be in the line MN . The position of A' is determined by the intersection of the perpendicular AA' with MN . The remaining points, B' , C' , etc., in the projection of the base, are found, in a similar manner, by the intersections raised from the corresponding points in the elevation, with lines drawn parallel to MN , at a distance (set off at o , p) equal to the width of the base. By joining all the contiguous points, the figure $A'B'C'D'E'F'$ is obtained representing the horizontal projection of the base, two of its sides, however, being dotted, as they must be supposed to be concealed by the body of the pyramid. The vertex S having been similarly projected to S' , and joined by straight lines to the several angles of the base, the projection of the solid is completed.

INTERSECTIONS

If one surface meets another at some angle, an intersection is produced. Either surface may be plane, or curved. If both are plane, the intersection is a straight line; if one is curved, the intersection is a curve, except in a few special cases; and if both are curved, the intersection is usually curved. In the latter case, the

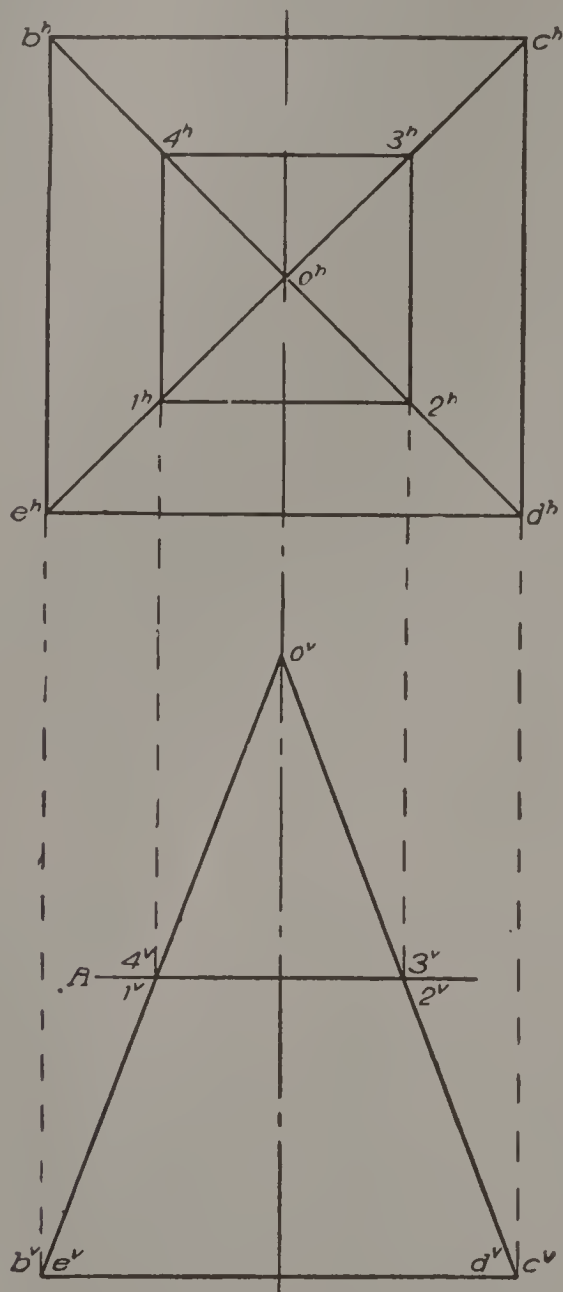


Fig. 131. Intersection of Plane and Square Pyramid

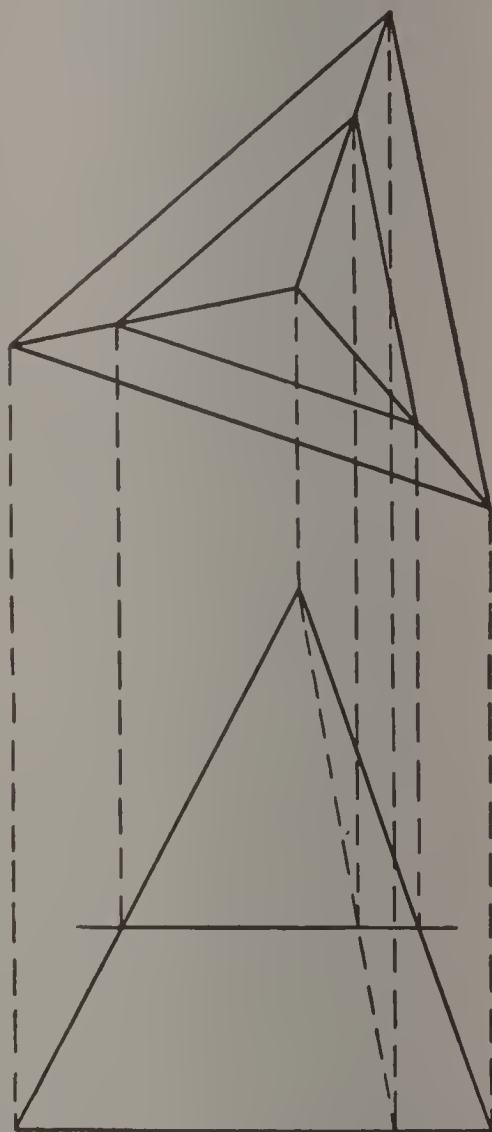


Fig. 132. Intersection of Plane and Triangular Pyramid

entire curve does not always lie in the same planes. If all points of any curve lie in the same plane, it is called a *plane curve*. A plane intersecting a curved surface must always give either a plane curve or a straight line.

Planes with Planes. In Fig. 131 a square pyramid is cut by a plane *A* parallel to the horizontal. This plane cuts from the pyra-

mid a four-sided figure, the four corners of which will be the points where A cuts the four slanting edges of the solid. The plane intersects edge ob at point 4^v in elevation. This point must be found in plan vertically above on the horizontal projection of line ob , that is, at point 4^h . Edge oe is directly in front of ob , so is shown in elevation as the same line, and plane A intersects oe at point 1^v in

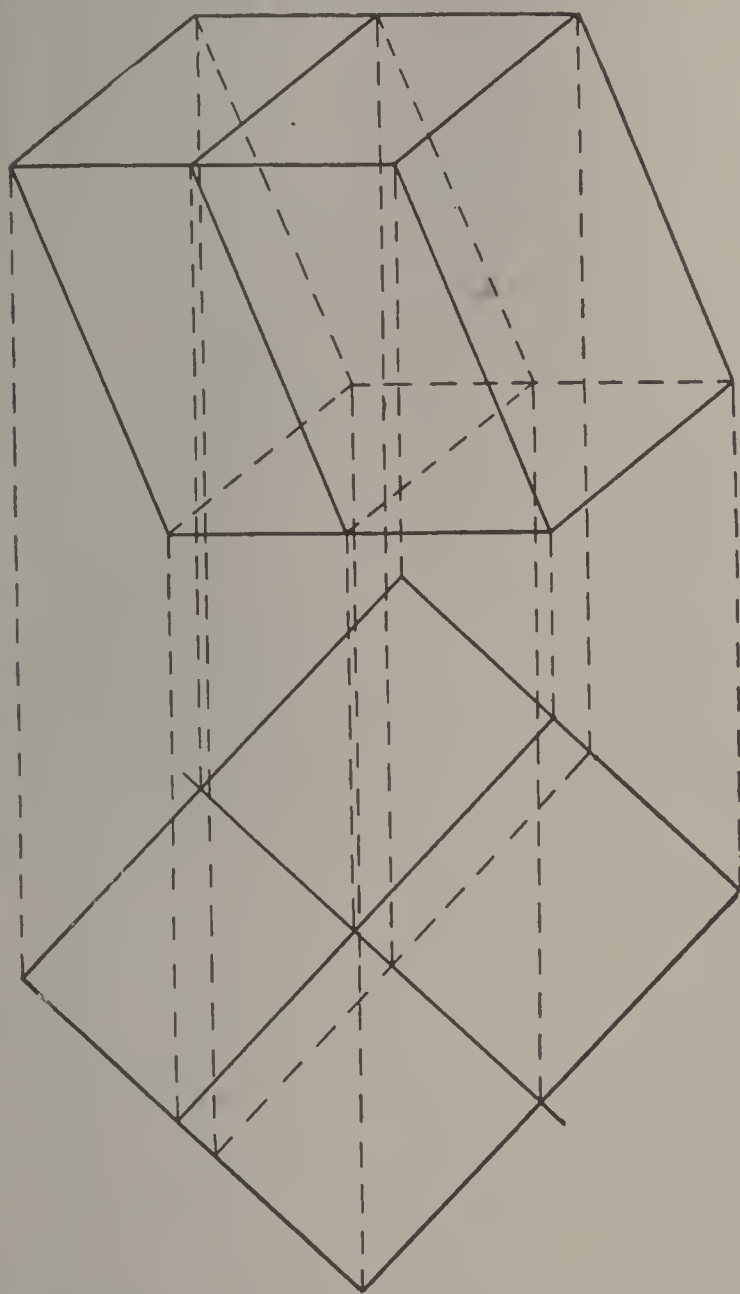


Fig. 133. Intersection of Plane and Prism

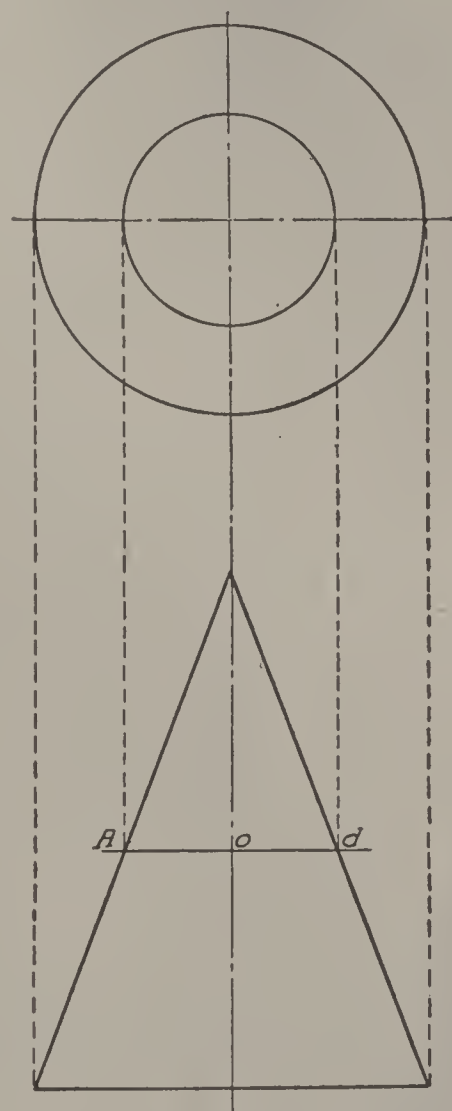


Fig. 134. Intersection of Plane and Cone

elevation, found in plan at 1^h . Points 3 and 2 are obtained in the same way. The intersection is shown in plan as the square 1-2-3-4, which is also its true size as it is parallel to the horizontal plane. In a similar way the intersections are found in Figs. 132 and 133. It will be seen that in these three cases where the planes are parallel to the bases, the sections are of the same shape as the bases, and have their sides parallel to the edges of the bases.

It is an invariable rule that when such a solid is cut by a plane parallel to its base, the section is a figure of the same shape as the base. If then in Fig. 134 a right cone is intersected by a plane parallel to the base the section must be a circle, the center of which in plan coincides with the apex. The radius must equal od .

In Fig. 135 and Fig. 136 the cutting plane is not parallel to the base, hence the section will not be of the same shape as the base.

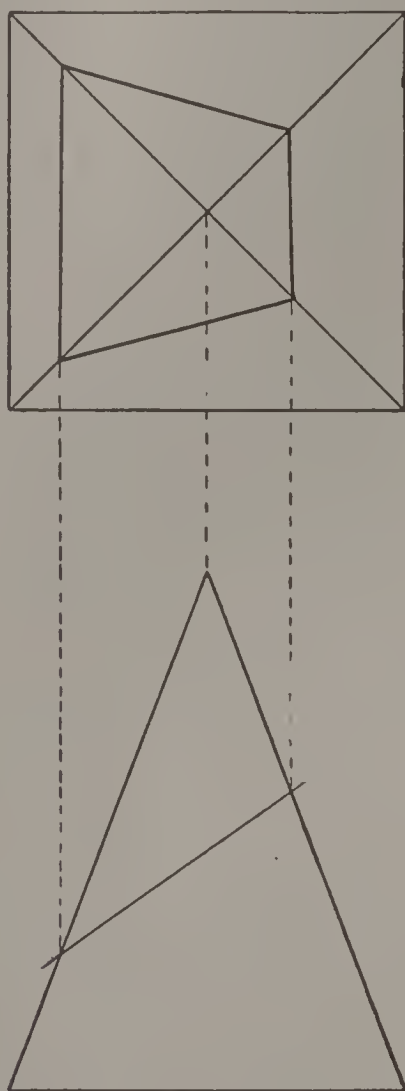


Fig. 135. Intersection of Plane and Square Pyramid

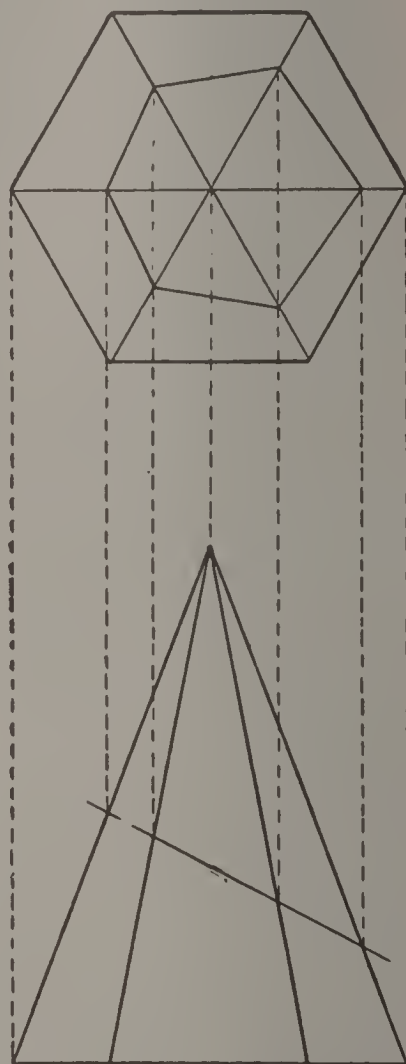


Fig. 136. Intersection of Plane and Hexagonal Pyramid

The intersections are found, however, in exactly the same manner as in the previous figures, by projecting the points where the plane intersects the edges in elevation, on to the other view of the same line.

ILLUSTRATIVE EXAMPLES

1. Find the horizontal projection of a transverse section of the pyramid of Fig. 130, made by a plane perpendicular to the vertical, but inclined at an angle to the horizontal plane of projection; and let all the sides of the base be at an angle with MN , Fig. 137.

Having drawn the vertical SS' , the center line of the figures, its point of intersection with the line MN is the center of the plan. Since none of the sides of the base are to be parallel with MN , draw a diameter $A'D'$ making the required angle with MN , and from the points A' and D' proceed to set out the angular points of the hexagon, as in Fig. 130. Then join the angular points which are diametrically opposite and project the figure thus obtained upon the vertical plane, as shown.

Now, if the cutting plane be represented by the line ad in the elevation, it is obvious that it will expose, as the section of the pyramid, a polygon whose angular points being the intersections of the various edges with the cutting plane, will be projected in perpendiculars drawn from the points where it meets these edges respectively. From the points a, f, b , etc., raise the perpendiculars aa', ff', bb' , etc., to meet the lines $A'D', F'C', B'E'$, etc. When the contiguous points of intersection of these lines are joined, a six-sided figure will be formed which will represent the section required. The edges FS and ES being concealed in the elevation, but necessary for the construction of the plan, have been expressed in dotted lines, as is also the portion of the pyramid situated above the cutting plane which, though supposed to be removed, is necessary in order to draw the lines representing the edges.

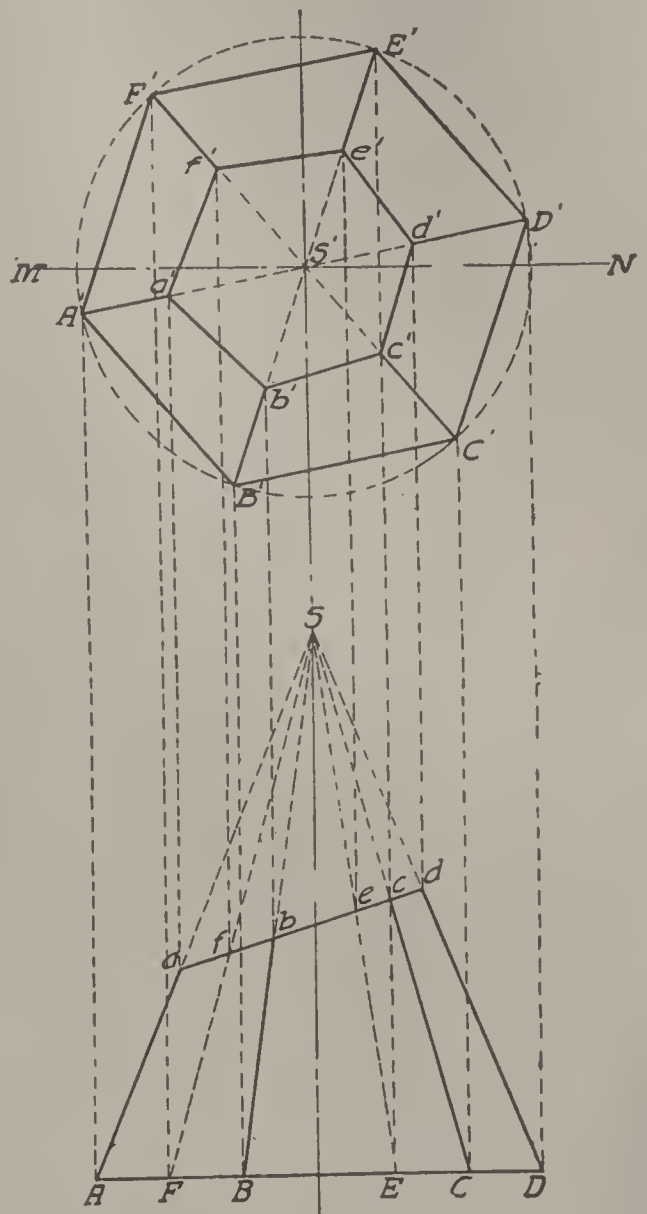


Fig. 137. Frustum of Hexagonal Pyramid

2. Find the horizontal projection of the transverse section of a regular five-sided pyramid, cut by a plane perpendicular to the vertical, but inclined at an angle to the horizontal plane of projection; and let one edge of the pyramid, BS , be in a plane

perpendicular to both the horizontal and the vertical planes of projection, as shown in Fig. 138.

The plan of the pyramid is constructed by describing from the center S' a circle circumscribing the base, and from B' dividing the circumference into five equal parts, and joining the contiguous points of division by straight lines. These form the polygon

$A'B'C'D'E'$, whose angles, when joined to the center S' , show the projections of the edges of the pyramid. Then, following the method above explained, the elevation and the horizontal projection of the section made by the plane ac are obtained. But that method will not suffice for the determination of the point b' , because the perpendicular let fall from the corresponding point b , in the elevation, coincides with the projection of the edge BS . Let the pyramid supposedly be turned a quarter of a revolution round its axis; the line $B'S'$ will then have assumed the position $S'b^2$. Project the point b^2 to b^3 , and join Sb^3 . Then since the required point must also be conceived to have described a quarter of a circle in a plane parallel to the horizontal plane, and that its new position

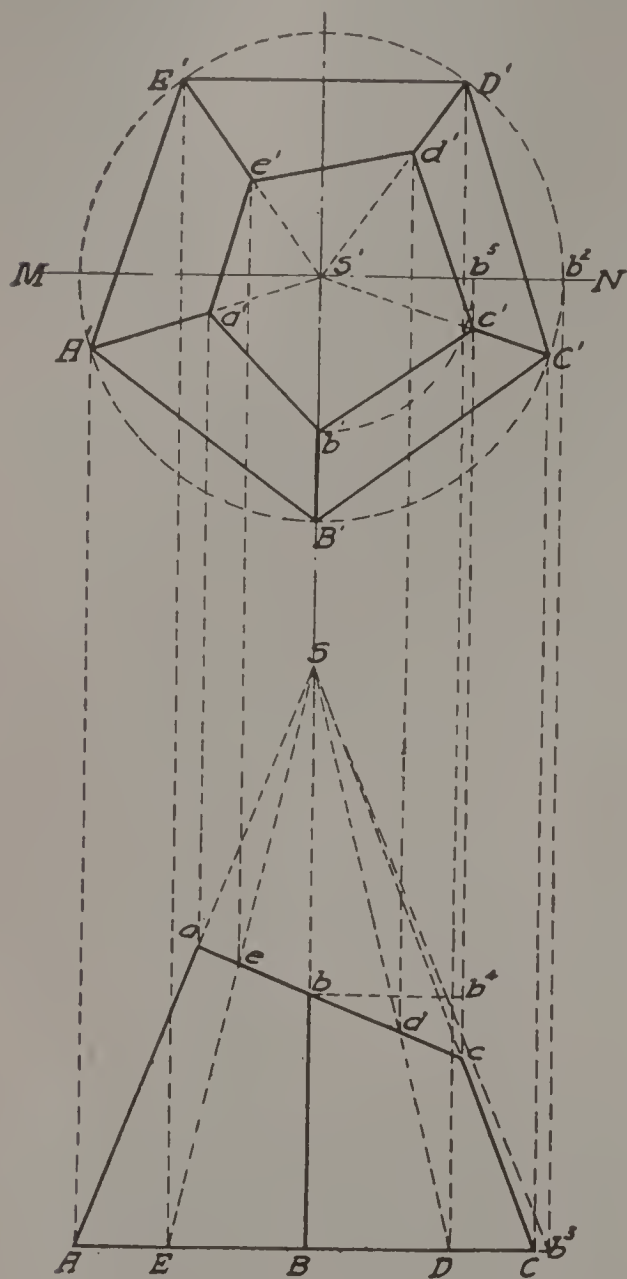


Fig. 138. Frustum of Pentagonal Pyramid

must be in the line Sb^3 , it is obvious that its vertical projection is the point b^4 , the intersection of a horizontal line drawn through b with the line Sb^3 . The distance b^4b^5 may then be used to determine the distance from S' to b' , and determines the position of the latter point in the plan; or, following a more methodical process, by projecting the point b^4 to b^5 , and describing a circle from the center S' passing through b^5 , its intersection with $B'S'$ is the point sought.

Planes with Cones or Cylinders. Sections cut by a plane from a cone have already been defined as *conic sections*. These sections may be any of the following: two straight lines, circle, ellipse, parabola, hyperbola. All except the parabola and hyperbola may also be cut from a cylinder.

Methods have previously been given for constructing the ellipse, parabola, and hyperbola, without projections; it will now be shown that they may be obtained as actual intersections.

Ellipse. In Fig. 139 the plane cuts the cone obliquely. To find points on the curve in plan take a series of horizontal planes xyz , etc., between points c^v and d^v . One of these planes, as w , should be taken through the center of cd . The points c and d must be points on the curve, since the plane cuts the two contour elements at these points. Contour elements are those forming the outline. The horizontal projections of the contour elements will be found in a horizontal line passing through the center of the base; hence the horizontal projection of c and d will be found on this center line, and will be the extreme ends of the curve.

The plane x cuts the surface of the cone in a circle, as it is parallel to the base, and the diameter of the circle is the distance between the points where x crosses the two contour elements. This circle, lettered x on the plan, has its center at the horizontal projection of the apex. The circle x and the curve cut by the plane are both on

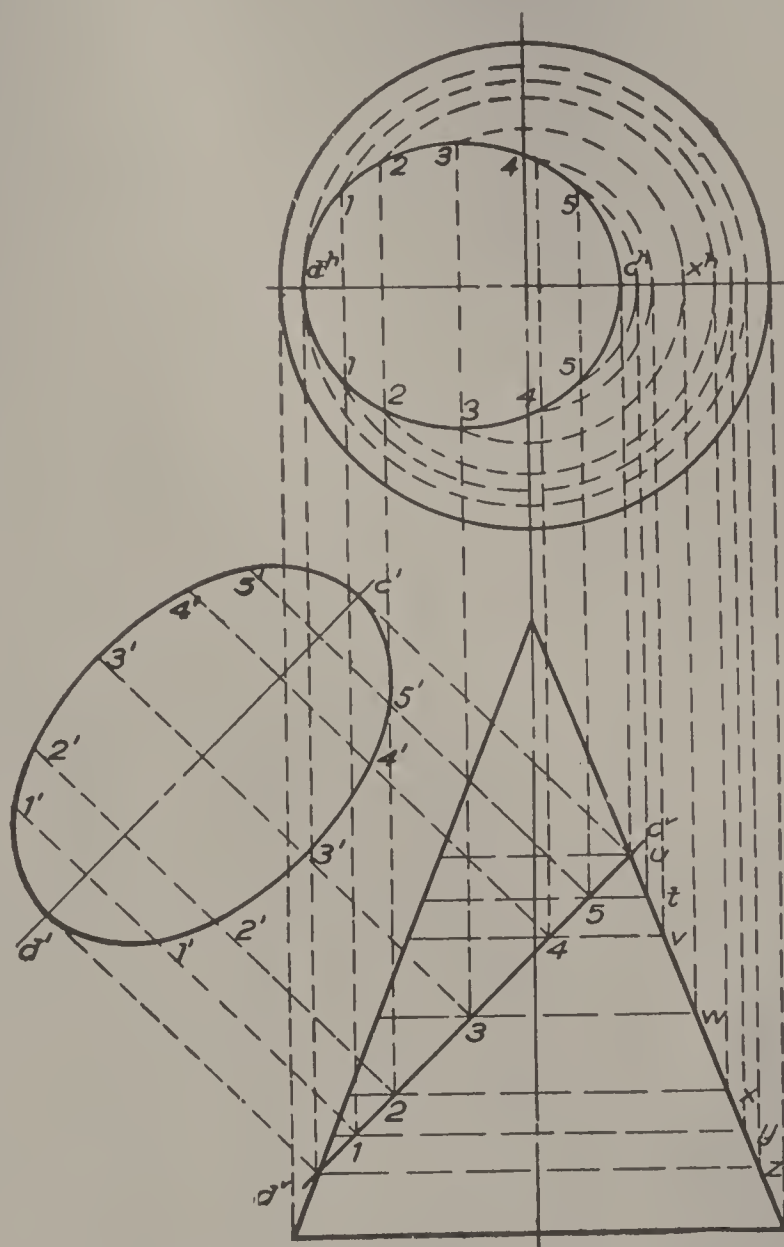


Fig. 139. Ellipse—Section from a Cone

the surface of the cone, and their vertical projections intersect at the points 2-2. Point 2 on the elevation then represents two points which are shown in plan directly above on the circle x , and are points on the required intersection. Planes y and z , and as many more as may be necessary to determine the curve accurately, are used in the same way. The curve found is an ellipse. The student will readily see that the true size of this ellipse is not shown in

the plan, for the plane containing the curve is not parallel to the horizontal.

In order to find the *actual size* of the ellipse, it is necessary to place its plane in a position parallel either to the vertical or to the horizontal. The actual length of the long diameter of the ellipse must be shown in elevation, $c^v d^v$, because the line is parallel to the vertical plane. The plane of the ellipse then may be revolved about $c^v d^v$ as an axis until it becomes parallel to V , when its true size will be shown. For the sake of clearness of construction, $c^v d^v$ is imagined moved over to the position $c' d'$, parallel to $c^v d^v$. The lines 1-1, 2-2, 3-3 on the plan show the true width of the ellipse, as these lines are parallel to H , but are projected closer together than their actual distances. In elevation these lines are shown as the points 1, 2, 3,

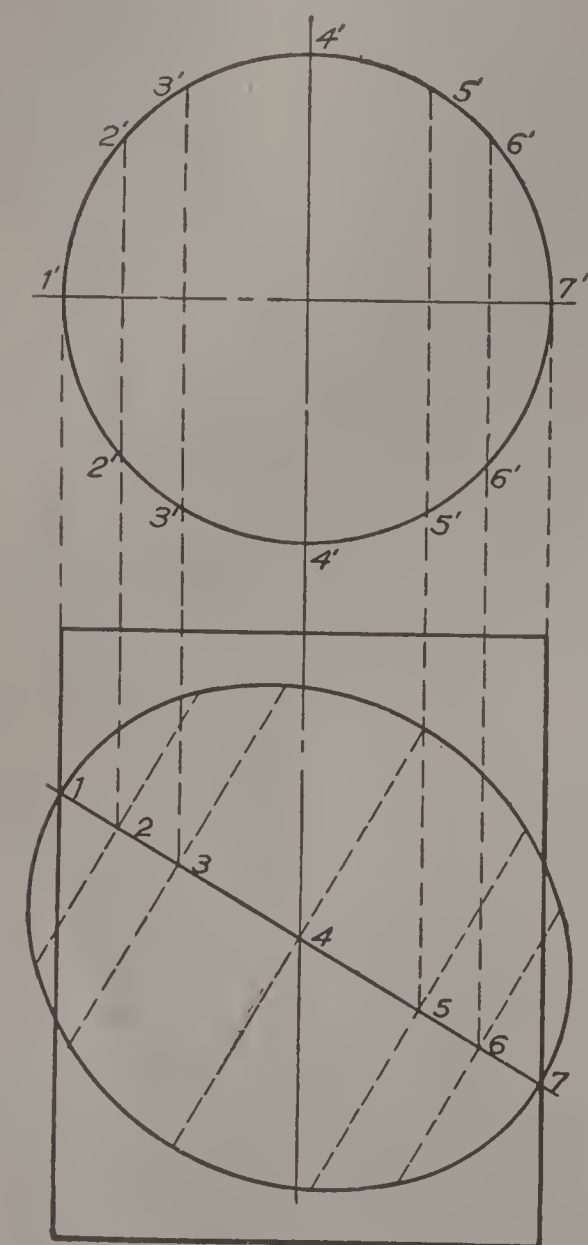


Fig. 140. Ellipse—Section from a Cylinder

at their true distance apart. Hence if the ellipse is revolved around its axis $c^v d^v$, the distances 1-1, 2-2, 3-3 may be laid off on lines perpendicular to $c^v d^v$, and the true size of the figure be shown.

In Fig. 140 a plane cuts a cylinder obliquely. This is a simpler case, as the horizontal projection of the curve coincides with the base of the cylinder. To obtain the true size of the section, which is an ellipse, any number of points are assumed on the plan and

projected down on the cutting plane, at 1, 2, 3, etc. The lines drawn through these points perpendicular to $1'-7'$ are made equal in length to the corresponding distances $2'-2'$, $3'-3'$, etc., on the plan, because $2'-2'$ is the true width of curve at 2.

Parabola. If a cone is intersected by a plane which is parallel to only one of the elements, as in Fig. 141, the resulting curve is

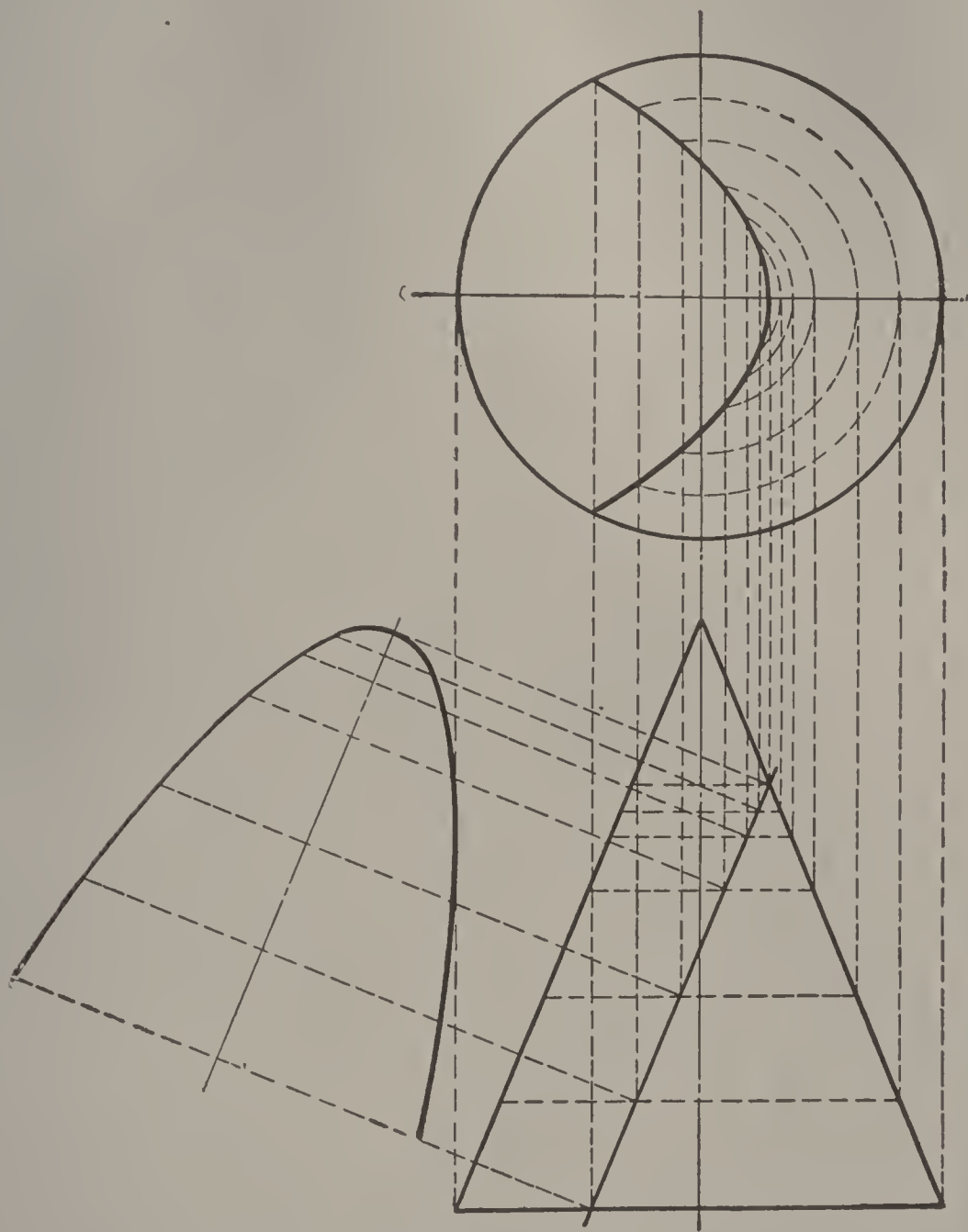


Fig. 141. Parabola—Section from a Cone

the *parabola*, the construction of which is exactly similar to that for the ellipse, as given in Fig. 139. If the intersecting plane is parallel to more than one element, or is parallel to the axis of the cone, a hyperbola is produced.

In Fig. 142, the vertical plane A is parallel to the axis of the cone. In this instance the curve when found will appear in its true

size, as plane *A* is parallel to the vertical. Observe that the highest point of the curve is found by drawing the circle *X* on the plan

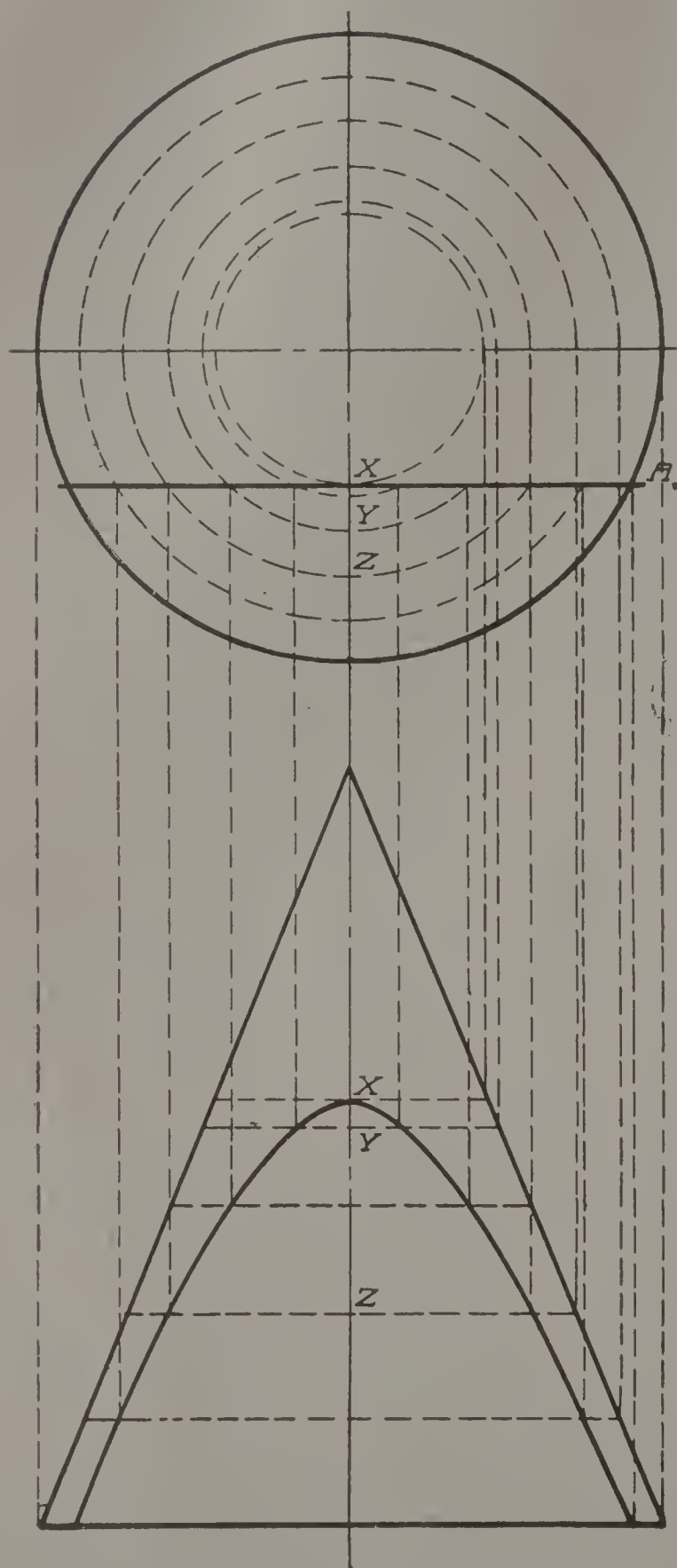


Fig. 142. Hyperbola—Section from a Cone

tangent to the given plane. One of the points where this circle crosses the diameter is projected down to the contour element of the cone, and the horizontal plane *X* drawn. Intermediate planes *Y*, *Z*, etc., are chosen, and corresponding circles drawn in plan. The points where these circles are crossed by the plane *A* are points on the curve, and these points are projected down to the elevation on the planes *Y*, *Z*, etc.

DEVELOPMENT OF SURFACES

General Details of Process. A surface may be considered as formed by the motion of a line. Any length of line moved side-wise in any direction will form a surface, of a width equal to the length of the line, and of a length equal to the distance over which the line is moved. There are two different classes of surfaces; namely, those formed by a moving

straight line, and those formed by a moving curved line.

In some construction work, patterns of different faces or of the whole surface must be made; in stone cutting, for example,

there must be a pattern giving the shape of any irregular surface, and in sheet-metal work a pattern must be made such that, when a sheet is cut, it can be so formed that it will be of the same shape as the original object.

This pattern making, or the laying out of a complete surface on one plane, is called the development of the surface. Any surface

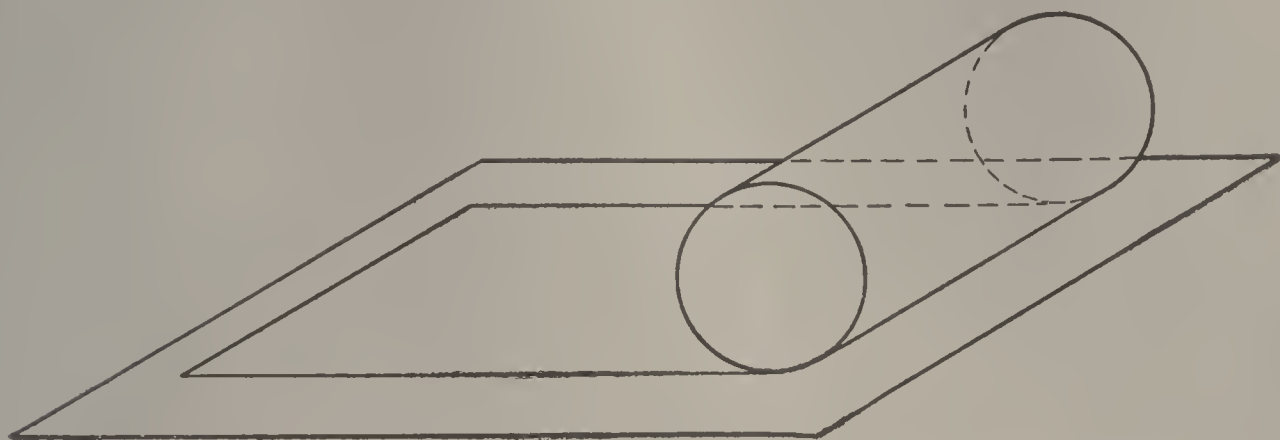


Fig. 143. Development of a Right Cylinder Rolled Out on a Plane

which can be smoothly wrapped about by a sheet of paper, can be developed. Figures made up of planes and single curved surfaces only would be of this nature. Double curved surfaces and warped surfaces cannot be developed, and patterns of such surfaces, when desired, must be made by an approximate method which requires two or more pieces to make the complete pattern.

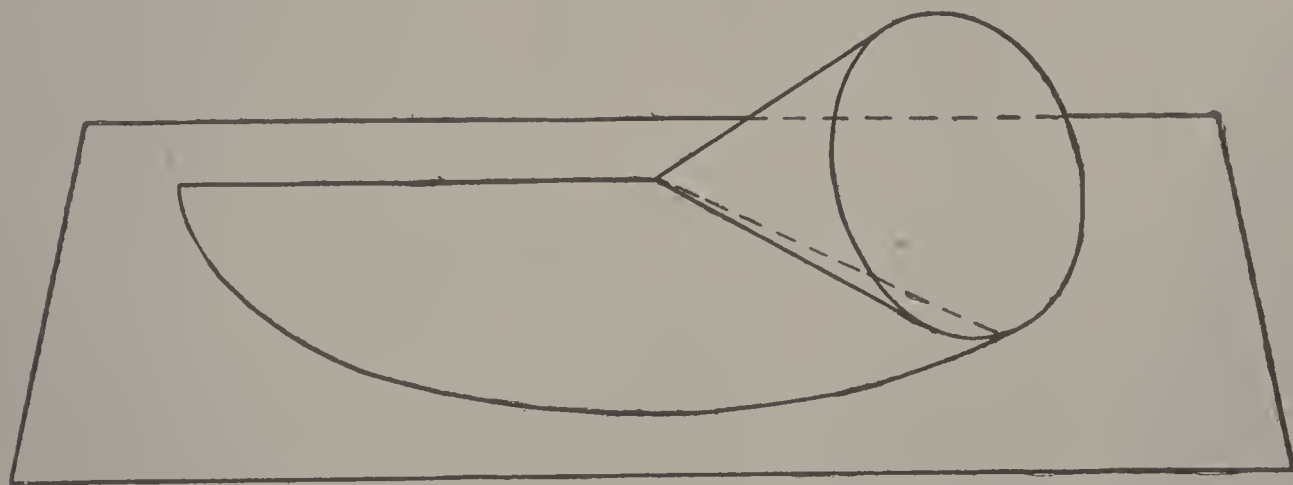


Fig. 144. Development of a Right Cone Rolled Out on a Plane

By finding the true size of all the faces of an object made up of planes, and joining them in order at their common edges, the developed surface will be formed. The best way to do this is to find the true length of the edges of the object.

Right Cylinder. In Fig. 143 is represented a right cylinder rolling on a plane. The development is formed by one complete

revolution of the cylinder and is a rectangle, the width being equal to the height of the cylinder and the length to the circumference.

Right Cone. In Fig. 144 is represented a right cone rolling out its development, which is a sector of a circle. The arc equals the circumference of the circle forming the base of the cone, and the radius equals the slant height.

The projections of any object must be drawn before the development can be made, but it is necessary only to draw such views as are required for finding the lengths of elements, and true sizes of cut surfaces.

Rectangular Prism. In order to find the development of the rectangular prism in Fig. 145, the back face, 1-2-7-6, is supposed

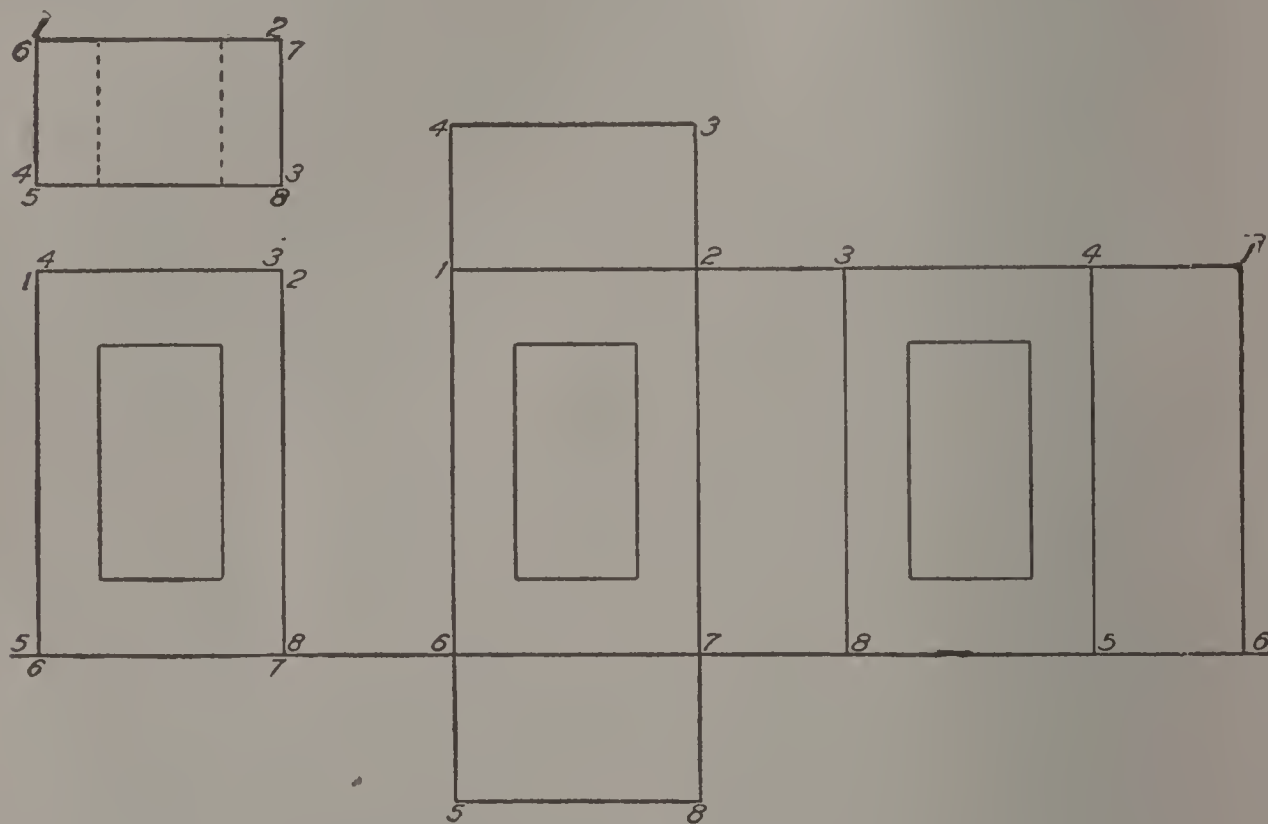


Fig. 145. Development of Hollow Rectangular Prism

to be placed in contact with some plane, then the prism turned on the edge 2-7 until the side 2-3-8-7 is in contact with the same plane, and this process continued until all four faces have been placed on the same plane. The rectangles 1-2-3-4 and 6-7-8-5 are for the top and bottom, respectively. The development then is the exact size and shape of a covering for the prism. If a rectangular hole is cut through the prism, the openings in the front and back faces will be shown in the development in the centers of the two broad faces.

The development of a right prism, then, consists of as many rectangles joined together as the prism has sides, these rectangles being the exact size of the faces of the prism, and in addition two polygons the exact size of the bases. It will be found helpful in developing a solid to number or letter all of the corners on the projections, then designate each face when developed in the same way as in the figure.

Cone. If a cone be placed on its side on a plane surface, one element will rest on the surface. If now the cone be rolled on the

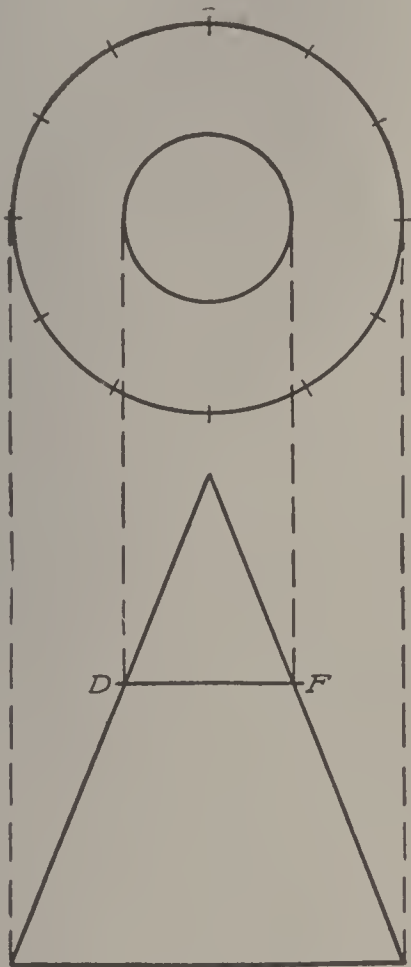


Fig. 146. Plan and Elevation of Cone

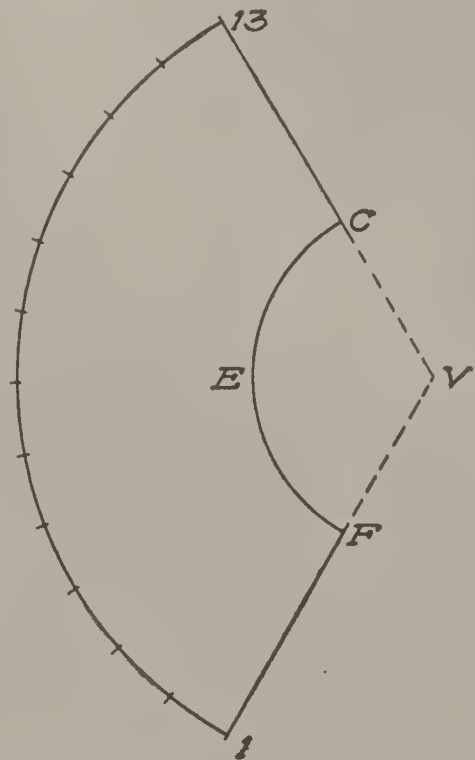


Fig. 147. Development of Cone

plane, the vertex remaining stationary until the same element is in contact again, the space rolled over will represent the development of the convex surface of the cone. Fig. 146 is a cone cut by a plane parallel to the base. In Fig. 147, let the vertex of the cone be placed at V , and one element of the cone coincide with $VF1$. The length of this element is taken from the elevation, Fig. 146, of either contour element. All of the elements of the cone are of the same length, so that when the cone is rolled, each point of the base as it touches the plane will be at the same distance from the vertex. From this it follows that in the development of the base,

the circumference will become the arc of a circle of radius equal to the length of an element, and of a length equal to the distance around the base. To find this length divide the circumference of the base in the plan into any number of equal parts, say twelve, and lay off twelve such spaces, 1 13 along an arc drawn with radius equal to $V1$; join 1 and 13 with V , and the resulting sector is the development of the cone from vertex to base. In order to represent on the development the circle cut by the section plane DF , draw, from the vertex V as a center and with VF as a radius, the

arc FC . The development of the frustum of the cone will be a portion of a circular ring. This of course does not include the development of the bases, which would be simply two circles the same sizes as shown in plan.

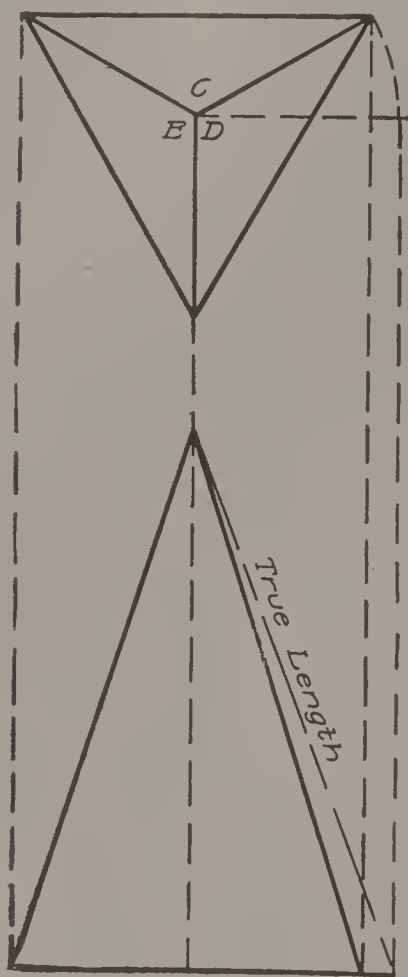


Fig. 148. Plan and Elevation of Triangular Pyramid

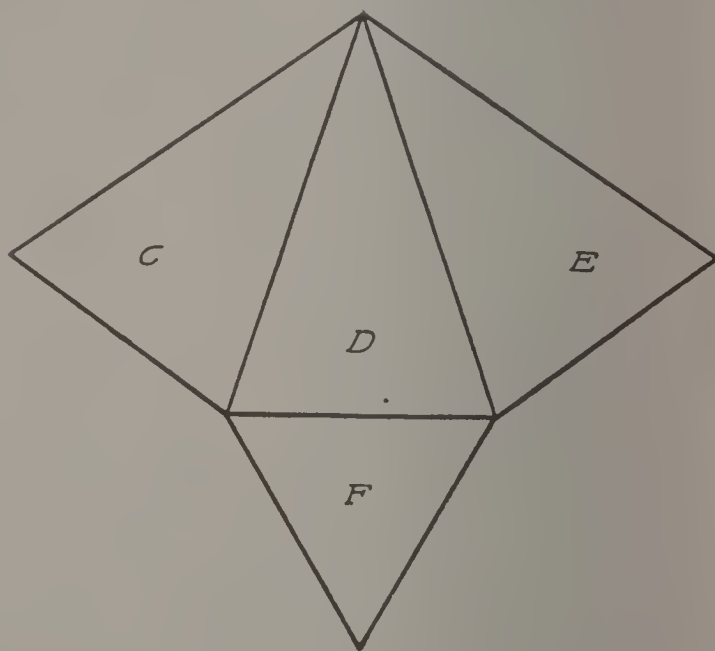


Fig. 149. Development of Triangular Pyramid

Regular Triangular Pyramid. Fig. 148 represents the plan and elevation of a regular triangular pyramid, and Fig. 149 its development. If face C is placed on the plane its true size will be shown in the development. The true length of the base of triangle C is shown in the plan. As the slanting edges, however, are not parallel to the vertical, their true length is not shown in elevation but must be obtained by the method given on page 88, as indicated in Fig. 148. The triangle may now be drawn in its full size at C in the development, and as the pyramid is regular, two other equal triangles,

D and *E*, may be drawn to represent the other sides. These, together with the base *F*, constitute the complete development.

Truncated Circular Cylinder. If a truncated circular cylinder is to be developed, or rolled upon a plane, the elements, being parallel, will appear as parallel lines, and the base line being perpendicular to the elements, will appear as a straight line of length equal to the circumference of the base. The base of the cylinder in Fig. 150 is divided into twelve equal parts, 1, 2, 3, etc., and commencing at point 1 on the development, these twelve equal spaces are laid off along the straight line, giving the total width.

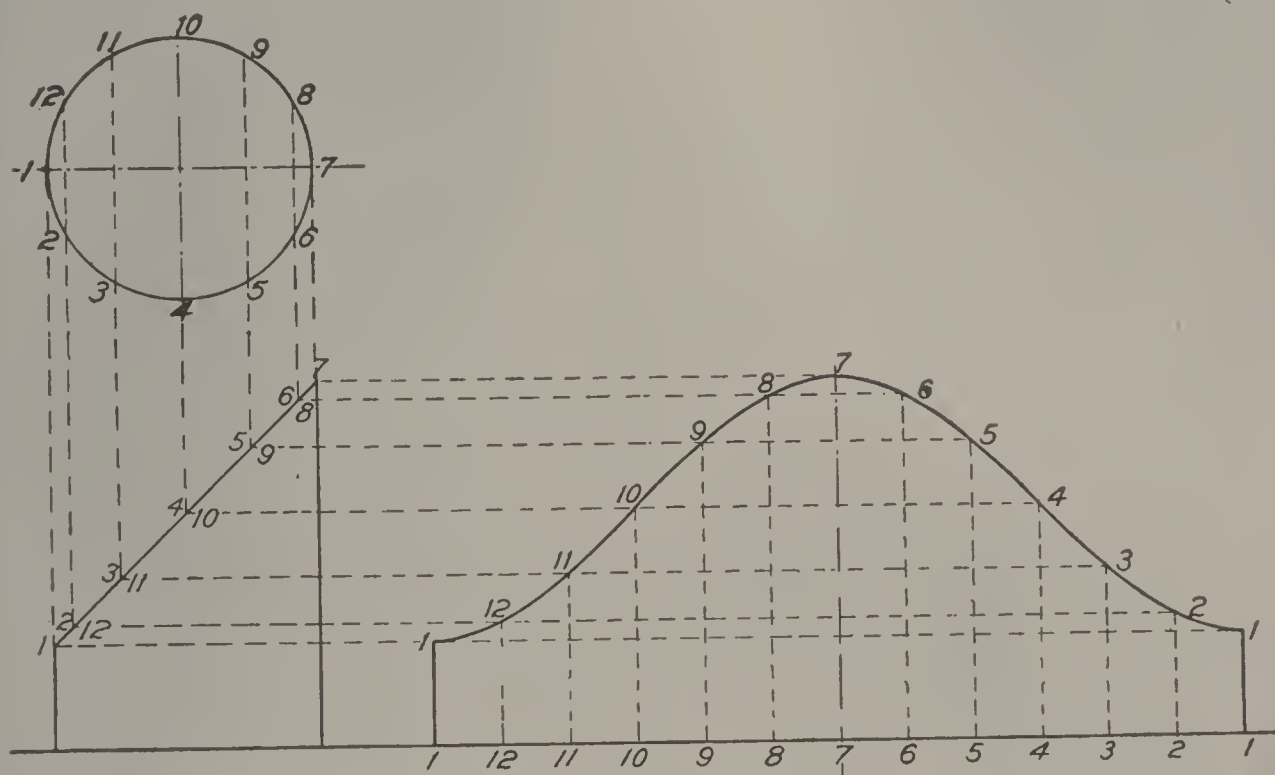


Fig. 150. Projections and Development of Truncated Cylinder

Draw in elevation the elements corresponding to the various divisions of the base, and note the points where they intersect the oblique plane. As the cylinder is rolled beginning at point 1, the successive elements, 1, 12, 11, etc., will appear at equal distances apart, and equal in length to the lengths of the same elements in elevation. Thus point number 10 on the development is found by projecting horizontally across from 10 in elevation. It will be seen that the curve formed is symmetrical, the half on the left of 7 being similar to that on the right. The development of any similar surface may be found in the same manner.

The principle of cylinder development is used in laying out elbow joints, pipe ends cut off obliquely, etc. In Fig. 151 is shown

plan and elevation of a three-piece elbow and collar, and developments of the four pieces. In order to construct the various parts making up the joint, it is necessary to know what shape and size must be marked out on the flat sheet metal so that when cut out and rolled up the three pieces will form cylinders with the ends fitting together as required. Knowing the kind of elbow desired, first draw the plan and elevation, and from these make the develop-

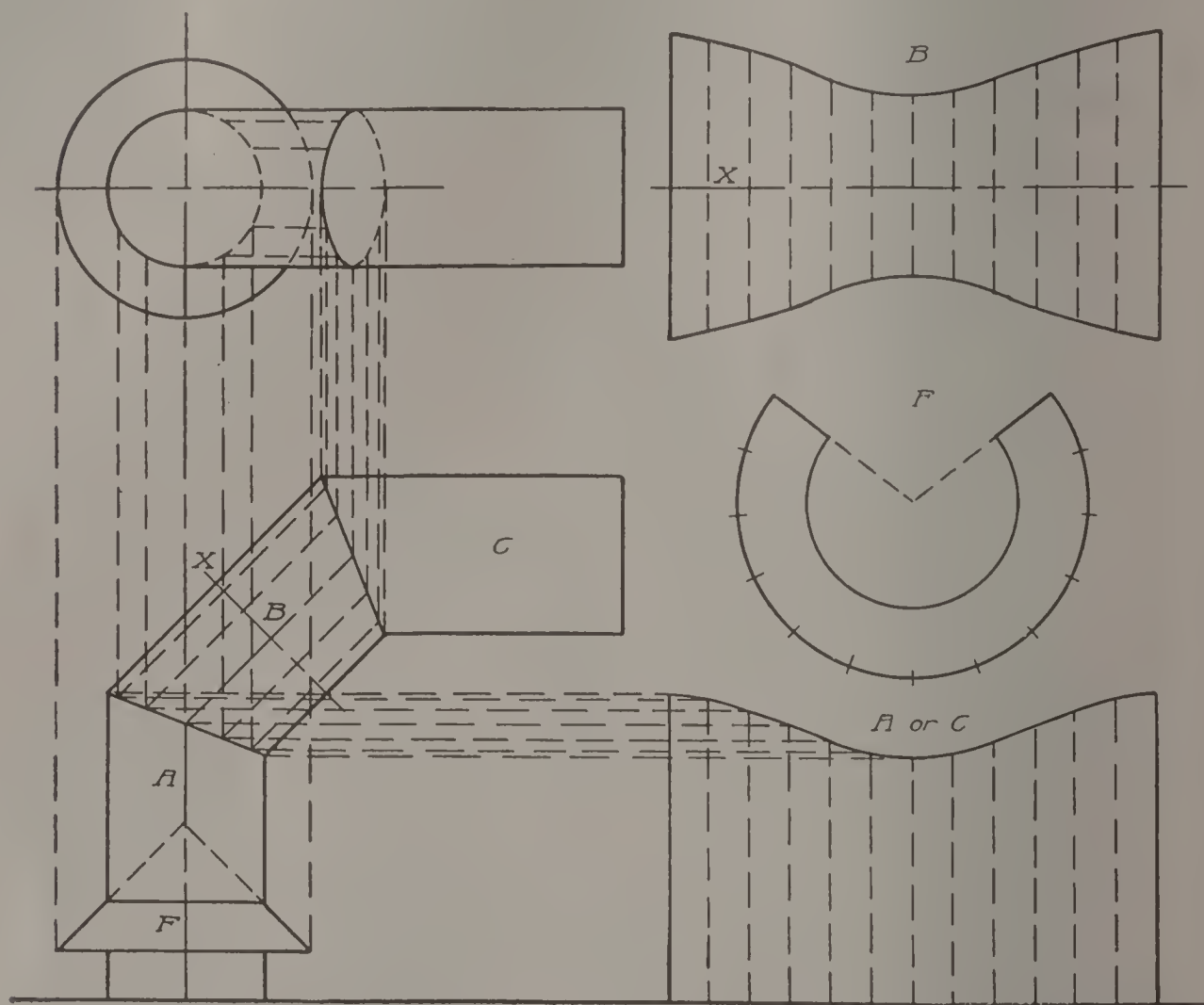


Fig. 151. Plan, Elevation, and Development of Three-Piece Elbow and Collar

ments. Let the lengths of the three pieces *A*, *B*, and *C* be the same on the upper outside contour of the elbow, the piece *B* at an angle of 45 degrees; the joint between *A* and *B* bisects the angle between the two lengths, and in the same way the joint between *B* and *C*. The lengths *A* and *C* will then be the same and one pattern will answer for both. The development of *A* is made exactly as just explained for Fig. 150, and this is also the development of *C*.

It should be borne in mind that in developing a cylinder the base must always be at right angles to the elements, and if the cylinder as given does not have such a base, it becomes necessary

to cut the cylinder by a plane perpendicular to the elements, and use the intersection as a base. This point must be clearly understood in order to proceed intelligently. A section at right angles to the elements is the only section which will unroll in a straight line, and is, therefore, the section from which the other sections must be developed. As *B*, Fig. 151, has neither end at right angles to its length, the plane *X* is drawn at the middle and perpendicular to the length. *B* has the same diameter as *C* and *A*, so the section cut by *X* will be a circle of the same diameter as the base of *A*, and is shown in the development at *X*.

The elements on *B* are drawn from the points where the elements on the elevation of *A* meet the joint between *A* and *B*, and are equally spaced as shown on the plan of *A*. Commencing with the left-hand element in *B*, the length of the upper element between *X* and the top corner of the elbow is laid off above *X*, giving the first point in the development of the end of *B* fitting with *C*. The lengths of the other elements in the elevation of *B* are measured in the same way and laid off from *X*. The development of the other end of the piece *B* is laid off below *X*, using the same distances, since *X* is half way between the ends. The development of the collar is simply the development of the frustum of a cone, which has already been explained, Fig. 147. The joint between *B* and *C* is shown in plan as an ellipse, the construction of which the student should be able to understand from a study of the figure.

ISOMETRIC PROJECTION

Isometric of a Cube. In orthographic projection an object has been represented by two or more projections; another system, called isometrical drawing, is often used to show in one view the three dimensions of an object, length (or height), breadth, and thickness. An isometrical drawing of an object, as a cube, is called for brevity the isometric of the cube.

To obtain a view which shows the three dimensions in such a way that measurements may be taken from them, draw the cube in the simple position shown at the left, Fig. 152, with two faces parallel to *V*; the diagonal from the front upper right-hand corner to the back lower left-hand corner is indicated by the dotted line. Swing the cube around until the diagonal is parallel with *V*, as shown in the

second position. Here the front face is at the right. In the third position the lower end of the diagonal has been raised so that it is parallel to II , becoming thus parallel to both planes. The plan is found by the principles of projection, from the elevation and the preceding plan. The front face is now the lower of the two faces shown in the elevation. From this position the cube is swung around, using the corner as a pivot, until the diagonal is perpendicular to V but still parallel to II . The plan remains the same, except as regards position; while the elevation, obtained by projecting across from the previous elevation, gives the isometrical projection of the cube. The front face is now at the left.

Distinction between Isometric Projection and Isometric Drawing. In the last position, as one diagonal is perpendicular to V , it follows

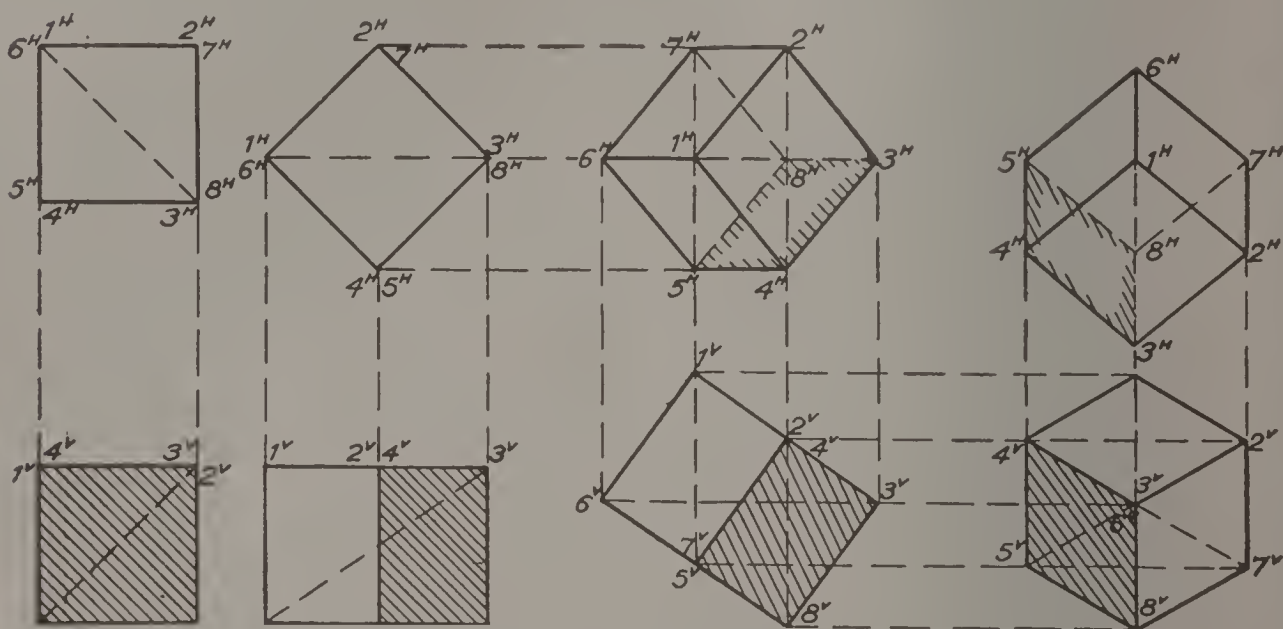


Fig. 152. Development of an Isometric of a Cube

that all the faces of the cube make equal angles with V , hence are projected on that plane as equal parallelograms. For the same reason all the edges of the cube are projected in elevation in equal lengths, but, being inclined to V , appear shorter than they actually are on the object. Since they are all equally foreshortened and since a drawing may be made at any scale, it is customary to make all the isometrical lines of a drawing full length. This will give the same proportions, and is much the simpler method. Herein lies the distinction between an isometric projection and an isometric drawing.

It will be noticed that the figure may be inscribed in a circle, and that the outline is a perfect hexagon. Hence the lines showing

breadth and length are 30-degree lines, while those showing height are vertical.

True Length of Lines. Fig. 153 shows the isometric of a cube 1 inch square. All of the edges are shown in their true length, hence

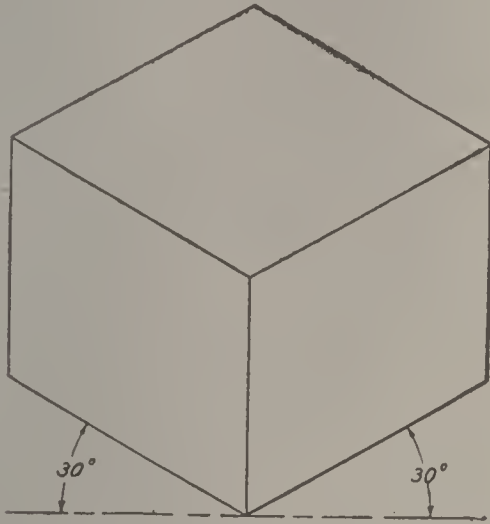


Fig. 153. Isometric of a Cube

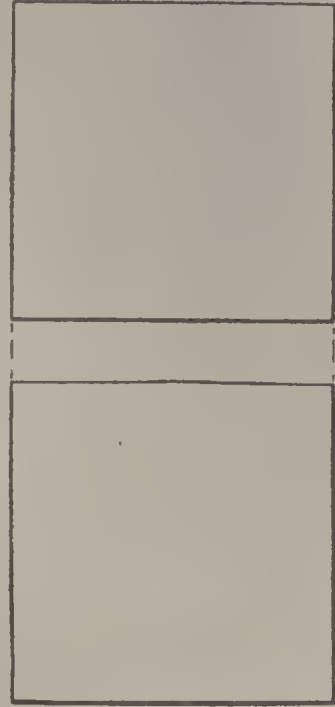


Fig. 154. Plan and Elevation of a Cube

all the surfaces appear of the same size. In the figure the edges of the base are inclined at 30 degrees with a T-square line, but this is not always the case. For rectangular objects, such as prisms, cubes, etc., the base edges are at 30 degrees only when the prism or cube is supposed to be in the simplest possible position. The cube in Fig. 153 is supposed to be in the position indicated by plan and elevation in Fig. 154, that is, standing on its base, with two faces parallel to the vertical plane.

If the isometric of the cube in the position shown in Fig. 155 were required, it could not be drawn with the base edges at 30 degrees; neither would these edges appear in their true lengths. It

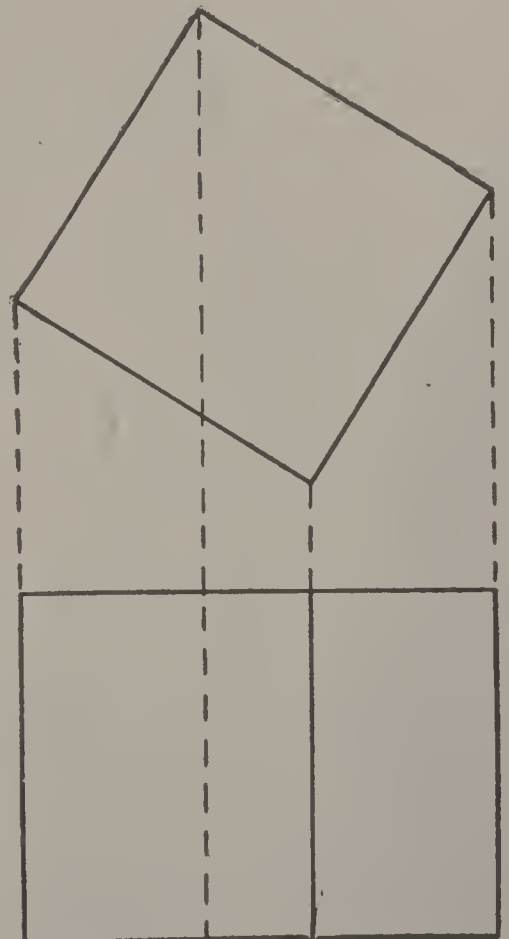


Fig. 155. Cube of Fig. 154 Rotated 30 Degrees with Vertical Plane

follows, then, that in isometrical drawing, true lengths appear only as 30-degree lines or as vertical lines. Edges or lines that in actual projection are either parallel to a T-square line or perpendicular to V , are drawn in isometric as 30-degree lines, full length; and those that are actually vertical are made vertical in isometric, also full length.

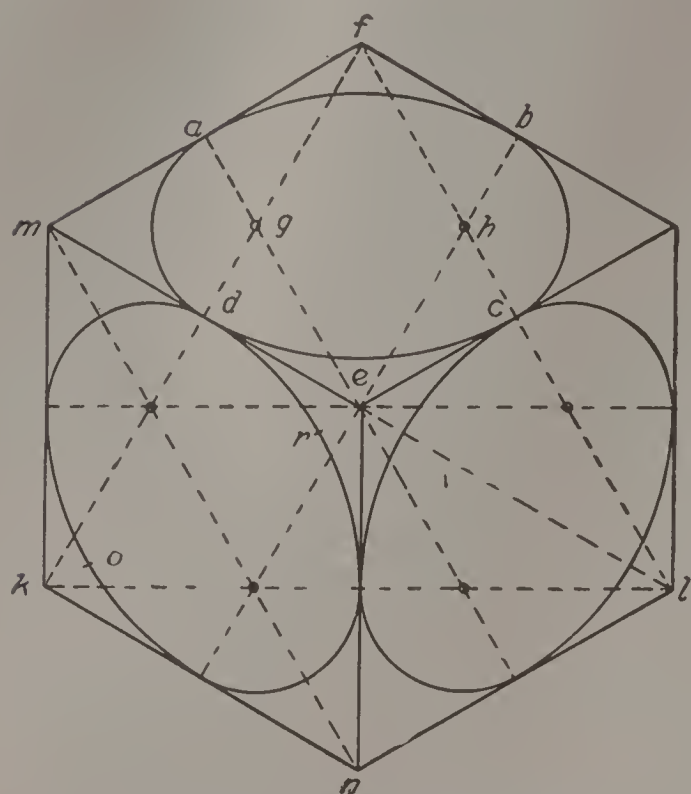


Fig. 156. Isometric of a Cube with Circles Inscribed on its Faces

only by reference to their projections, by methods which will be explained in the section on "Oblique Projection", page 123.

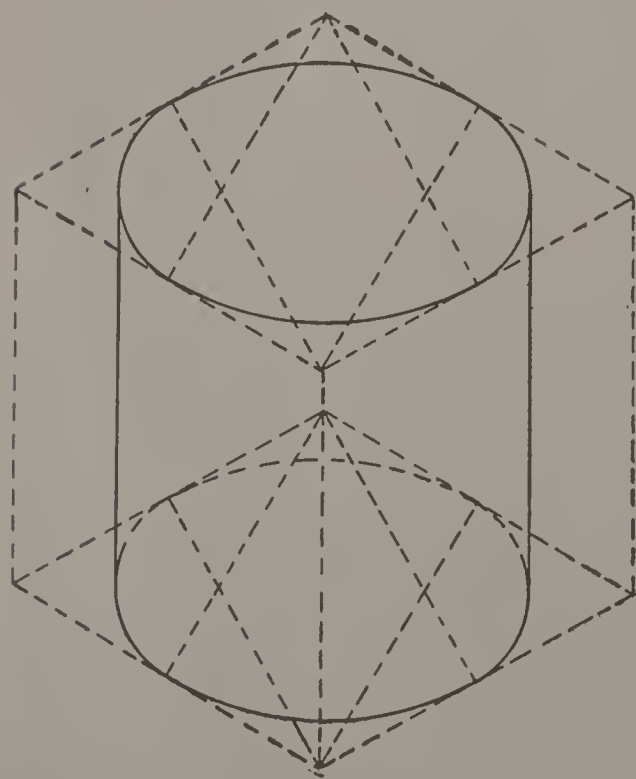


Fig. 157. Isometric of a Cylinder

Three Isometric Axes. In Fig. 152, lines such as the front vertical edges of the cube and the two base edges are called the *three isometric axes*. The isometric of objects in oblique positions, as in Fig. 155, can be constructed

Applications of Isometric Projections. In isometric drawing small rectangular objects are more satisfactorily represented than large curved ones. In woodwork, mortises and joints and various parts of framing are well shown in isometric. This system is used also to give a kind of bird's-eye view of mills or factories. It is also used in making sketches of small rectangular pieces of machinery, where it is desirable to give shape and dimensions in one view.

Characteristics of Various Isometrics. *Cube with Inscribed Circles.* Fig. 156 shows a cube with circles inscribed in the top and two side faces. The isometric of a circle is an ellipse, the

exact construction of which would necessitate finding a number of points; for this reason an approximate construction by arcs of circles is often made. In the method, Fig. 156, four centers are used. Considering the upper face of the cube, lines are drawn from the obtuse angles f and e to the centers of the opposite sides. The intersections of these lines give points g and h , which serve as centers for the ends of the ellipse. With g as center and radius ga , the arc ad is drawn, and with f as center and radius fd , the arc

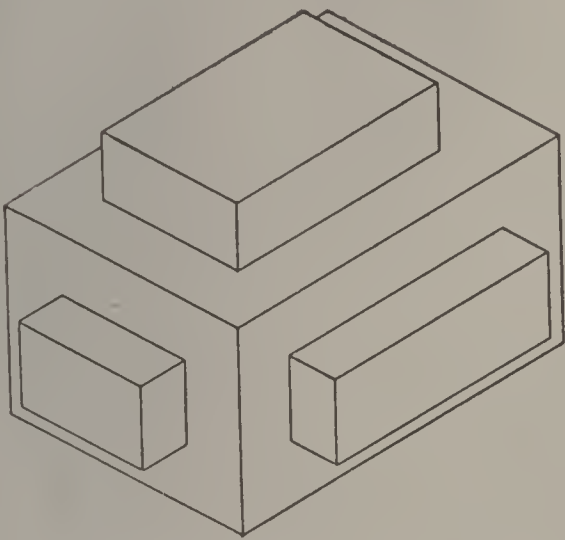


Fig. 158. Isometric of a Wooden Block

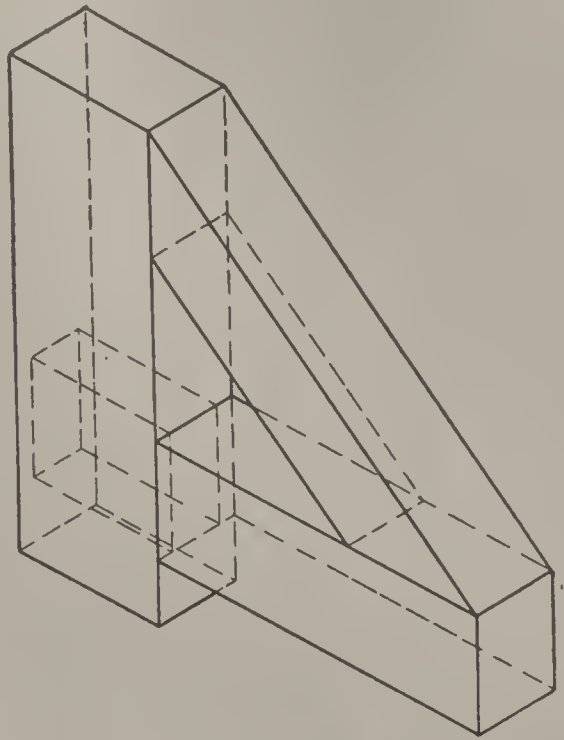


Fig. 159. Isometric of a Wooden Brace

dc is drawn; the ellipse is finished by using centers h and e . This construction is applied to all three faces.

Cylinder. Fig. 157 is the isometric of a cylinder standing on its base.

Blocks. Fig. 158 represents a block with smaller blocks projecting from three faces.

Framework. Fig. 159 shows a framework of three pieces, two at right angles and a slanting brace. The horizontal piece is mortised into the upright as indicated by the dotted lines.

House. In Fig. 160 the isometric outline of a house is represented, showing a dormer window and a partial hip roof; ab is a hip rafter, cd a valley. Let the pitch of the main roof be shown at B , and let m be the middle point of the top of the end wall of the house. Then, by measuring vertically up a distance ml equal to the vertical

height an shown at B , a point on the line of the ridge will be found at l . Line li is equal to bh , and ih is then drawn. Let the pitch of the end roof be given at A . This shows that the peak of the roof, or the end a of the ridge, will be back from the end wall a distance equal to the base of the triangle at A . Hence, lay off from l this distance, giving point a , and join a with b and x .

The height ke of the ridge of the dormer roof is known, and it must be found where this ridge will meet the main roof. The ridge must be a 30-degree line as it runs parallel to the end wall of the house and to the ground. Draw from e a line parallel to bh to meet a vertical through h and f . This point is in the vertical plane of

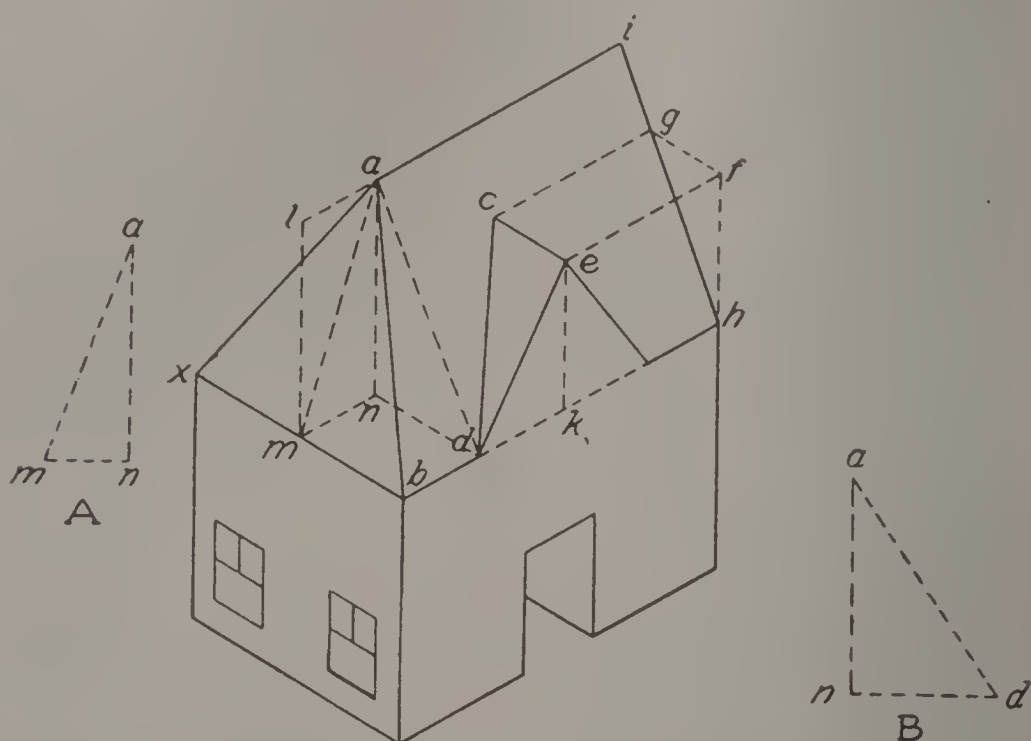


Fig. 160. Isometric Outline of a House

the end wall of the house, hence in the plane of ih . If now a 30-degree line be drawn from f parallel to xb , it will meet the roof of the house at g . The dormer ridge and fg are in the same horizontal plane, hence will meet the roof at the same distance below the ridge ai . Therefore draw the 30-degree line gc , and connect c with d .

Box with Cover. In Fig. 161 a box is shown with the cover opened through 150 degrees. The right-hand edge of the bottom shows the width, the left-hand edge shows the length and the vertical edge shows the height. The short edges of the cover are not isometric lines, hence are not shown in their true lengths; neither is the angle through which the cover is opened represented in its actual size.

The corners of the cover must then be determined by co-ordinates from an end view of the box and cover. As the end of the cover

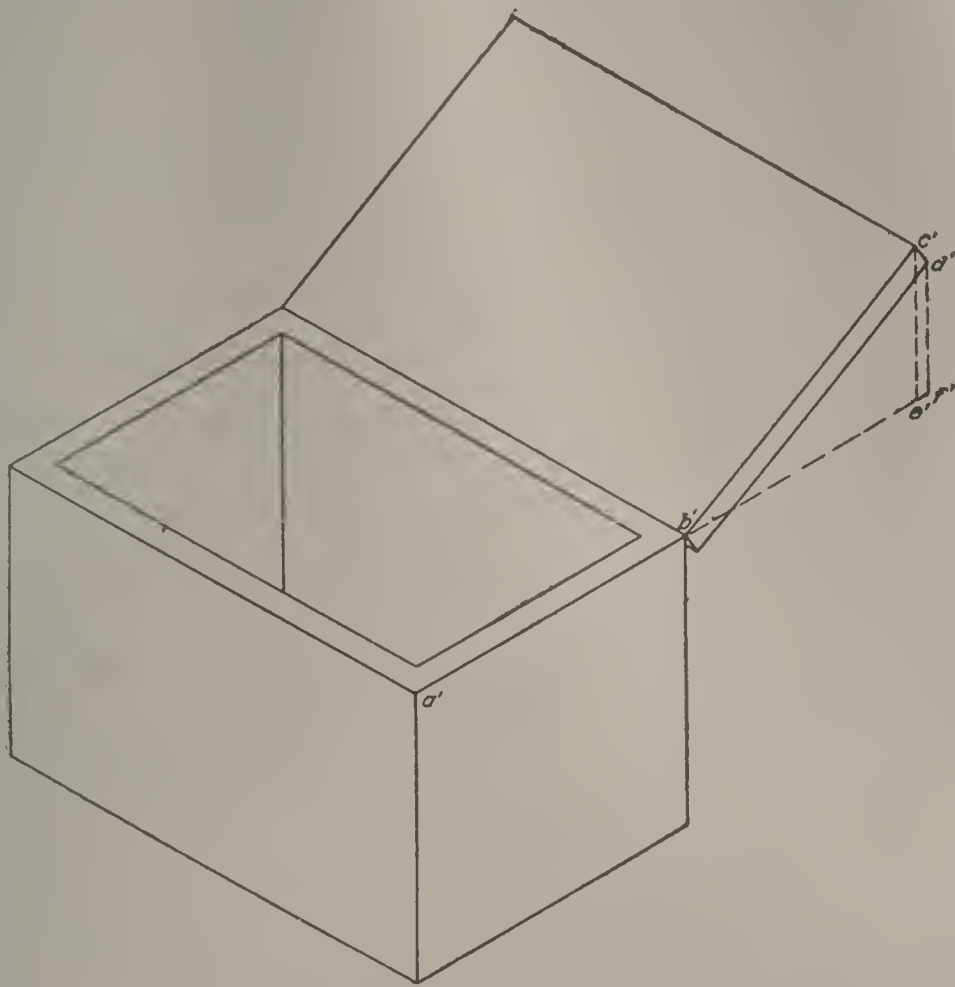


Fig. 161. Isometric of a Box and Cover

is in the same plane as the end of the box, the simple end view as shown in Fig. 162 will be sufficient. Extend the top of the box to the right, and from c and d let fall perpendiculars on ab produced, giving the points e and f . The point c may be located by means of the two distances or co-ordinates be and ec , and these distances will appear in their true lengths in the isometric view. Hence produce $a'b'$ to e' and f' ; and from these points draw verticals $e'c'$ and $f'd'$; make $b'e'$ equal to be , $e'c'$ equal to ec ; and similarly for d' . Draw the lower edge parallel to $c'd'$ and equal to it in length, and connect with b' .

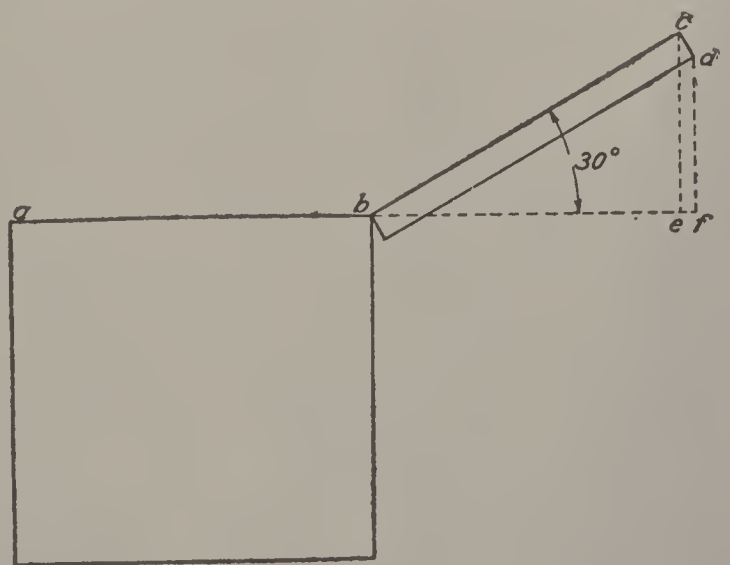


Fig. 162. End View of Box Shown in Fig. 161

It will be seen that in isometric drawing parallel lines always appear parallel. It is also true that lines divided proportionally maintain this same relation in isometric drawing.

Prism with Semicircular Top. Fig. 163 shows a block or prism with a semicircular top. Find the isometric of the square circumscribing the circle, then draw the curve by the approximate method. The centers for

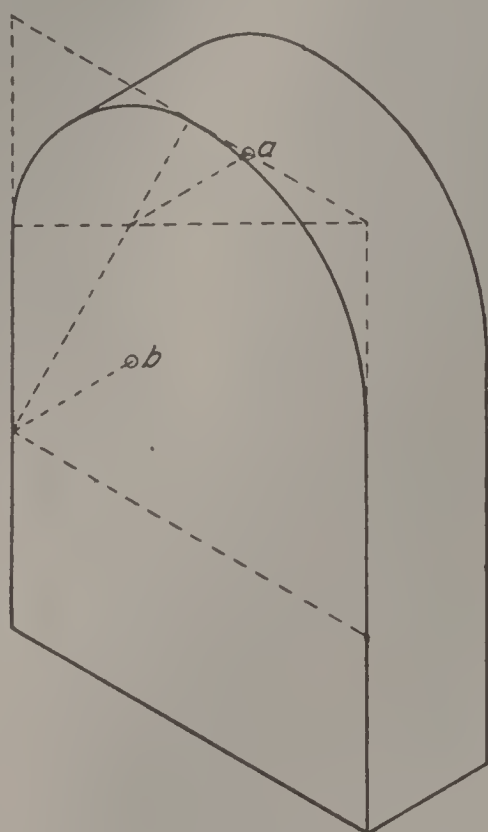


Fig. 163. Isometric of a Prism with Semicircular Top

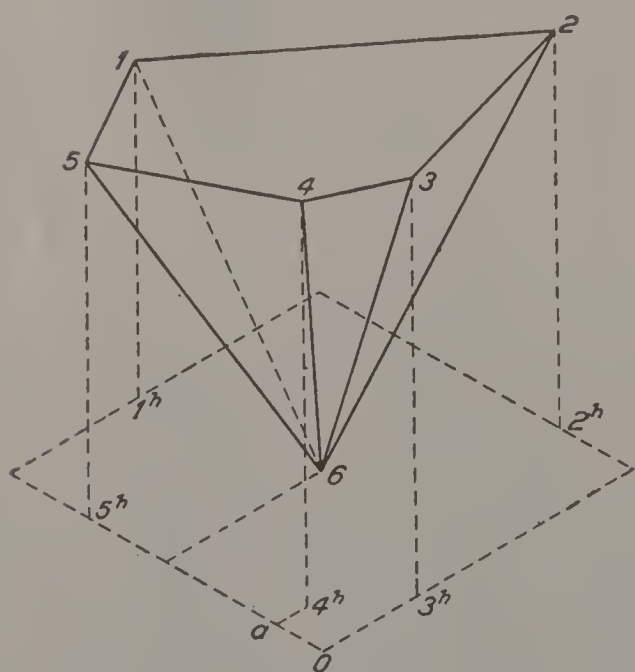


Fig. 165. Isometric of Fig. 164

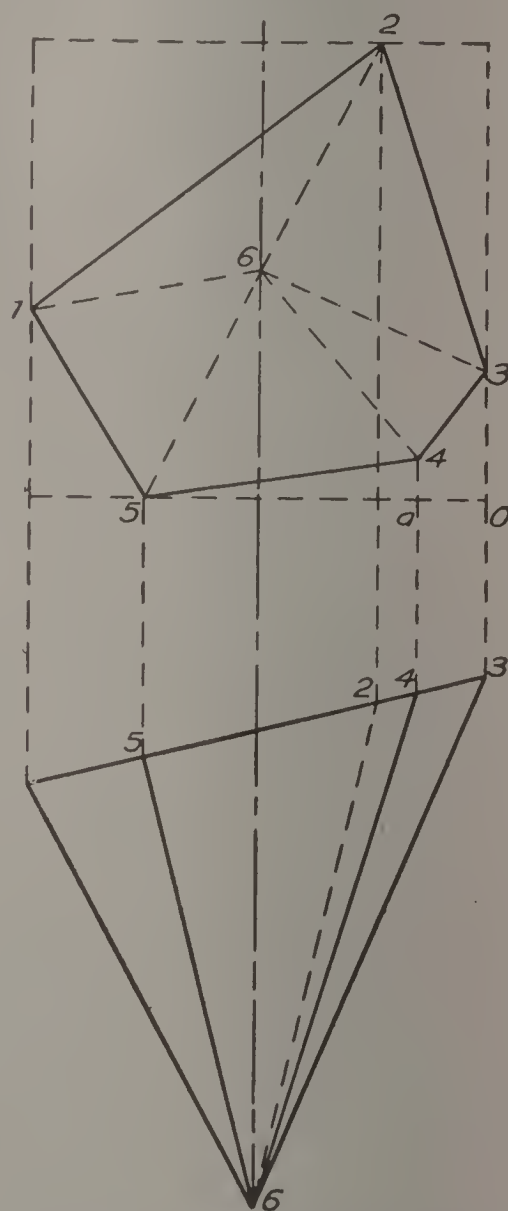


Fig. 164. Plan and Elevation of Oblique Pentagonal Pyramid

the back face are found by projecting the front centers back 30 degrees equal to the thickness of the prism, as shown at *a* and *b*.

Pyramid. The plan and elevation of an oblique pentagonal pyramid are shown in Fig. 164. It is evident that none of the edges

of the pyramid can be drawn in isometric as either vertical or 30-degree lines; hence a system of co-ordinates must be used as shown in Fig. 165. This problem illustrates the most general case; and to locate some of the points three co-ordinates must be used, two at 30 degrees and one vertical.

Circumscribe, about the plan of the pyramid, a rectangle which shall have its sides respectively parallel and perpendicular to a T-square line.

The isometric of this rectangle can be drawn at once with 30-degree lines, as shown in Fig. 165, o being the same point in both figures. The horizontal projection of point 3 is found in isometric at 3^h , at the same distance from o as in the plan. That is, *any distance which in plan is parallel to a side of the circumscribing rectangle, is shown in isometric in its true length and parallel to the corresponding side of the isometric rectangle.* If point 3 were on the horizontal plane its isometric would be 3^h , but the point is at the vertical height above H given in the elevation; hence, lay off above 3^h this vertical height, obtaining the actual isometric of the point. To locate point 4, draw $4a$ parallel to the side of the rectangle; then lay off oa and $a4^h$, giving what may be called the isometric plan of 4. The

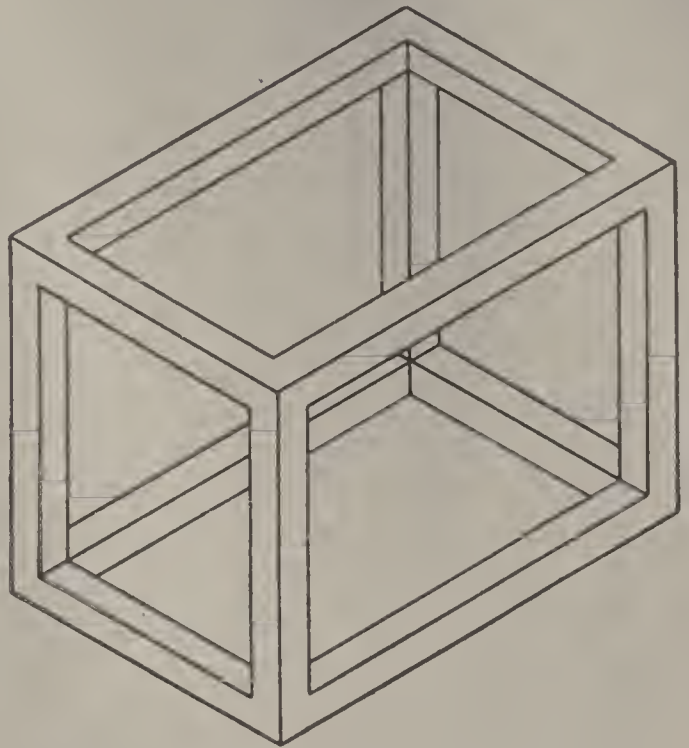


Fig. 166. Isometric of a Skeleton of a Box

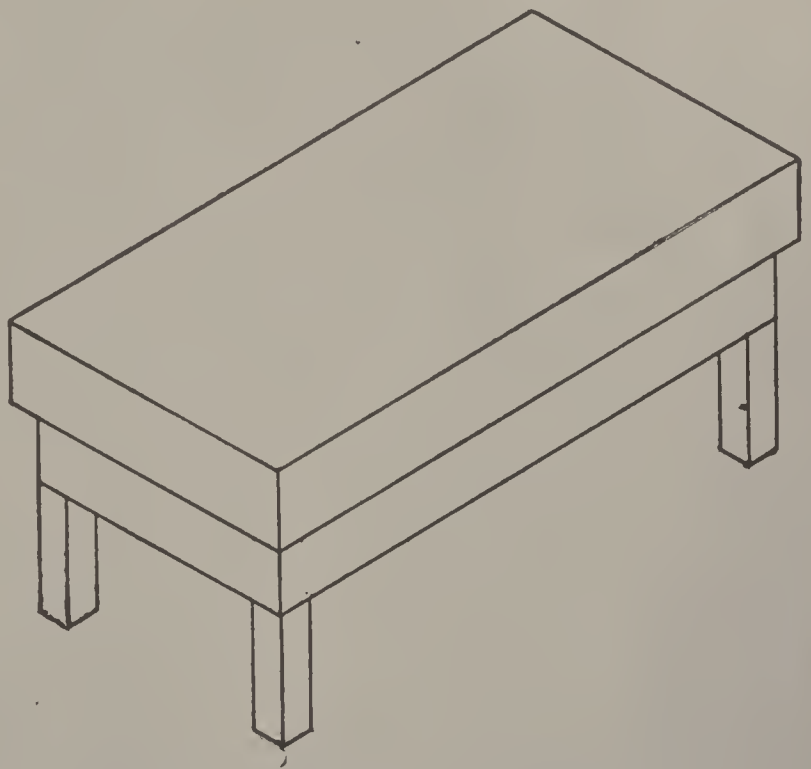


Fig. 167. Isometric of a Carpenter's Bench

vertical height taken from the elevation locates the isometric of the point.

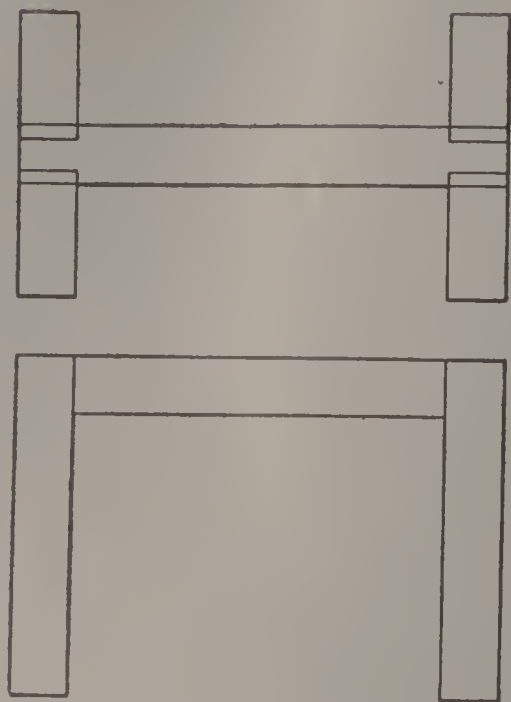


Fig. 168. Plan and Elevation of Sawhorse

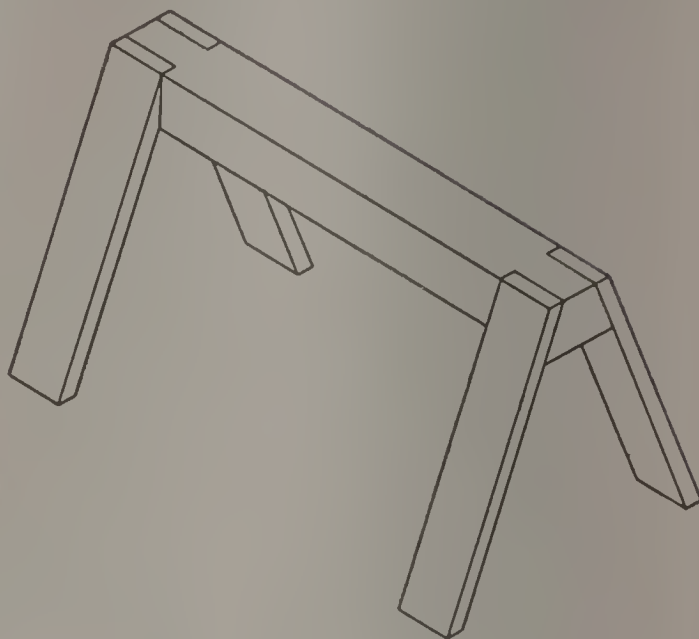


Fig. 169. Isometric of Fig. 168

In like manner all the corners of the pyramid, including the apex, are located. The rule is, *locate first in isometric the horizontal*



Fig. 170. End Elevation of Stairs

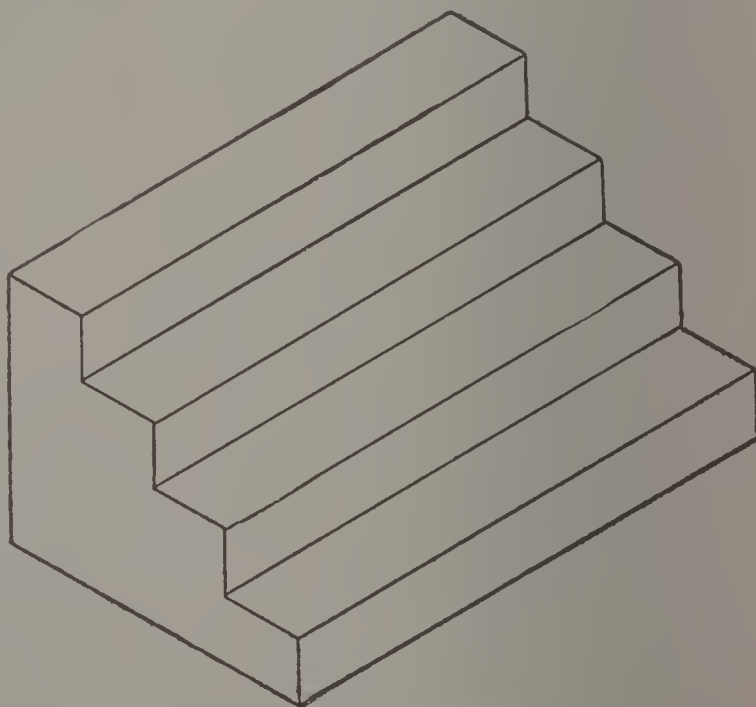


Fig. 171. Isometric of Stairs

projection of a point by one or two 30-degree co-ordinates; then vertically above this point, locate its height as taken from the elevation.

Figs. 166 to 173 give examples of the isometric of various objects.

Fig. 168 is the plan and elevation, and Fig. 169 the isometric, of a carpenter's sawhorse.

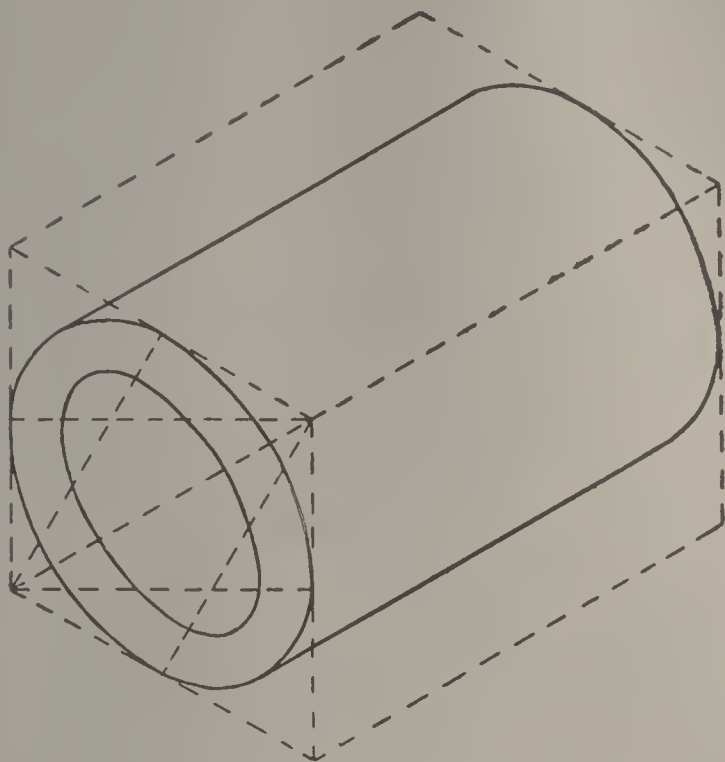


Fig. 172. Isometric of a Hollow Cylinder

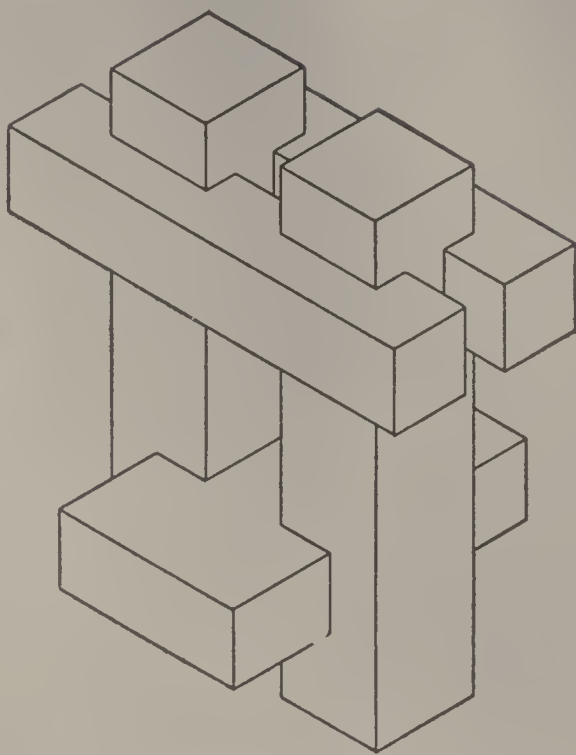


Fig. 173. Isometric of a Wooden Model

OBLIQUE PROJECTION

Comparison with Isometric Projection. In oblique projection, as in isometric, the end sought for is the same—a more or less complete representation, in one view, of any object. Oblique projection differs from isometric in that one face of the object is represented as if parallel to the vertical plane of projection, the others inclined to it. Another point of difference is that oblique projection cannot be deduced from orthographic projection, as is isometric.

Characteristics of Method. In oblique projection all lines in the front face are shown in their true lengths and in their true relation to one another, and lines which are perpendicular to this front face are shown in their true lengths at any

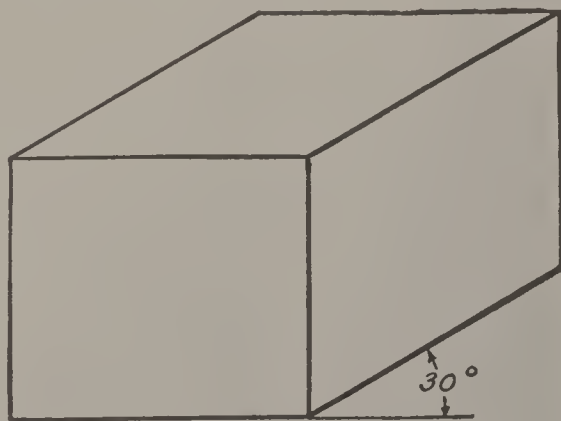


Fig. 174. Oblique View of Cube at 30 Degrees

angle that may be desired for any particular case. Lines not in the plane of the front face nor perpendicular to it must be determined by co-ordinates, as in isometric. It will be seen at once that this system

possesses some advantages over the isometric, as, for instance, in the representation of circles, as any circle or curve in the front face is actually drawn as such. Fig. 174, Fig. 175, and Fig. 176 show a cube in oblique projection with the 30-degree, 45-degree, and 60-degree

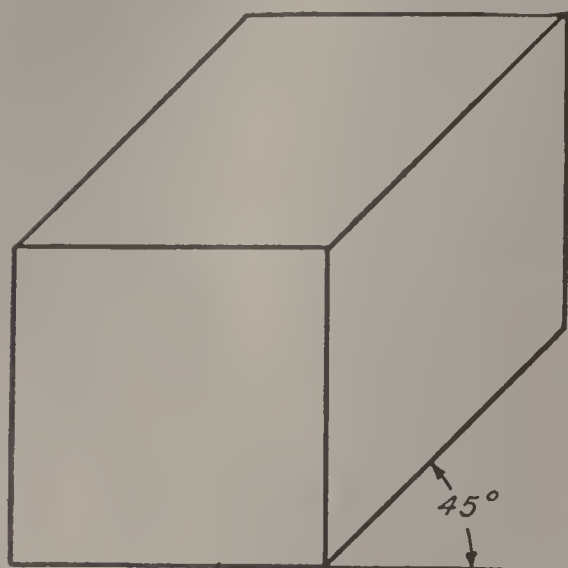


Fig. 175. Oblique View of Cube at 45 Degrees

slant, respectively. Fig. 177 shows a hollow cylinder in oblique projection. Figs 178, 179, 180, 182 are other examples of oblique projections. Fig. 180 is a crank arm.

The method of using co-ordinates for lines of which the true lengths are not shown, is illustrated by Figs 181 and 182. Fig. 182 represents the oblique projection of the two joists shown in plan and elevation in Fig. 181. The dotted

lines in the elevation, Fig. 181, show the heights of the corners above the horizontal stick. The feet of these perpendiculars give the horizontal distances of the top corners from the end of the horizontal piece.

In Fig. 182 lay off from the upper right-hand corner of the front end a distance equal to the distance between the front edge of the

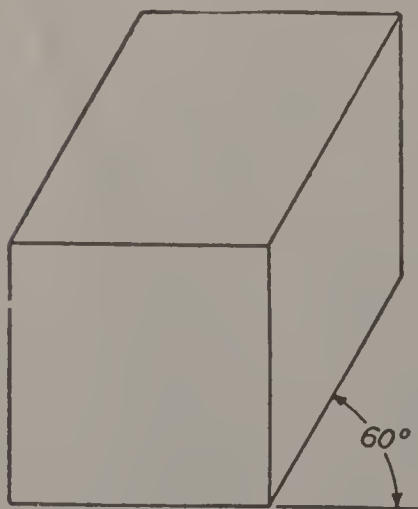


Fig. 176. Oblique View of Cube at 60 Degrees

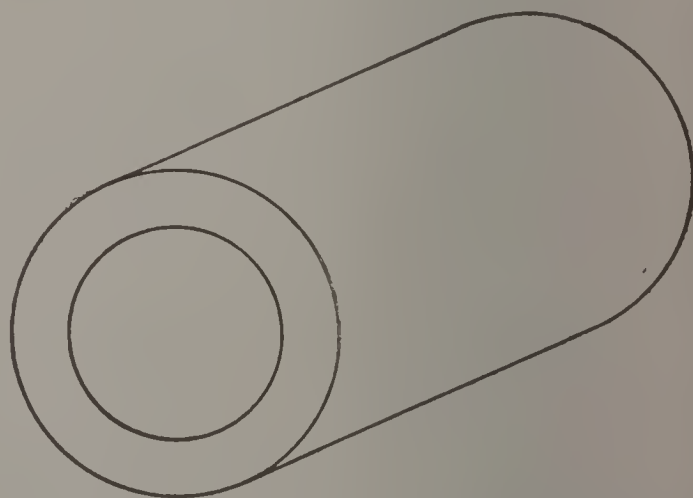


Fig. 177. Oblique View of Hollow Cylinder

inclined piece and the front edge of the bottom piece, Fig. 181. From this point draw a dotted line parallel to the length. The horizontal distances from the upper left corner to the dotted perpendicular are then marked off on this line. From these points verticals

are drawn, and made equal in length to the dotted perpendiculars of Fig. 181, thus locating two corners of the end.

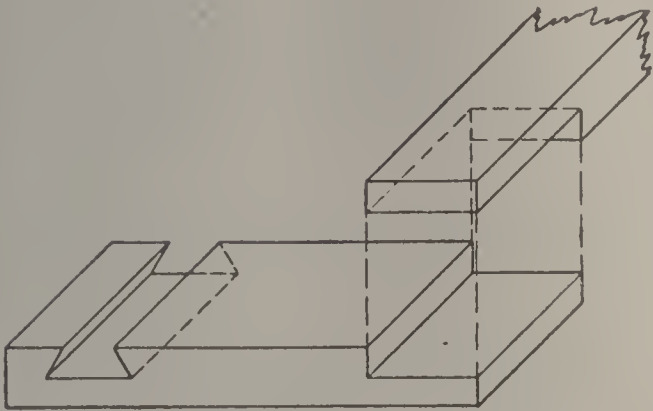


Fig. 178. Oblique View of a Miter Joint

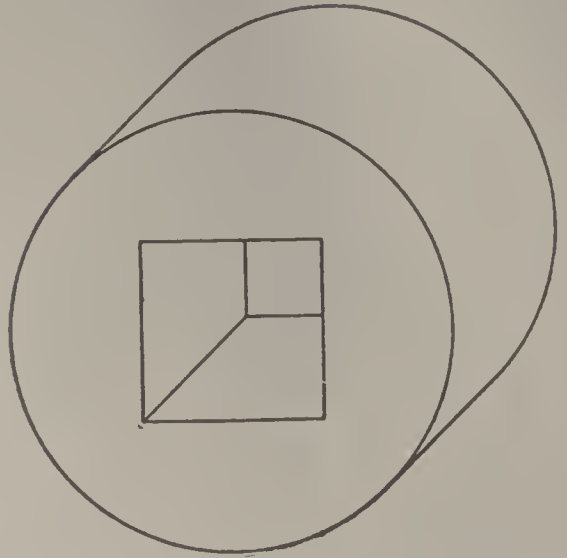


Fig. 179. Oblique View of Cylinder

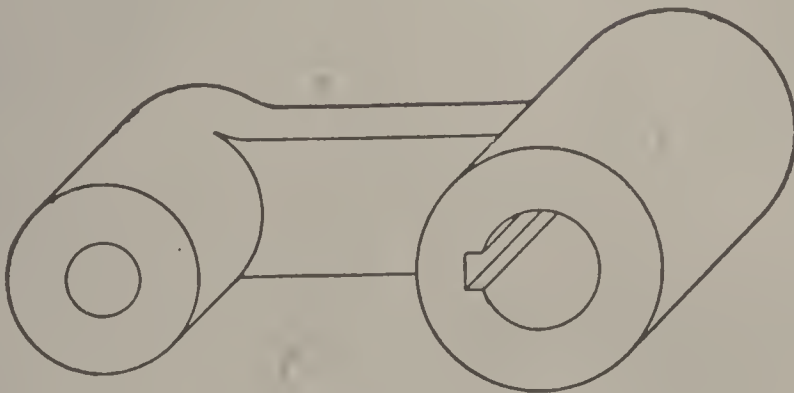


Fig. 180. Oblique View of Crank Shaft

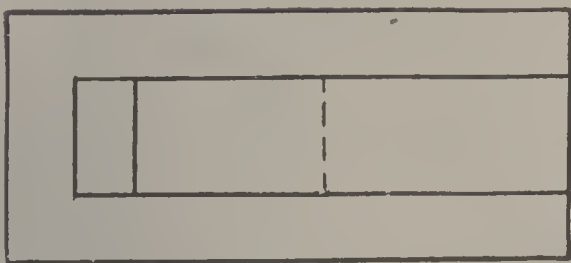


Fig. 181. Plan and Elevation of Wooden Brace

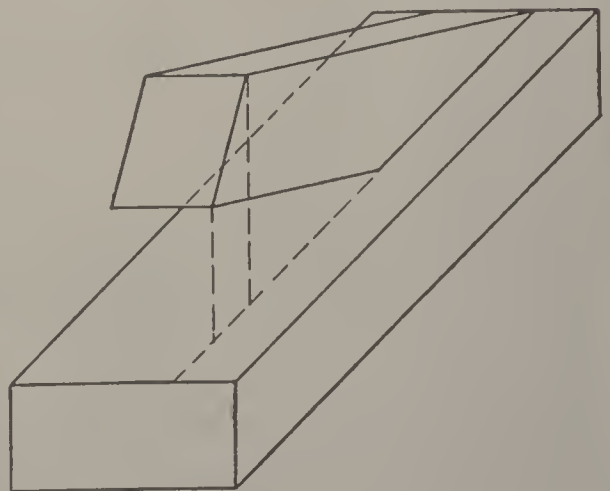


Fig. 182. Oblique View of Wooden Brace

LINE SHADING

Object of Line Shading. In finely finished drawings it is frequently desirable to make the various parts more readily seen by showing the graduations of light and shade on the curved surfaces. This is especially true of such surfaces as cylinders, cones, and spheres. The effect is obtained by drawing a series of parallel or converging lines on the surface at varying distances from one another. Sometimes draftsmen, themselves, vary the width of the lines. These lines are farther apart on the lighter portion of the surface, and closer together and heavier on the darker part.

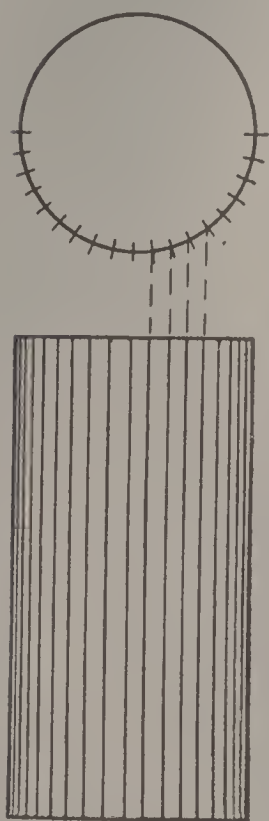


Fig. 183. Plan and Shaded Elevation of Cylinder

Fig. 183 shows a cylinder with elements drawn on the surface equally spaced on the plan. On account of the curvature of the surface, however, the elements are not equally spaced on the elevation, in order to give the effect of the graduations of light on the curved surface. The result is that in drawing the elevation of the cylinder, the distances between the elements are made gradually less from the center toward each side, thus giving a correct representation of the convexity of the cylinder. This effect is intensified by making the



Fig. 184. Shaded Vertical Cylinder

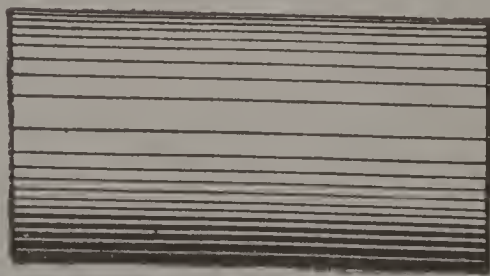


Fig. 185. Shaded Horizontal Cylinder

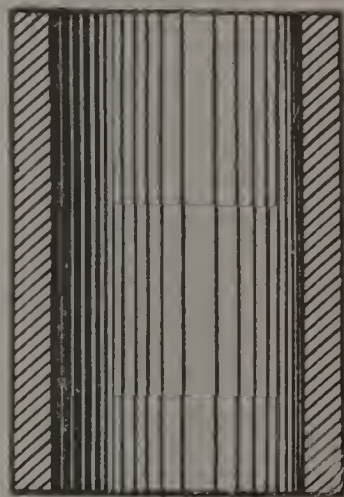


Fig. 186. Shaded Section of Hollow Cylinder

outside elements heavier as well as closer together, as shown in Figs. 184 to 190. Concavity is shown in the same manner, the

heavy shading always appearing on the left to indicate the deeper shadow, Figs. 186 and 188.

Fig. 184 is a cylinder showing the heaviest shade at the right, a method often used. Considerable practice is necessary to obtain good results; but in this, as in other portions of mechanical drawing, repetition is unavoidable. Fig. 185 represents a cylinder in a hori-

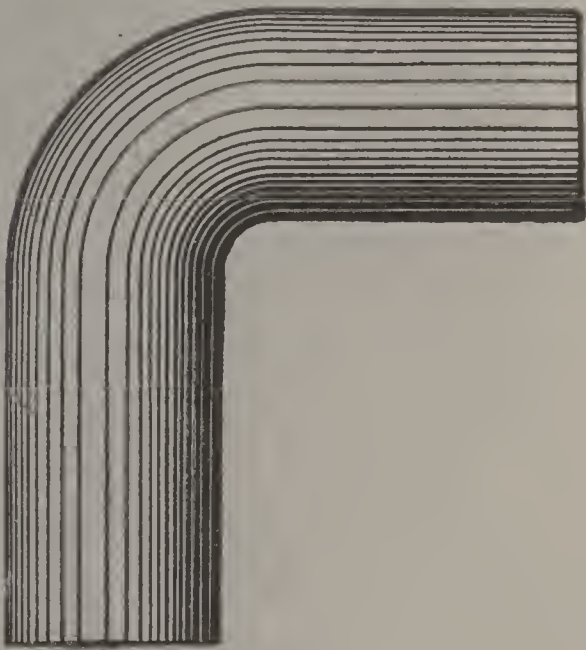


Fig. 187. Shaded Elbow Joint

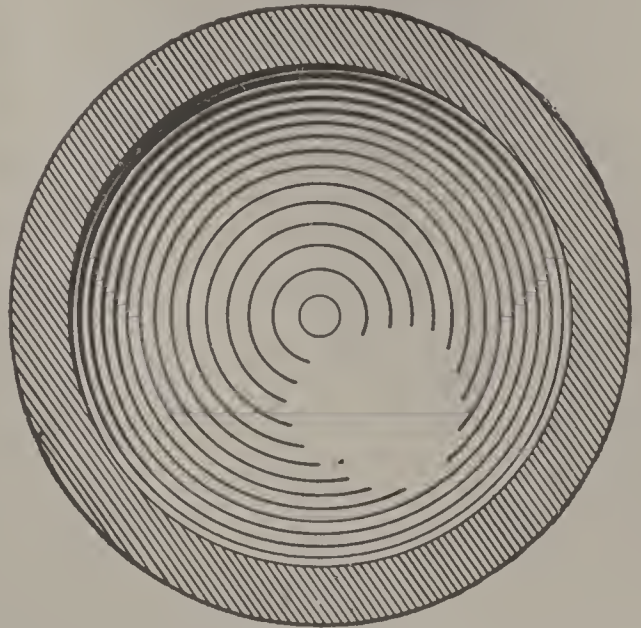


Fig. 188. Shaded Section of Hollow Sphere

zontal position, and Fig. 186 represents a section of a hollow vertical cylinder. Figs. 187 to 190 give other examples of familiar objects.



Fig. 189. Shaded Sphere

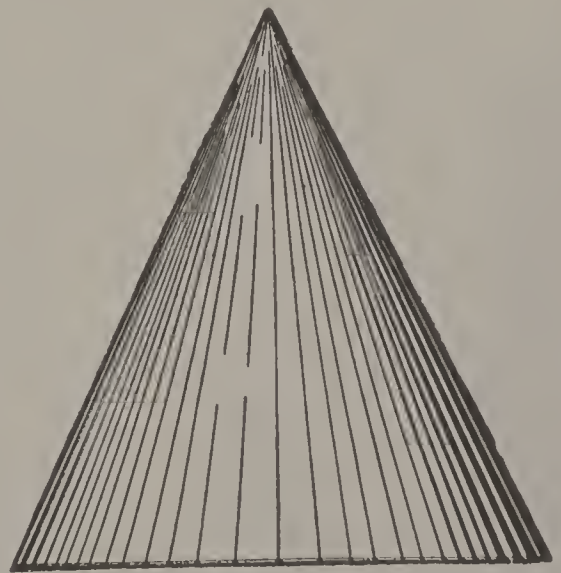


Fig. 190. Shaded Cone

In the elevation of the cone shown in Fig. 190 the shade lines should diminish in weight as they approach the apex. Unless this is done it will be difficult to avoid the formation of a blot at that point.

LETTERING

Types of Lettering. In the early part of this course, the inclined Gothic letter was described, and the alphabet given. The Roman, Gothic, and block letters are perhaps the most used for titles. These letters, being of comparatively large size, are generally made mechanically; that is, drawing instruments are used in their construction. In order that the letters may appear of the same height, some of them, owing to their shape, must be made a little higher than the others. This is the case with the letters curved at the top and bottom, such as C, O, S, etc., as shown somewhat exaggerated in Fig. 191. Also, the letter A should extend a little above, and V a little below, the guide lines, because if made of the same height as the others they will appear shorter. This is true of all capitals, whether of Roman, Gothic, or other alphabets. In the block letter, however, they are frequently all of the same size.

Size of Letters. There is no absolute size or proportion of letters, as the dimensions are regulated by the amount of space in which the letters are to be placed, the size of the drawing, the effect desired, etc. In some cases letters are made so that the height is greater than the width, and sometimes the reverse; sometimes the height and width are the same. This last proportion is the most common. Certain relations of width, however, should be observed. Thus, in whatever style of alphabet used, the W should be the widest letter; J the narrowest, M and T the next widest to W, then A and B. The other letters are of about the same width.

Vertical Gothic. In the vertical Gothic alphabet, the average height is that of B, D, E, F, etc., and the additional height of the curved letters and of the A and V is very slight. The horizontal cross lines of such letters as E, F, H, etc., are slightly above the center; those of A, G, and P slightly below.

Inclined Gothic. For the inclined letters, Fig. 192, 60 degrees is a convenient angle, although they may be at any other angle suited to the convenience or fancy of the draftsman. Many draftsmen use an angle of about 70 degrees.

Roman. The letters of the Roman alphabet, whether vertical, Fig. 193, or inclined, Fig. 194, are quite ornamental in effect if well made, the inclined Roman being a particularly attractive letter,

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 & 2 $\frac{5}{8}$

Fig. 191. Vertical Gothic Letters and Figures

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 & 2 $\frac{5}{8}$

Fig. 192. Inclined Gothic Letters and Figures

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 & 2 $\frac{5}{8}$

Fig. 193. Vertical Roman Letters and Figures

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 & 2 $\frac{5}{8}$

Fig. 194. Inclined Roman Letters and Figures

although rather difficult to make. The block letter, Fig. 195, is made on the same general plan as the Gothic, but much heavier. Small squares are taken as the unit of measurement, as shown. The use of this letter is not advocated for general work, although

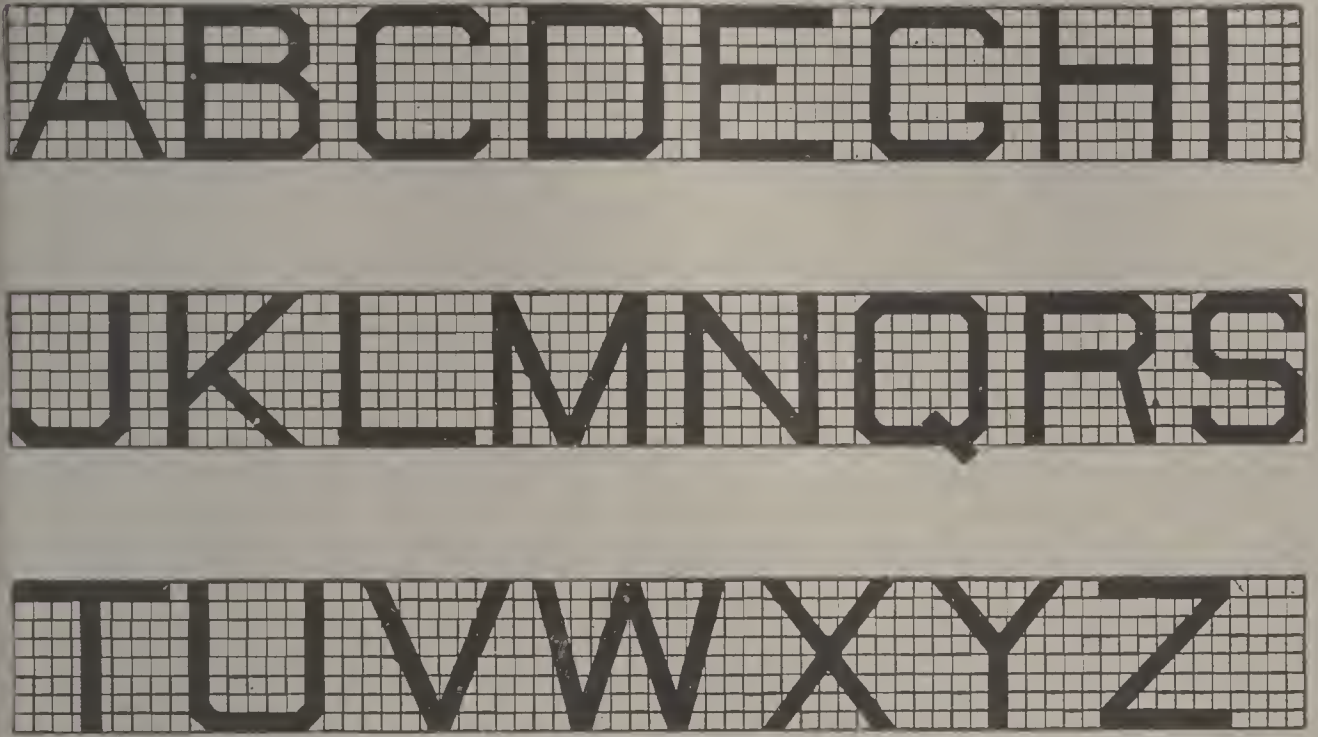


Fig. 195. Block Letters

if made merely in outline the effect is pleasing. The styles of numbers, corresponding with the alphabets of capitals given here, are also inserted. When a fraction, such as $2\frac{5}{8}$ is to be made, the proportion should be about as shown. For small letters, usually

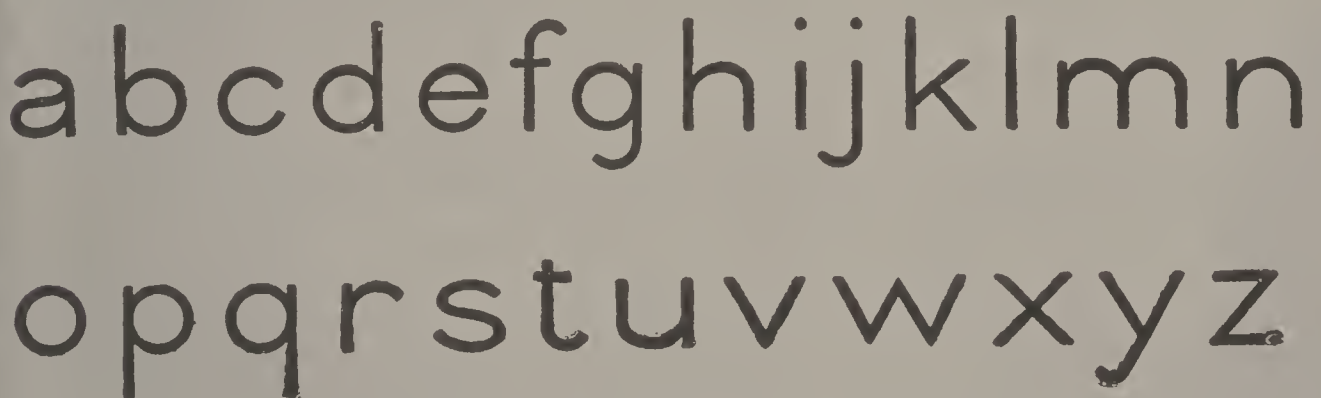


Fig. 196. Vertical Gothic Lower-Case Letters

called lower-case letters, the height may be made about two-thirds that of the capitals. This proportion, however, varies in special cases.

Lower-Case Letters. The principal lower-case letters in general use among draftsmen are shown in Figs. 196, 197, 198, and 199.

The Gothic letters shown in Figs 196 and 197 are much easier to make than the Roman letters in Figs. 198 and 199. These letters,

*abcdefghijklmnop
opqrstuvwxyz*

Fig. 197. Inclined Gothic Lower-Case Letters

however, do not give as finished an appearance as the Roman. As has already been stated in Mechanical Drawing, Part I, the inclined letter is easier to make because slight errors are not so apparent.

*abcdefghijklmnop
opqrstuvwxyz*

Fig. 198. Vertical Roman Lower-Case Letters

Spacing. One of the most important points to be remembered in lettering is the spacing. If the letters are finely executed but

*abcdefghijklmnop
opqrstuvwxyz*

Fig. 199. Inclined Roman Lower-Case Letters

poorly spaced, the effect is not good. To space letters correctly and rapidly requires considerable experience; and rules are of little

TECHNICALITY

Fig. 200. Sample of Letter Spacing

value on account of the many combinations in which letters are found. A few directions, however, may be found helpful. For

instance, take the word TECHNICALITY, Fig. 200. If all the spaces were made equal, the space between the L and the I would appear to be too great, and the same would apply to the space between the I and the T. The space between the H and the N and that between the N and the I would be insufficient. Usually, when the vertical side of one letter is followed by the vertical side of another, as in H E, H B, I R, etc., the maximum space should be allowed. Where T and A come together the least space is given, for in this case the top of the T frequently extends over the bottom of the A. In general, the spacing should be such that a uniform appearance is obtained. For the distances between words in a sentence, a space of about $1\frac{1}{2}$ the width of the average letter may be used. The space, however, depends largely upon the desired effect.

Penciling before Inking. For large titles, such as those placed on charts, maps, and some large working drawings, the letters should be penciled before inking. If the height is made equal to the width, considerable time and labor will be saved in laying out the work. This is especially true with such Gothic letters as O, Q, C, etc., as these letters may then be made with compasses. If the letters are of sufficient size, the outlines may be drawn with the ruling pen or compasses, and the spaces between filled in with a fine brush.

Titles for Working Drawings. The titles for working drawings are generally placed in the lower right-hand corner. Usually a draftsman has his choice of letters, mainly because after he has become used to making one style he can do it rapidly and accurately. However, in some drafting rooms the head draftsman decides what lettering should be used. In making these titles, the different alphabets are selected to give the best results without spending too much time. In most work the letters are made in straight lines, although frequently a portion of the title is found lettered on an arc of a circle.

In Fig. 201 is shown a title having the words CONNECTING ROD lettered on an arc of a circle. To do this work requires considerable patience and practice. First, draw the vertical center line as shown at C in Fig. 201, then, draw horizontal lines for the horizontal letters. The radii of the arcs depend upon the general

arrangement of the entire title, and this is a matter of taste. The difference between the arcs should equal the height of the letters. After the arc is drawn, the letters should be sketched in pencil to find their approximate positions. After this is done, draw radial lines from the center of the letters to the center of the arcs. These



Fig. 201. Sample Title

lines will be the centers of the letters, as shown at *A*, *B*, *D*, and *E*. The vertical lines of the letters should not radiate from the center of the arc, but should be parallel to the center lines already drawn; otherwise the letters will appear distorted. Thus, in the letter *N*

SAFETY STOP VALVE

Fig. 202. Sample Title

the two verticals are parallel to the line *A*. The same applies to the other letters in the alphabet. In making the curved letters such as *O* and *C*, the centers of the arcs will fall upon these center lines; and if the compasses are used, the lettering is a comparatively simple matter. In Fig. 202 is shown another title in which all the letters are in horizontal lines.

PLATES

Plates IX to XV, inclusive, are to be drawn by the student for practice in applying the principles of orthographic projection, intersections and developments, isometric and oblique projection, and for practice in lettering. These plates are to be made 11 inches by 15 inches outside, with a margin of $\frac{1}{2}$ inch, making the clear space for the drawing 10 inches by 14 inches. All the plates are to be inked.

PLATE IX

After laying out the border line on the plate, draw a ground line horizontally across the upper part of the plate, 3 inches below the upper border line. On this ground line six figures, spaced as regularly as possible, are to be drawn, as follows:

1. Draw the projections of a line $1\frac{1}{2}$ inches long which is parallel to both planes, 1 inch above the horizontal, and $\frac{3}{4}$ inch from the vertical.

2. Draw the plan and elevation of a line $1\frac{1}{2}$ inches long which is perpendicular to the horizontal plane and 1 inch from the vertical. Lower end of line is $\frac{1}{2}$ inch above *H*.

3. Draw the projections of two intersecting lines: one 2 inches long to be parallel to both planes, 1 inch above *H*, and $\frac{3}{4}$ inch from the vertical; and the other to be oblique to both planes and of any desired length.

NOTE. The idea for drawing the three figures referred to in 1, 2, and 3 can be obtained from Figs. 104 and 105 in this textbook.

4. Find the true length of a line whose vertical projection is $1\frac{1}{4}$ inches long, the left end on the ground line and inclined at 30 degrees. The horizontal projection has the left end $\frac{1}{2}$ inch from *V*, and the right $1\frac{1}{2}$ inches from *V*.

5. Find the true length of a line whose horizontal projection is 1 inch long, whose right end is $\frac{1}{2}$ inch above the ground line, and inclined at 60 degrees. The vertical projection has the right end $\frac{1}{2}$ inch below the ground line and the left 1 inch.

6. Find the true length of a line whose projections are perpendicular to the ground line. The horizontal projection is 2 inches long, the bottom end being $\frac{1}{2}$ inch above the ground line. The vertical projection is 1 inch long, the top end being $\frac{1}{2}$ inch below the ground line.

NOTE. The idea for drawing the figures referred to in 4, 5, and 6 can be obtained from Figs. 120 and 121 in this textbook.

In the lower half of the plate, four more figures are to be drawn, also spaced as regularly as possible, so that the finished plate will be well balanced:

7. Draw the plan and elevation of a round bolt with a square head. The head is to be uppermost in the elevation. The bolt

is to be 2 inches long and $\frac{1}{2}$ inch in diameter. The head is to be $\frac{3}{4}$ inch square, $\frac{1}{4}$ inch thick, and have one face parallel to V .

8. Draw the plan and elevation of a round bolt having the same dimensions as in 7, but with a hexagonal head; the head to be uppermost in the elevation, and to be $\frac{3}{4}$ inch in width between faces $\frac{1}{4}$ inch thick, and to have one face parallel to V .

9. Draw the plan and elevation of a cylinder, perpendicular to H , 2 inches high and 2 inches in diameter, with a hole 1 inch in diameter passing vertically completely through it.

10. Draw the plan, elevation, and end view of a rectangular block 6 inches long, 2 inches wide, and 1 inch thick. One of the 2 inch by 6 inch sides is to be parallel to H . The right end is turned down to a cylindrical form 1 inch in length and 1 inch in diameter.

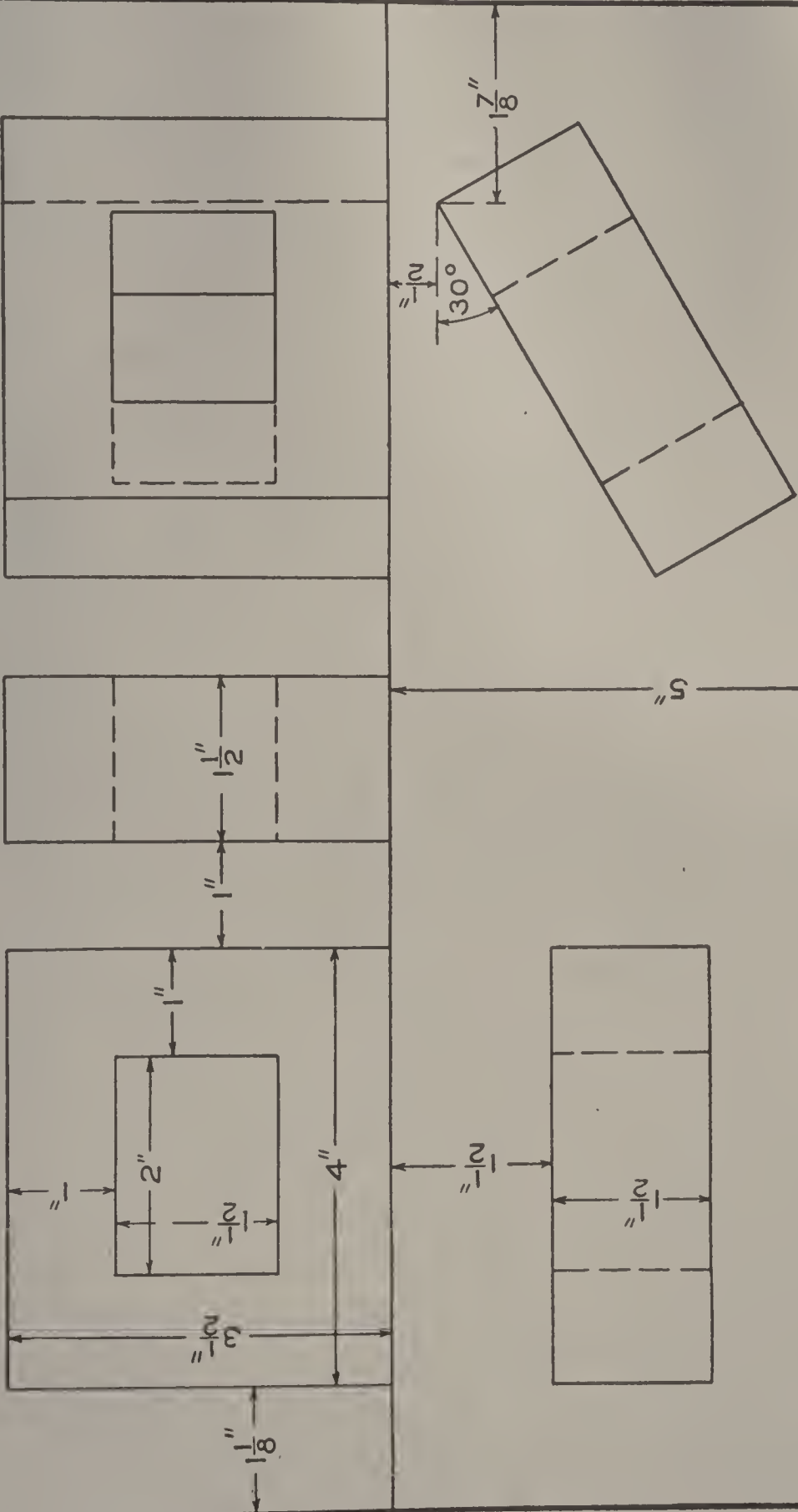
In all the work of this plate, construction lines should be fine dotted lines and should be inked in.

PLATE X

The figures on the reproduced Plate X on the opposite page give the outline of the work that is to be completed by the student. The dimensions given on this plate are to be used in working out the problem, but are not to appear on the finished plate. The first figure shown represents a rectangular block with a rectangular hole cut through from front to back. The other two figures represent the same block in different positions. In drawing these figures, the student must put in all construction lines in order to show how each view is obtained.

After completing the construction of the views as shown, the projection of four holes, $\frac{1}{2}$ inch in diameter each, are to be drawn. One hole passes through the center of each end, and one hole through the center of each side. All these small holes pass completely through to the large hole in the center of the block. Next, put two square projecting pieces on the front face of the block, on the center line, $\frac{1}{2}$ inch from each end. These projecting pieces are to be $\frac{1}{2}$ inch square and $\frac{1}{4}$ inch deep.

The projections of the four small holes and two projecting pieces are to be drawn in all views in the conventional manner, and the necessary construction lines for this work are to be left on the plate and inked in.



HERBERT CHANDLER, CHICAGO, ILL.

FEBRUARY 20, 1916.

PLATE XI

At the left of this plate draw the plan, front and side views of the monument shown in elevation on reproduced Plate XI on the opposite page. The total height of the monument is 6 inches. All four sides are alike except that the width of the base is 2 inches and the depth $1\frac{1}{2}$ inches, and the width of the body of the monument is $1\frac{1}{2}$ inches and the depth 1 inch. The height of the base is $\frac{1}{2}$ inch, of body 3 inches, and the faces just above the base have a slope of 60 degrees with the horizontal. The width of the ridge at the extreme top of the monument is 1 inch.

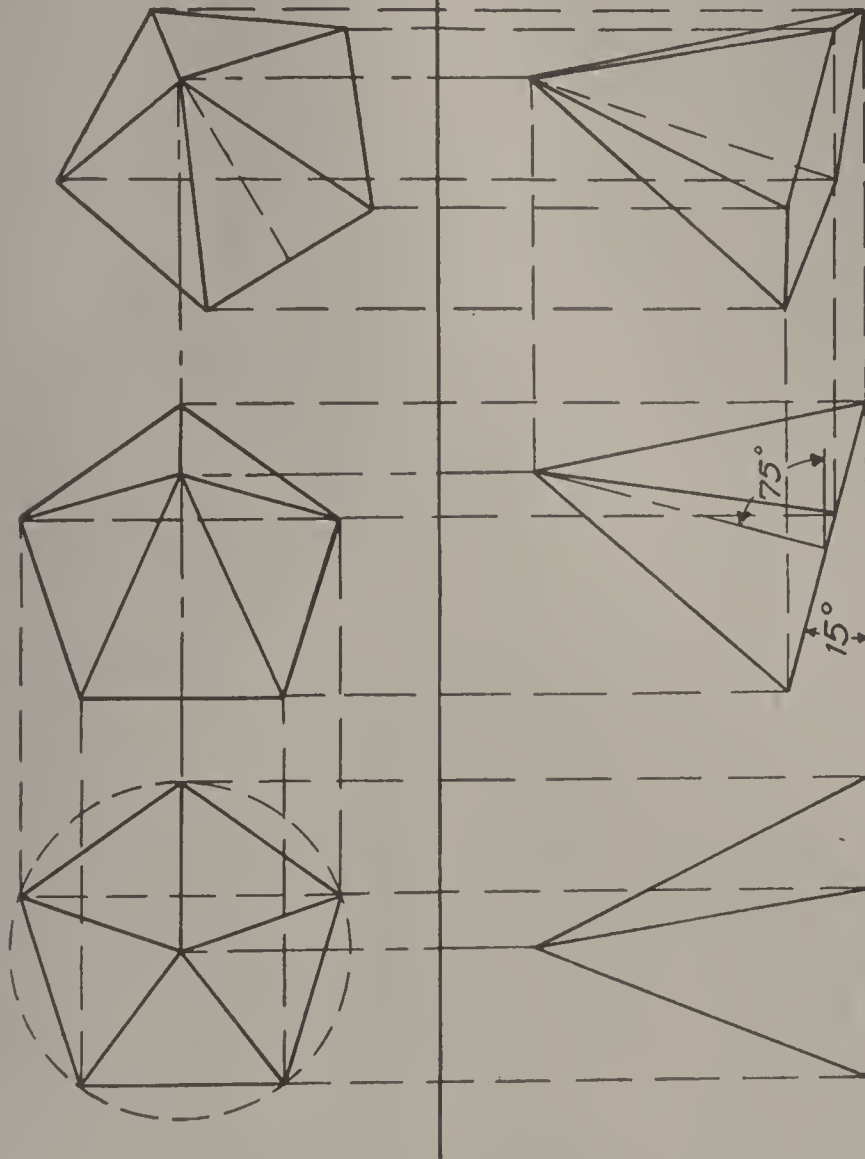
The figures for the right side of the plate represent a pentagonal pyramid in three positions. The first position is the pyramid with the axis vertical. The height of the pyramid is $2\frac{1}{2}$ inches, and the diameter of the circle circumscribed about the base $2\frac{1}{2}$ inches. The center of the circle is 6 inches from the left margin and $2\frac{1}{2}$ inches below the upper border line. Spaces between figures to be $\frac{1}{2}$ inch.

In the second figure the pyramid has been revolved about the right-hand corner of the base as an axis, through an angle of 15 degrees. The axis of the pyramid, shown dot and dash, is therefore at 75 degrees. The method of obtaining 75 degrees and 15 degrees with the triangles was shown in Part I. From the way in which the pyramid has been revolved, all angles with V must remain the same as in the first position; hence the vertical projection will be the same shape and size as before. All points of the pyramid remain the same distance from V . The points on the plan are found on T-square lines through the corners of the first plan and directly above the points in elevation. In the third position the pyramid has been swung around, about a vertical line through the apex as axis, through 30 degrees. The angle with the horizontal plane remains the same; consequently the plan is the same size and shape as in the second position, but at a different angle. Heights of all points of the pyramid have not changed this time, and hence are projected across from the second elevation.

PLATE XII

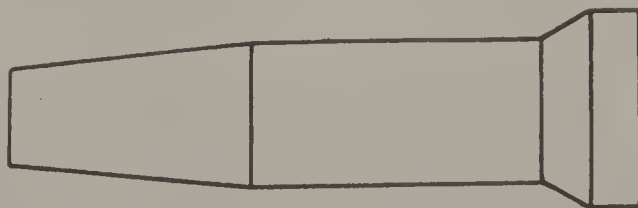
DEVELOPMENTS

On this plate draw the developments of a truncated octagonal prism, and of a truncated pyramid having a square base. The



PLAN
HERE

SIDE ELEVATION HERE



arrangement on the plate is left to the student; but it is suggested that the truncated prism and its development be placed at the left,

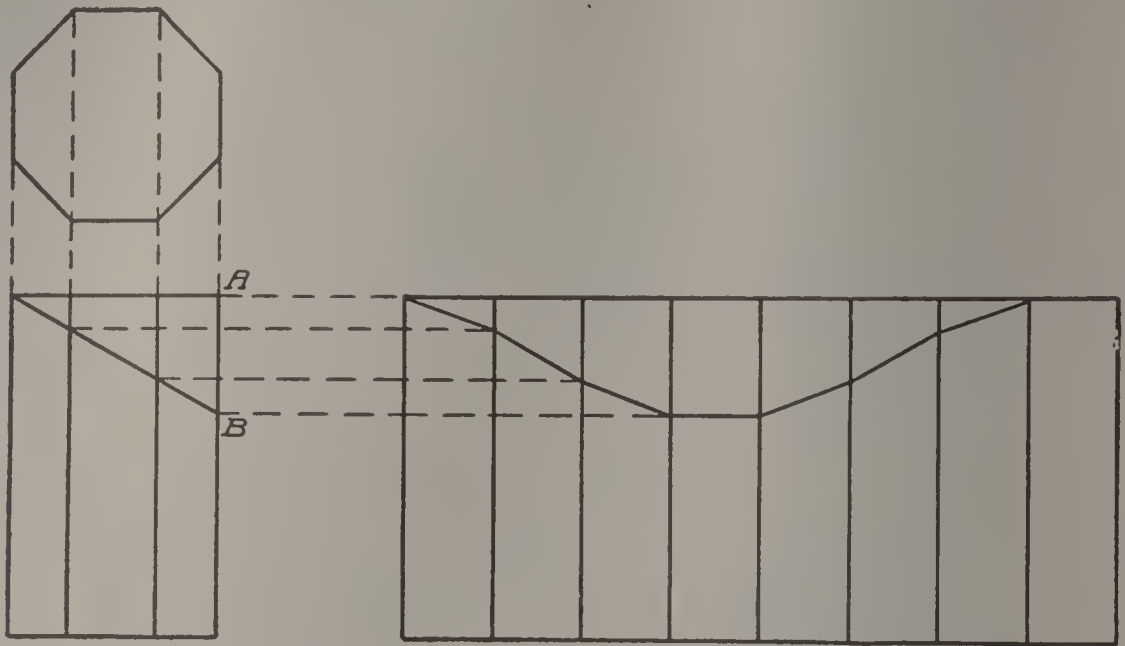


Fig. 203. Plan, Elevation, and Development of an Octagonal Prism

and that the development of the truncated pyramid be placed under the development of the prism; the truncated pyramid may be placed at the right.

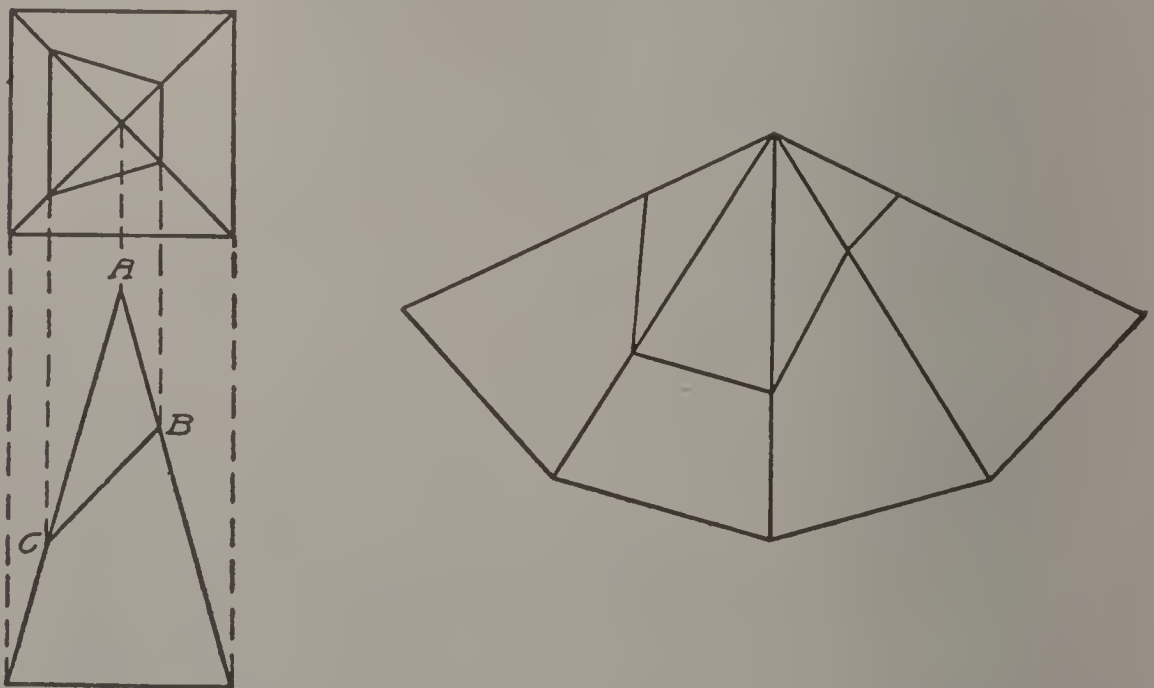


Fig. 204. Plan, Elevation, and Development of a Square Pyramid and Cutting Plane

The prism and its development are shown in Fig. 203. The prism is 3 inches high, and the base is inscribed in a circle $2\frac{1}{8}$ inches in diameter. The plane forming the truncated prism is passed as indicated, the distance AB being 1 inch. Ink a sufficient number of construction lines to show clearly the method of finding the development.

The pyramid and its development are shown in Fig. 204. Each side of the square base is 2 inches, and the altitude is $3\frac{1}{2}$ inches. The plane forming the truncated pyramid is passed in such a position that AB equals $1\frac{3}{8}$ inches, and AC equals $2\frac{1}{2}$ inches. In this figure the development may be drawn in any convenient position, but in the case of the prism it is better to draw the development as shown. Indicate clearly the construction by inking the construction lines.

PLATE XIII

ISOMETRIC AND OBLIQUE PROJECTION

In the upper left quarter of this plate draw the isometric projection of the block which is shown on reproduced Plate X, page 137, taking the dimensions from your finished Plate X. The idea for this problem can be obtained by referring to Fig. 158 in this textbook.

In the upper right quarter of this plate draw the isometric projections of the two round bolts described in 7 and 8 of Plate IX, taking dimensions from your finished Plate IX.

In the lower half of this plate draw, at 45 degrees, the oblique projections of the cylinder and the rectangular block, described in 9 and 10 of Plate IX, taking dimensions from your finished Plate IX. The idea for this can be obtained by referring to Figs. 175 and 179 in this textbook.

PLATE XIV

FREE-HAND LETTERING

On account of the importance of free-hand lettering, the student should practice it at every opportunity. For additional practice, and to show the improvement made since completing Part I, lay out Plate XIV in the same manner as Plate I, and letter all four rectangles. Use the same letters and words as in the lower right-hand rectangle of Plate I.

PLATE XV

LETTERING

First lay out Plate XV in the same manner as previous plates. After drawing the vertical center line, draw light pencil lines as

PLATE XV

COURSE
IN
MECHANICAL DRAWING
AMERICAN SCHOOL
OF
CORRESPONDENCE
CHICAGO, ILL., U.S.A.

MAR. 16, 1916.

HERBERT CHANDLER,

CHICAGO, ILL.

guide lines for the letters. The height of each line of letters is shown on the reproduced plate. The distance between the letters should be $\frac{1}{2}$ inch in every case. The spacing of the letters is left to the student. He may facilitate his work by lettering the words on a separate piece of paper, and finding the center by measurement or by doubling the paper into two equal parts. The styles of letters shown on the reproduced plate should be used.

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