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NOTES ON MECHANICAL DRAWING

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A SUPPLEMENT TO THE DRAWING COURSES
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Drawing is a medium of expression necessary to the engineer. By its use he is enabled to present the details of his ideas far more effectively than could be done by description in words. In fact, it would be an almost hopeless undertaking to attempt the written description of a complicated machine so that it could be accurately reproduced by a workman.

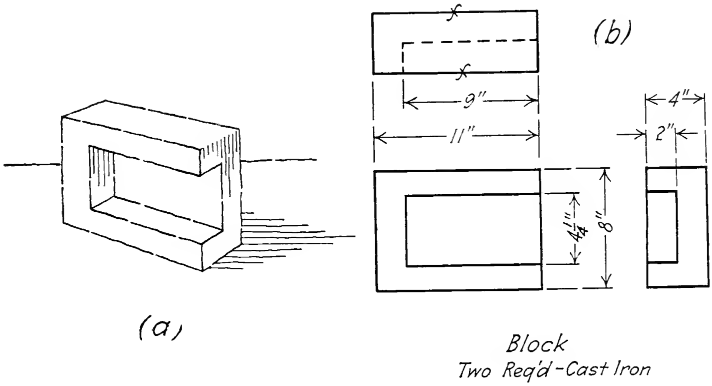


Fig. 1.—An artist's sketch (a) and a working drawing (b).

An artist's sketch (Fig. 1a) is of value in presenting general ideas, but the demands made on the technical draftsman are much more exacting. He must show with mathematical exactness the shape and the size of each piece he wishes to represent, and frequently the accurate relation of various parts of a complicated machine or structure. To accomplish this he usually makes what are termed "working drawings" or "mechanical drawings." Each of these (Fig. 1b) consists of a set of two or more different views of the machine or structure, arranged in accordance with a definite system generally understood by engineers, and with the necessary lines and figures added to show the size and shape of its parts.

Such drawings are usually made to scale and executed with drafting instruments. Strictly speaking, all drawings made with instruments may be termed mechanical drawings, but the term is generally taken to refer to engineering or working drawings. The technical draftsman represents by means of outline drawing, making little or no use of shading to represent depth or relief.

The ability to read drawings is vital to all connected in any way with technical industry, while the added ability to execute such drawings neatly and quickly is as essential to an engineer as is a knowledge of practical mathematics.

Requirements of a Good Draftsman.—A good draftsman is neat and accurate and works rapidly. Neatness in drafting includes the arrangement and finish of line work and lettering, as well as cleanliness. Accuracy can be attained by care in the use of the scale and by keeping pencil points and drafting instruments in proper condition. Speed is desirable up to the point where it conflicts with neatness and accuracy. It may be attained by systematic procedure in all routine operations.

Drawing Instruments and Materials

Selection of Drawing Instruments.—The beginner is cautioned against the common error of purchasing cheap tools, as this is mistaken economy. A satisfactory quality of materials and workmanship necessarily means increased cost over inferior instruments which are worthless for accurate work and expensive at any price. There is usually enough to occupy the mind of a beginner without the perpetual annoyance attending the use of poor tools.

The assistance and advice of an experienced draftsman will prove valuable in the selection of drafting instruments and supplies, as the differences in material and workmanship are usually not readily apparent to one not accustomed to handling them. Small variations from the sizes given in the suggested list are permissible.

The Necessary Outfit.—The following instruments and materials will be required by the student:

- Set of drawing instruments, including:
  - Compasses (6-inch) with extension bar, fixed needle-point, and removable pen and pencil-points.
  - Dividers ($5\frac{1}{2}$-inch)
  - Ruling pen (5-inch)
  - Bow pencil
  - Bow pen
  - Bow dividers
- Drawing board (16″x22″)
- T-square (24-inch)
- Triangle (45°, 6-inch)
- Triangle (30°-60°, 9-inch)
- French curve
- Architects' scale (12-inch, triangular)
- Engineers' scale (12-inch, triangular)
- Thumb tacks
- Drawing pencils (H and 3H)

Drawing paper (11″x15″ sheets, white)
Pencil eraser (Fabers "Ruby," No. 112, or equivalent)
Cleaning eraser (or "Art-Gum")
Pencil pointer (6-inch flat single-cut file, or sand-paper block)
Drawing ink (Black, waterproof)
Penholder and lettering pens (See chapter on lettering)
Dusting brush or cloth
Penwiper
Erasing shield

Drawing Board.—Drawing boards are made of soft wood, usually white pine or basswood, free from knots and with the upper surface dressed to a true plane surface. To prevent warping they are made of narrow strips of wood glued together, commonly with their ends set into end pieces (Fig. 2a). Large boards should be provided with

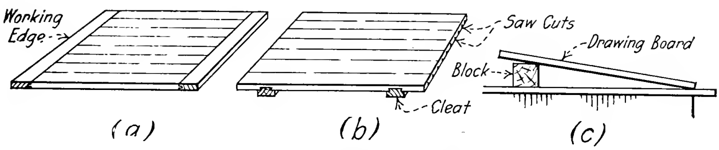


Fig. 2.—Drawing Boards.

cleats so fastened that the wood of the board is free to expand or contract. Saw cuts made with the grain and part way through the board from the back (Fig. 2b) further reduce any tendency to warp.

The working edge, along which the head of the T-square is operated, must be smooth and straight. This edge should be marked for easy identification, and always kept at the left of the draftsman.

It is convenient to raise slightly the far edge of the board by means of a suitable block (Fig. 2c), but the inclination should not be enough to cause the T-square to slide down or pencils to roll. Large drawing boards are often supported on wooden horses or folding stands of various sorts.

Large drawings are frequently tacked directly to the drawing tables instead of to separate boards which are expensive and awkward to handle in large sizes. Such tables have tops of soft wood, these being either horizontal or adjustable as to inclination.

Some draftsmen find it convenient to keep either the far or the near edge of the drawing board straight and at right angles with the working edge, so that long vertical lines may be drawn with the aid of the T-square. This is not good practice except for lines (such as border lines) which do not affect the accuracy of the drawing itself.

T-Square.—The T-square (Fig. 3b) consists of a thin blade rigidly attached to a head, preferably at right angles with its working edge. While commonly made of wood, they are also obtainable with steel blades and cast-metal heads. Wood blades with transparent celluloid edges (Fig. 3d) are popular.

There are two working edges (Fig. 3b)—the sliding edge on the head and the drawing edge on the blade. While the lower and upper edges of the blade are usually parallel, the lower edge should not be used as a working edge. The drawing edge serves as a guide in drawing horizontal lines (the pencil moving to the right as indicated in Fig. 4), and as a support for the triangles.

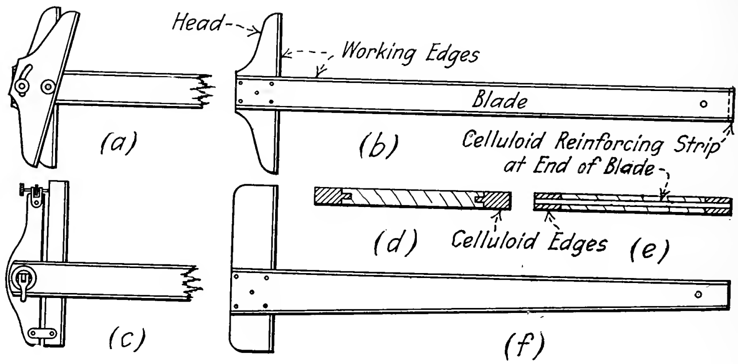


Fig. 3.—T-squares.

Either an extra swivel head (Fig. 3a) or an adjustable blade (Fig. 3c) are convenient in work involving many parallel lines at odd angles. The micrometer screw in the head of the latter style offers a convenient means of trueing up the blade to agree with the drawing.

T-squares with long blades are best made in the "English" pattern (Fig. 3f) with the blade widest near the head, and the head with its greater portion above the working edge of the blade. This style has a good balance and a longer lever arm to hold the blade in position.

Drawing boards or tables may be fitted with some one of the various parallel-blade attachments, and the necessity of using a T-square thus done away with. These are combinations of strings, wires, pulleys and clamps so arranged as to keep the blade at all times parallel to its original position as it is moved up or down by the draftsman.

Triangles.—Drafting triangles are made of wood, hard rubber, celluloid or steel. Those constructed of wood are clumsy, soon become inaccurate due to loosened joints or warping, and are easily damaged. They have the advantage of being light and cheap, but are no longer in common use.

Hard-rubber triangles, while light and relatively cheap, are brittle and easily chipped or broken. Steel triangles are accurate, but they are expensive, apt to soil or cut the drawings, and easily tarnished.

Celluloid triangles are almost universally used at the present time.

They are light, strong, flexible, nearly transparent, easily trued up, and show little tendency to warp if properly cared for.

The 45° and the 30°-60° triangles are used separately along the upper edge of the T-square as indicated in Fig. 5. Lines are correctly

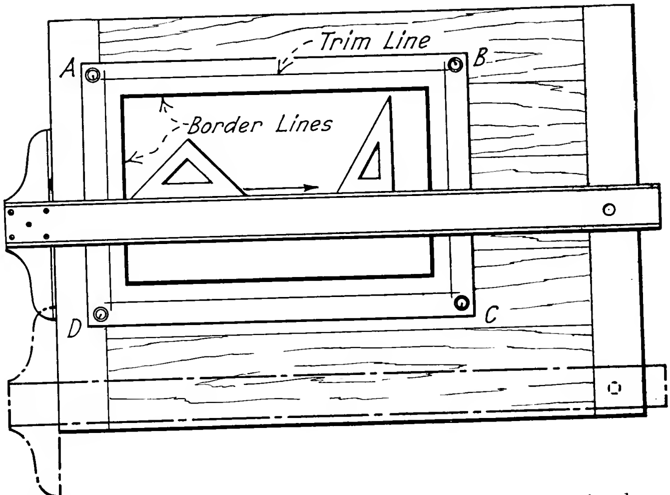


Fig. 4.—Relative positions of drawing board, T-square and triangles.

drawn along the triangles only in the directions indicated by the arrows—that is, always away from the body and to the right. The lines which may be drawn with the 30°-60° triangle are shown combined in Fig. 5j and those with the 45° triangle in Fig. 5k. The triangles may also be used in combination (Fig. 6) to obtain lines at 15° and 75° with the horizontal and the vertical.

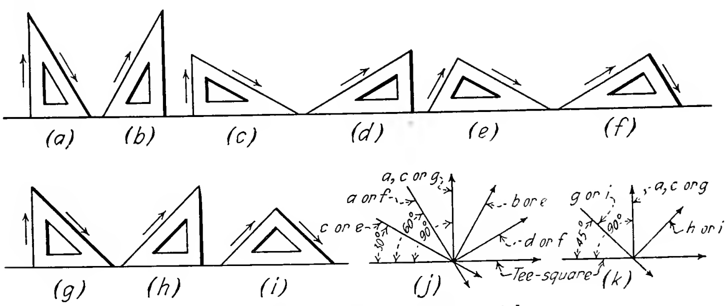


Fig. 5.—The triangles used separately.

Lines parallel to any given line may be drawn conveniently by bringing one edge of a triangle to coincide with the line, and then placing

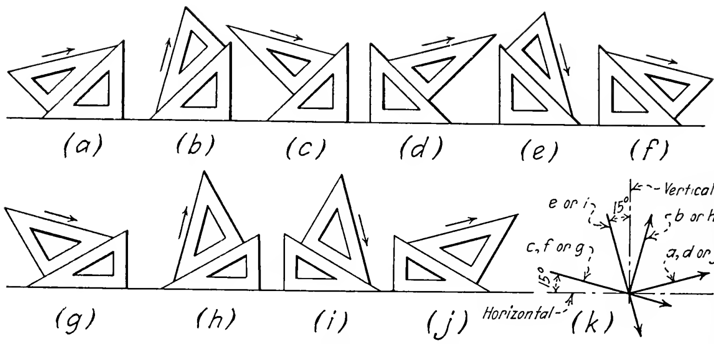


Fig. 6.—The triangles used in combination.

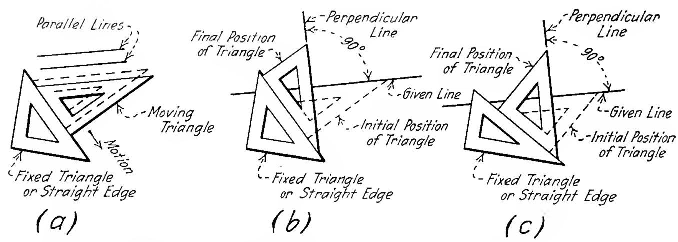


Fig. 7.—Drawing parallel and perpendicular lines with the triangles.

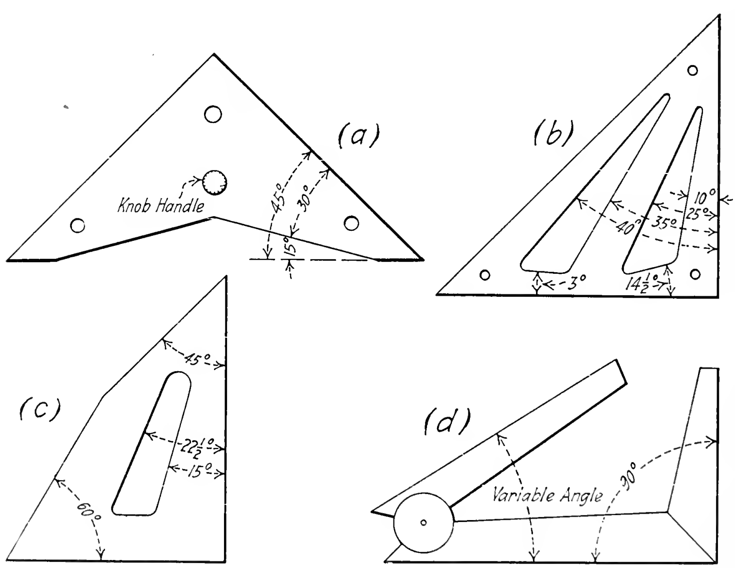


Fig. 8.—Some special triangles.

the other triangle or any straight-edge against either remaining edge of the first triangle (Fig. 7a). The second triangle is held fixed for the first to slide along to the desired position. The correct method of drawing a line perpendicular to any given line consists in bringing the hypotenuse of either triangle to coincide with the given line, the other triangle or a straight edge being placed in a fixed position in contact with the first (Figs. 7b and 7c). The first triangle is then reversed and the line drawn along the new position of its hypotenuse.

Several special triangles have been devised to take the place of the two standard triangles. The "Kelsey" triangle (Fig. 8a) is a very convenient instrument, and may be obtained with the under face graduated as a protractor. The "Zange" triangle (Fig. 8b) is designed to permit drawing all the 5-degree angles from 5° to 90°. The "Rondinella" triangle (Fig. 8c) combines the angles of the ordinary triangles with the addition of the 67½° and 22½° angles. An adjustable angle (Fig. 8d) is an inexpensive instrument and a decided convenience on odd-angle work.

Drawing Paper.—Drawing paper may be purchased in a large variety of qualities, tints, and surfaces, either in sheets or in rolls. The best hand-made paper is made in sheets only, and in the sizes listed in the following table. The symbol (*) indicates the sizes commonly obtainable in sheet papers.

Cap	13″x17″	Super Royal	19″x27″
Demy	15″x20″	*Imperial	22″x30″
Medium	17″x22″	*Double Elephant	27″x40″
*Royal	19″x24″	Antiquarian	31″x53″

Manilla papers of buff tints in sheets or in rolls are very commonly used for detail drawings intended to be traced on cloth for blueprinting. White papers of smooth surface are desirable for drawings that are to be inked.

A sheet of drawing paper correctly placed on the drawing board (Fig. 4) should be near the working edge of the drawing board so as to utilize the most rigid part of the T-square blade, and should be kept well away from the lower or near edge of the board in order to avoid the necessity of using the T-square in the extreme position indicated by dash and dot lines (Fig. 4). In this position it is apt to be unsteady, as the corner of the board is usually worn and inaccurate, and as only about half of the head bears against the board.

To fasten the sheet of paper to the board, a tack is first placed at "A." The T-square is then moved to the upper edge of the paper and this edge swung into line by grasping the paper at "C." A tack is placed at "C" and the sheet stretched slightly by pushing toward "B" and "D" with the palm of the hand, tacks being placed at these corners in turn. Thumb-tack holes should be kept outside of the trim lines (Fig. 4) of the finished drawing.

Thumb Tacks.—The drawing paper is fastened to the board or table by means of thumb tacks. The better grades are made of brass, German-silver or steel, usually with sharp, steel pins riveted or screwed into the heads (Figs. 9a and 9b). They should be thin, especially at the edges, so as to offer little obstruction to the T-square, and should be so constructed that the pins will not push through.

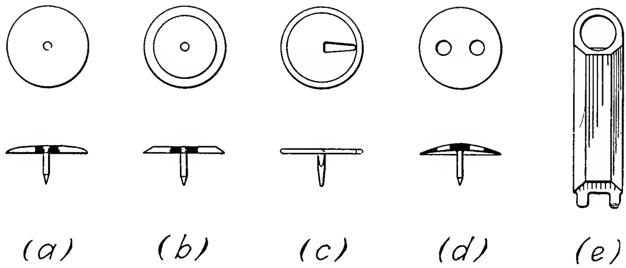


Fig. 9.—Thumb tacks.

A cheap and widely-used style of thumb tack (Fig. 9c) has the head and the point punched from the same piece of soft steel. The "Universal" tack (Fig. 9d) is turned from one piece of steel to a very thin edge. To protect the edge this tack is removed by a special puller (Fig. 9e). Tacks should be pushed straight into the board so as to present the minimum obstacle to the T-square.

Drawing Pencils.—Drawing pencils are manufactured in various degrees of hardness grading from very hard to very soft as follows: 9H, 8H, 7H, 6H, 5H, 4H, 3H, 2H, H, F, HB, B, 2B, 3B, 4B, 5B, 6B.

Considerable variation may be found in comparing the hardness of the same grades in different brands. The proper degree of hardness depends upon the surface of the paper, the atmospheric conditions, the nature of the work and the whim of the draftsman. It is advisable to use the softest pencil that can be made to do satisfactory work, as the resulting drawings are clearer and easier to ink or trace, while erasures and changes are easier to make than when the pencil is so hard as to cut into the surface of the paper.

Drawing pencils are usually made without eraser tips, and hexagonal to prevent rolling. They may be sharpened either to a long conical point or a flat chisel point. The chisel point has certain advantages in penciling lines where accuracy is especially desired, as the wear is so distributed as to lessen the need for frequent sharpening, and as the point can be kept close against the straight edge.

The conical point is generally preferred and its use is recommended. Such a point is easily and quickly formed and is suitable for lettering and general use as well as for line work. Ordinary pencil sharpeners can be used, though they give rather too short a bevel for drafting purposes. The wood should be cut away at a uniform taper to a distance of about $1\frac{1}{4}''$ from the point so as to leave about $\frac{3}{8}''$ of lead to be tapered to a uniform conical point. Carefully sharpened pencils are a necessity in neat and accurate drafting.

The conical point can be handled with a minimum amount of sharpening if inclined about 45° (Fig. 10a) so that wear comes on the side of the point. Then, if the pencil is rotated in the fingers as lines are ruled, this wear will be evenly distributed on all sides of the point. The pencil point should be kept close into the angle formed by the paper and the vertical face of the guiding straight-edge (Fig. 10a).

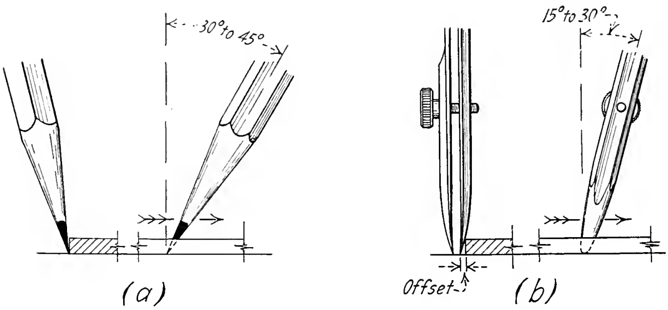


Fig. 10.—Ruling positions for drawing pencil and pen.

Neatness and speed in penciling may best be obtained by doing all blocking out in **very lightly** penciled lines. These lines are necessarily indefinite in length. As soon as the necessary intersections are obtained, the portions of these lines needed are strengthened by tracing over with more pressure on the pencil. **Do not** erase the light lines not needed. If drawn lightly they will not be distinct enough to confuse the drawing. The less erasing that is done, the more rapid and neat will be the drafting.

Erasers.—Erasers are needed by the draftsman for cleaning and for erasing. Cleaning rubber is very soft, and may be used to clean inked drawings without injury to the inked lines. Art gum, although "mussy," is frequently used for this purpose.

The so-called ink erasers should have no place in the draftsman's outfit, as their use results in injury to the surface of the paper or tracing cloth, making it impracticable to ink over the erased portion neatly. Ink lines are best removed by the use of a pencil eraser (such as Faber's "Ruby" No. 112), as these erasers (while slower) leave the surface of the drawing in good condition.

In an emergency a sharp pen-knife may be used as a preliminary operation in erasing ink lines, but this practice is not a good one, as the surface of the drawing is almost invariably injured.

Pencil Pointer.—Pencil pointers are used to sharpen accurately the lead of the drafting pencil. The usual type is a small block built up of sheets of fine sandpaper, but a small flat file is better.

Erasing Shield.—An erasing shield (Fig. 11) is a very thin piece of sheet metal, celluloid or cardboard, having various small openings of

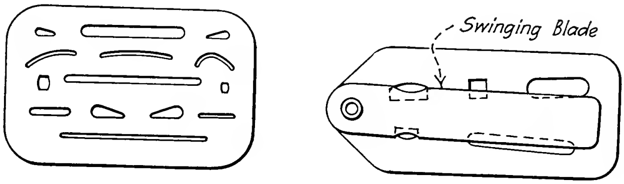


Fig. 11.—Erasing shields.

different sizes and shapes. In use it is so placed on the drawing as to confine the erasure to the part to be erased.

Ruling Pen.—Ink lines of uniform thickness are obtained by the use of a ruling pen moved in contact with the edge of a straight-edge,

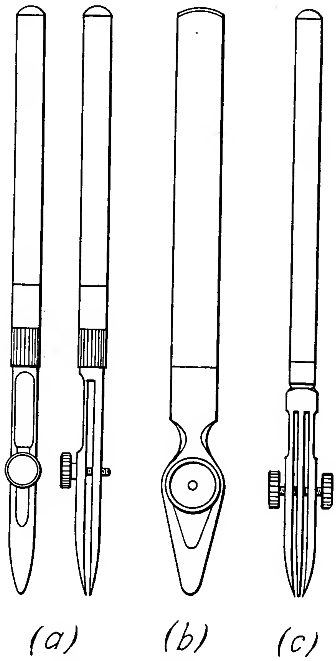


Fig. 12.—Ruling pens.

triangle or French curve. The usual pattern is indicated in Fig. 12a, both a front and side view being shown.

When the spring-blade is released such a pen will open as shown in

Fig. 13a. Various quick-opening devices which facilitate the cleaning of the pen nibs are shown in Fig. 13 (b to g, inclusive). Each style has certain merits and each is more apt to get out of order than is the plain pen.

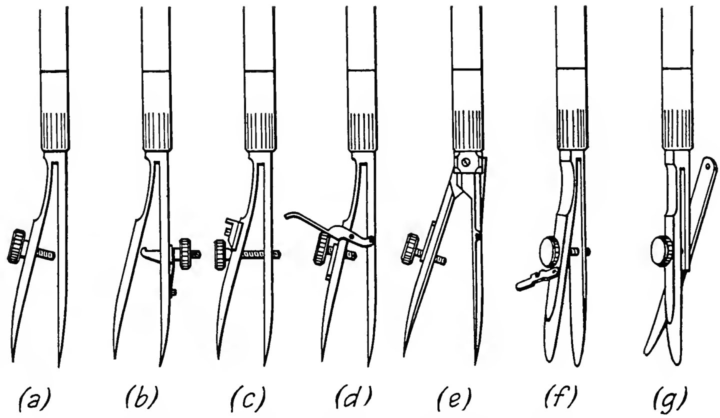


Fig. 13.—Various ruling pens opened for cleaning.

The width or weight of the line produced depends on the distance between the nibs or points, this distance being adjusted by the thumb screw. The pen should be held in a vertical plane containing the line being ruled, and with the top inclined in the direction of motion (Fig. 10). There should be a space between the ruled line and the edge of the straight edge. This offset (Fig. 10b) is necessary to prevent blotting the ruled lines, as the ink will run under the ruling edge if allowed to come into contact with it. Lines are ruled with a free-arm movement with the finger tips resting on the T-square blade. When near the end of the line the hand is stopped and the balance of the line ruled with a finger movement.

To give good results the points or nibs of the ruling pen must be kept sharp. If the worn ends are easily visible when held up to the light the pen should be sharpened. This process includes two operations. The nibs are screwed together till they touch, and the ends re-shaped on a fine oilstone by a motion as of ruling lines backward and forward. This dulls the ends of the nibs. The nibs are then separated, and each brought to a thin invisible edge by carefully rubbing the outside surface of each nib on the oilstone.

Due to its larger ink capacity the "detail" or "Swedish" type of ruling pen (Fig. 12b) is of value in inking long and heavy lines. Extra-heavy lines may be ruled with little danger of blotting with a pen having a central nib (Fig. 12c) which increases the capillary capacity for ink without interfering with the action of the outside nibs which define the width of the line ruled.

Ruling pens are filled with ink by inserting the quill of the ink bottle between the nibs, care being taken to see that no ink is on the outside of the nibs.

Dividers.—Three types of dividers or "spacers" in common use are illustrated in Fig. 14. In addition to the original pattern (14g) are shown the cylindrical (14h) and the "Richter" pattern (14i), the distinguishing features of the latter being the flattened legs and the easily interchangeable points. This instrument requires good workmanship in that the pivot joint must work smoothly and with uniform friction, while the points must be long, sharp and of equal length.

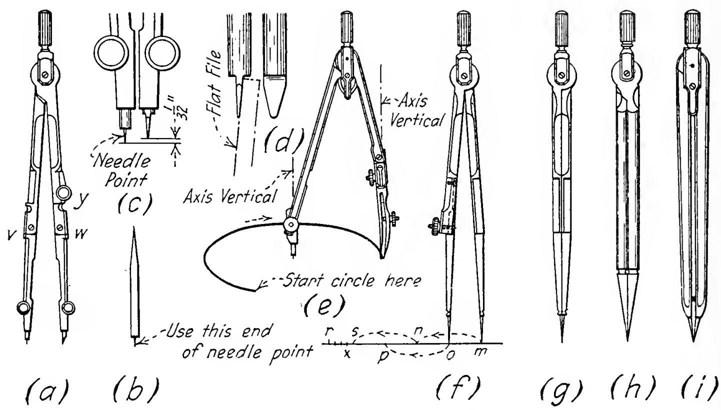


Fig. 14.—Compasses and dividers.

Dividers are used (1) for transferring unmeasured lengths or distances from one part of the drawing to another, (2) for stepping off any number of equal spaces and (3) for dividing any given length of line into a required number of equal spaces.

The second use should be avoided, where possible, due to the multiplication of any slight error made in setting the instrument to the required distance. If possible to scale off the distance first and then subdivide (the last use mentioned), this error will be eliminated. As an illustration of the method of subdivision let it be required to divide the line **rm** (Fig. 14f) into four equal parts. The dividers are set to a trial spacing **om** and the legs swung alternately in opposite directions, as indicated, until point **s** is reached. The total error is the distance **rs**, and the error of setting is one-fourth of this, or **xs**. The correct setting, then, is **xp**. The dividers should be set to this distance as accurately as possible and the operation repeated until the setting is proven correct by actual trial, when small punctures may be made in the paper to indicate these divisions.

Great care should be taken not to dull, bend or break the points of this instrument, as its value depends on their condition. When neces-

sary to sharpen them the outside surfaces of the points should be rubbed on a fine oilstone.

Compasses.—The large compasses are used for drawing circles and circular arcs in pencil or ink, and are made in the same styles as the dividers. In the ordinary style (Fig. 14a) the pencil-point may be released by the clamp screw at **y** and replaced by a pen-point or leg, as has been done in the "Richter" type (Fig. 14e). Always use the shoulder end of the needle point (Fig. 14b), adjusting it as indicated in Fig. 14c. A good style of flat point for the compass lead (Fig. 14d) is readily formed with the aid of a small flat file.

When in use the two legs of the compasses should be bent at the joints **v** and **w** (Fig. 14a) to a vertical position, as illustrated in Fig. 14e. This avoids any unnecessary enlargement of the puncture made by the needle point, and also permits the nibs of the pen to bear evenly on the paper.

Bow Instruments.—The convenience and increased accuracy obtained by the use of small bow-dividers and compasses make them a necessity to the draftsman. Separate compasses are provided for pen and pencil work—the bow-pen and the bow-pencil. A set of bow instruments of the common type is shown in Fig. 15 (a, b and c).

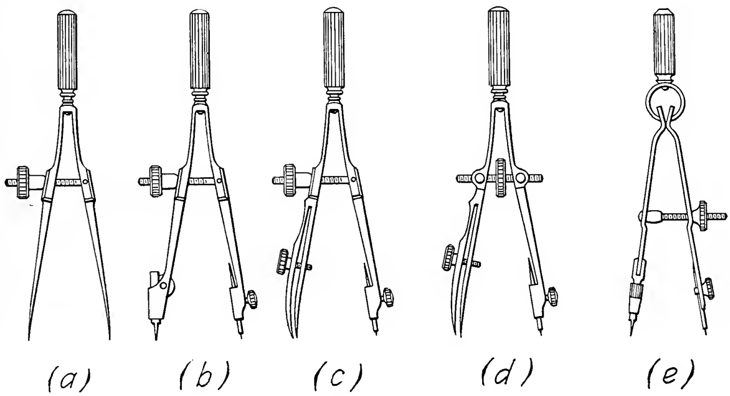


Fig. 15.—Bow instruments.

The advantage of quicker adjustment is claimed for the "center-screw" pattern (Fig. 15d), due to the double travel of the adjusting screw. As a matter of fact this is hardly the case, as the draftsman in changing the setting of the usual type pinches the ends together and spins the adjusting-screw into the approximate position desired, thus saving time and reducing the wear on the screw and threads.

The "hook-spring" pattern (Fig. 15e), if well made, has a somewhat more uniform spring tension, but most draftsmen find the position of the adjusting screw an awkward one.

Scales.—Scales for measuring and laying off distances on drawings are usually constructed of boxwood, preferably with the graduated edges covered with white celluloid. In Fig. 16 are shown cross-sections of the usual types of scales, all but (c) being of wood with or without white edges. The exception mentioned is made of steel and graduated

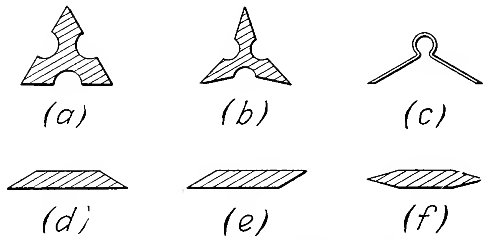


Fig. 16.—Forms of drafting scales.

on the two upper faces. From the standpoint of economy the six-scale faces of (a) and (b) are an advantage, but in use such scales are inconvenient and confusing, as they must be turned more or less to present the desired edge, and as there exists a strong chance for the careless use of the wrong scale.

The "improved" form of the triangular scale (Fig. 16b) presents the edges at a better angle for easy reading but concentrates the wear on the sharp edges of the scale—this soon rendering the scale practically useless. Of the flat shapes (e) is probably the best. It has two scale faces as has (d), but it is easier to pick up and to hold, and has only one scale in view at any time. The form shown at (f) has four scale faces, is convenient to use, and in the 6-inch length is a popular vest-pocket style.

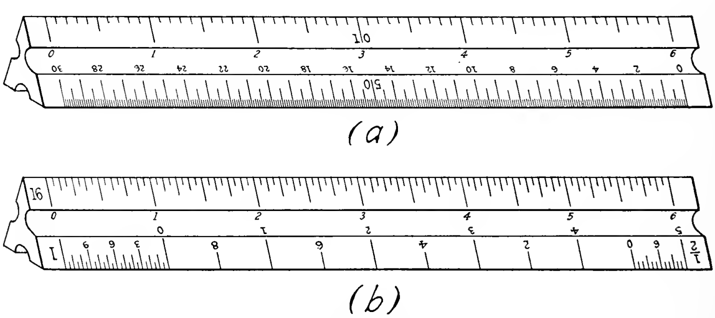


Fig. 17.—Triangular scales.

Scales may be "open" (Fig. 18) or "full" (Fig. 17a) divided. The "civil engineer's" scale (Fig. 17a), used in map drafting and graphical analysis, has inches divided into 10, 20, 30, 40, 50 and 60 equal parts, while the "architect's" or "mechanical engineer's" scale (Fig. 17b) usually carries a natural scale of inches into sixteenths, with the other scales divided into various equal lengths, each being considered as representing a foot and each such length being divided into 12 parts representing inches. Thus, on the lower scale in Fig. 17b, either ½″ or 1″ may be taken as representing one foot on the drawing.

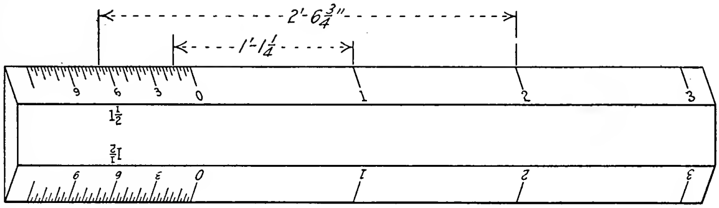


Fig. 18.—Reading a scale.

In Fig. 18 is indicated the method of laying off or reading dimensions with an architect's scale, the scale in use being known as the "inch and one-half scale." This scale is stated on a drawing as 1½″=1′—0″. The terms "half-size" and "quarter-size" are frequently used also, and mean 6″=1′—0″ and 3″=1′—0″, respectively.

French Curves.—French (or "irregular) curves are used to guide the ruling pen in inking non-circular arcs. They are made of wood, hard rubber, or transparent celluloid—the latter material being preferred on account of its transparency, flexibility and durability. They are

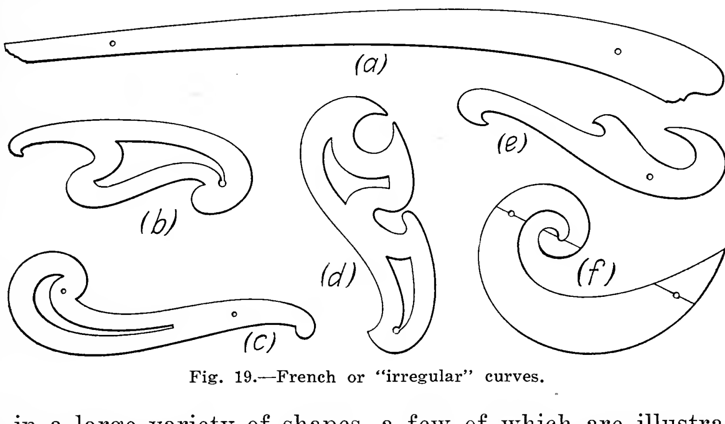


Fig. 19.—French or "irregular" curves.

made in a large variety of shapes, a few of which are illustrated in Fig. 19. The general type known as "ship" curves (a) is frequently valuable on account of the flat curves they carry. A curve of considerable practical value is known as a "logarithmic spiral" (f).

A curved line is usually determined on the drawing by a series of points. A freehand line should be drawn lightly through these points and a suitable part of the French curve fitted carefully to this line so as to contain at least three points. This portion of the line may then be drawn, it being best, however, to stop short of the distance the curve seems to fit. Then the curve is shifted along to include one or more additional points, and the line continued. In inking against a curve the left end should always be inked first, working towards the right. The ink line can be more accurately formed in this way as the junctions are at the left of the pen nibs instead of beneath it.

Drawing Ink.—Most engineering drawings are inked or traced with black India ink of the waterproof variety. This ink was introduced when inked drawings were more generally used, as with ordinary ink a little moisture was apt to smudge a drawing badly. Now that tracings seldom leave the drafting room except for blue printing the use of waterproof ink is not strictly necessary, and some draftsmen prefer to use the "general" drawing ink.

Drawing ink is usually purchased in small bottles equipped with quill or glass fillers attached to the stopper. As drawing ink dries rapidly the stopper should be kept in the bottle except when the pen is being filled.

Dusting Brush.—Every draftsman should have a wide brush to use in quickly freeing his drawing of dust and of the dirty rubber crumbs resulting from erasing. Its use will assist materially in keeping drawings clean. A dusting cloth should also be kept at hand with which to wipe the dust off of the T-square blade and triangles.

Tracing Cloth.—Tracings subject to much handling should be made on tracing cloth, a finely woven fabric so treated as to surface it for the pen and to make it translucent. One side is finished glossy and the other dull. While the glossy side was originally intended for inking, the dull side is now customarily used. Among the reasons for this practice are the facts that the dull side takes ink and especially pencil work better; is less disfigured by erasing; is less trying on the eyes, especially under artificial light; photographs better and lies better on the board. Tracing cloth is made in rolls of 24 yards, and in various widths and qualities.

Before inking on tracing cloth a little powdered chalk or "pounce" should be rubbed into the surface with a chamois skin or the palm of the hand. This removes a slight greasy desposit characteristic of tracing cloth, thus making it take ink more readily. All excess of chalk should be wiped off carefully. Pencil lines (such as guide lines for lettering) may be erased, when the inking is finished, with a soft rubber eraser or with a cloth moistened with benzine. All erasures necessary in connection with ink work should be made with a pencil eraser. A small piece of soapstone may be used to resurface the cloth after an erasure which roughens the surface.

Tracing Paper.—Tracing paper is a thin and tough paper which for work of temporary character is a cheap and satisfactory substitute for tracing cloth. Some of the tougher and thicker papers are used as drawing paper (blueprints being made from the inked drawings), while pencil drawings on the thinner sorts make satisfactory blueprints.

Tracing paper is much used by architects for studies, as changes may be made and studied without erasing the original plan, a new sheet being placed over the original sketch for each change considered.

Extra Instruments

The remainder of this chapter will describe various instruments which, while not essential to the draftsman, are decidedly convenient on certain kinds of work. Most large drafting rooms have, as a part of their equipment, an assortment of the rather unfrequently used instruments—especially those costing more than the average draftsman cares to invest in instruments that are not to be constantly used.

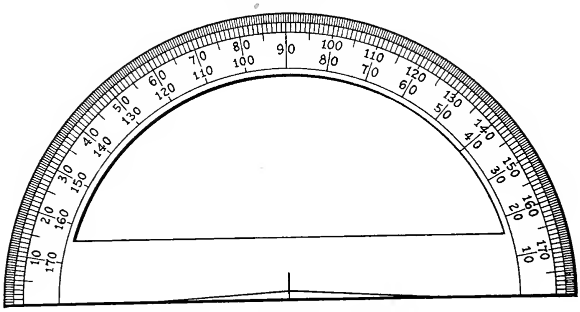
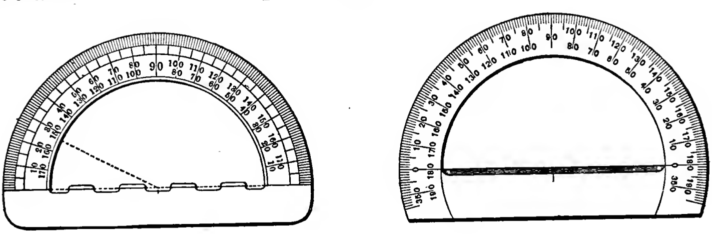


Fig. 20.—Standard protractor.

The beginner should obtain copies of the trade catalogues of firms making drafting and engineering instruments and supplies, and should study these to familiarize himself with the nature of the various devices on the market. Space limitations make it impossible to list and describe all of them in this publication.



(a) (b)

Fig. 21.—Improved protractors.

Protractor.—While not the most accurate method of measuring and laying out angles, the use of a protractor is one of the most convenient. There are many types available, ranging from the common semi-circular type (Fig. 20) to precise instruments equipped with verniers, micrometer screws, and magnifying glasses for close reading. They are usually made of brass or German-silver, but many excellent styles are now being made of heavy transparent celluloid, it being convenient to en-

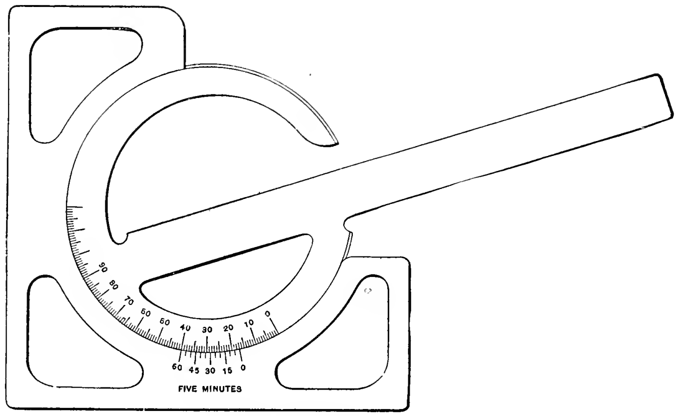


Fig. 22.—Movable-arm protractor.

grave the graduations on the under side so that they are in direct contact with the surface of the drawing. Two improved patterns of the semi-circular type are shown (Fig. 21), as well as a good movable arm

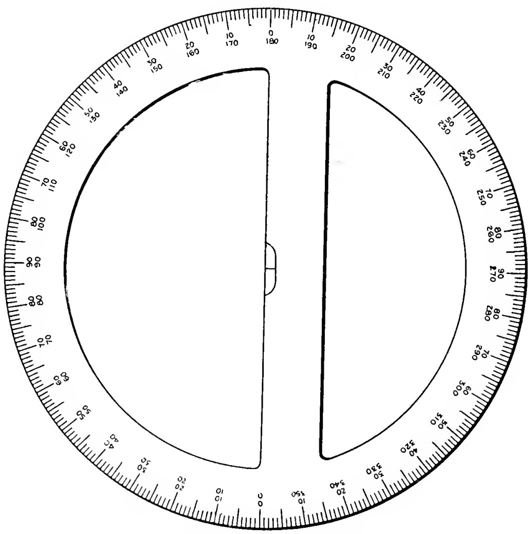


Fig. 23.—Full-circle protractor.

type (Fig. 22) for the mechanical draftsman. In the plotting of surveyors notes the topographical draftsman usually finds the full-circle type (Fig. 23) convenient.

Beam Compasses.—This instrument (Fig. 24) is used when it is necessary to draw circular arcs of greater radius than are possible with the ordinary compasses using an extension bar; and its use is advisable for smaller arcs where precision is necessary. This instrument consists

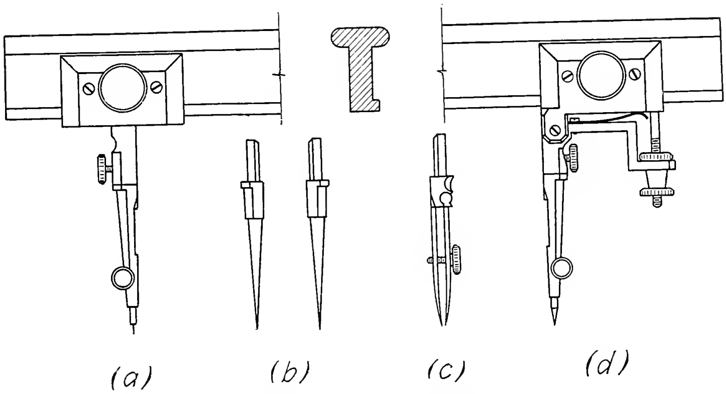


Fig. 24.—Beam compasses.

essentially of a bar or beam on which may be clamped suitable attachments for holding the needle point and the pen or pencil points. The pen point (c) replaces the pencil point (d) in inking; and all these points, including the divider points (b), are interchangeable. A serviceable beam compass of cheaper construction is shown in Fig. 25.

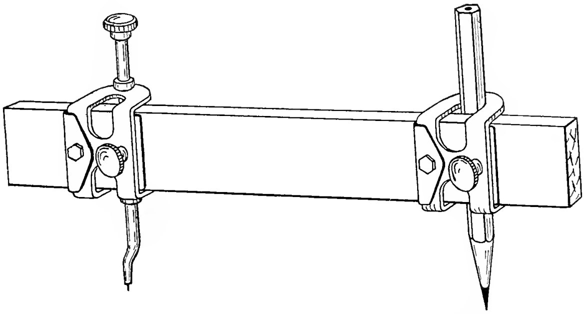


Fig. 25.—A simple form of beam compasses.

The beam compass is usually manipulated with both hands, one steadying the needle point while the free end is moved with the other. Where the beam is very long the use of a rolling carrier for the beam is a convenience, and such an attachment may be obtained for most instruments.

Drafting Machines.—Various mechanisms have been devised to reduce the constant moving about of triangles, scale and T-square. Probably the best of these is the Universal Drafting Machine, one type of which is shown in Fig. 26. Two sets of parallel arms permit the grad-

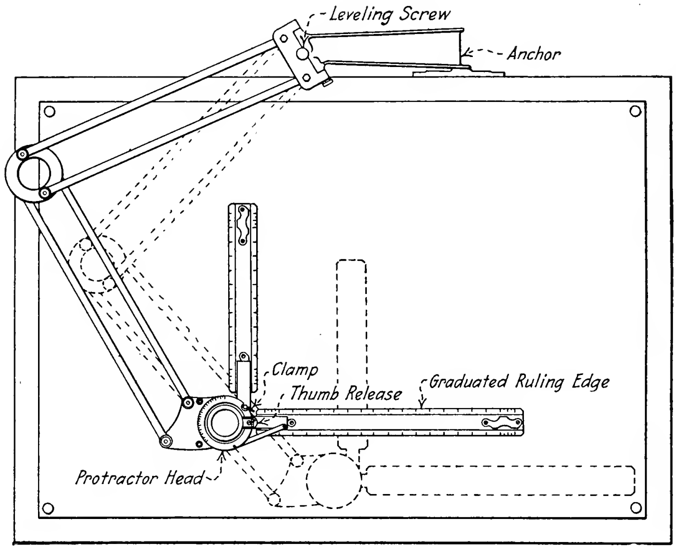


Fig. 26.—The "Universal" drafting machine.

uated head to be moved to any portion of the drawing without rotation. The two interchangeable drafting edges (graduated with suitable scales) always remain at right angles and parallel to their initial

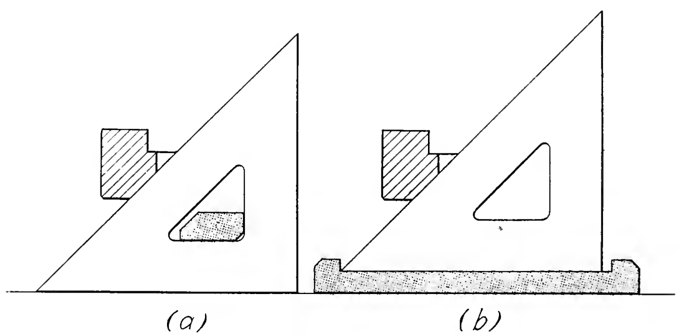


Fig. 27.—Home-made section liners.

positions. For angular work the two scales may be swung as one and clamped at any angle desired. Thus the use of triangles is not necessary, and lines may be drawn along the scale to any desired length in one operation. Variously graduated heads and scales are available especially suited to the class of work done by any draftsman.

Section Liners.—Considerable skill is required to space equally by eye such parallel lines as are used in cross-hatching or section-lining work, and a number of rather elaborate instruments have been devised to accomplish this spacing mechanically. Such devices are relatively expensive, and their use on ordinary work is hardly justified as a satisfactory degree of accuracy is within the ability of the ordinary draftsman. Two home-made section-liners are illustrated in Fig. 27. The shaded pieces may be made of celluloid or wood, and one such piece must be made for each spacing desired.

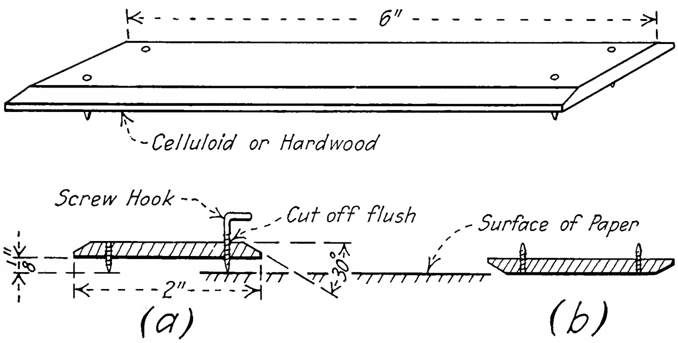


Fig. 28.—A raised ruler for inking. (University of Illinois.)

Raised Ruler.—Much time can be saved in inking by the use of a short ruler (Fig. 28) supported slightly above the surface of the drawing by four metal points. With this device wet ink lines may be worked over freely and little time need be spent waiting for the ink to dry. The construction is clearly indicated, and any draftsman can well afford to take the time and trouble necessary to make such a ruler.

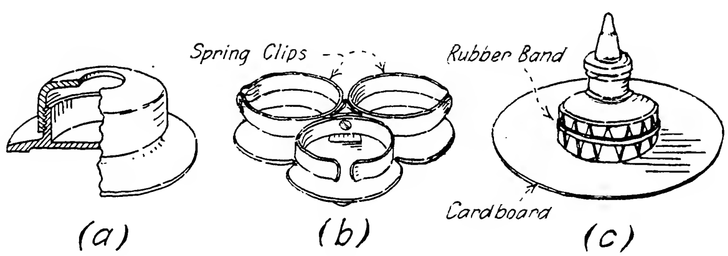


Fig. 29.—Ink-bottle holders.

Ink Bottle Holder.—The main purpose of an ink-bottle holder is to give the bottle sufficient stability to prevent overturning it on a drawing. Two metal holders are shown in Fig. 29, as well as one (c) easily constructed of cardboard. While the latter is not as heavy as the metal holders, its large base makes it difficult to overturn.

Straight Edge.—A straight edge is a necessity in map drafting and similar work, and consists simply of a thin strip of wood or steel having two edges straight and parallel. Wooden straight edges (Fig. 30a) usually have hardwood or celluloid edges, while those of steel (Fig.

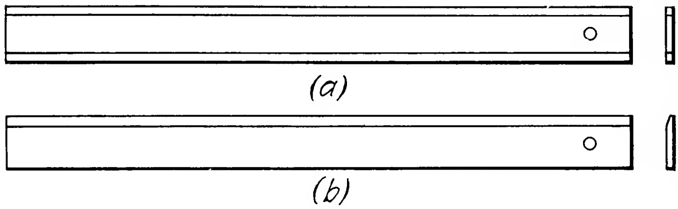


Fig. 30.—Straight edges.

30b) usually have one edge beveled for convenience in penciling. The straight edge is used for drawing long lines, and as a support for triangles and protractors.

Proportional Dividers.—The operation of redrawing any drawing to a different size is facilitated (particularly when the scale ratio is an odd one) by the use of proportional dividers (Fig. 31). This instru-

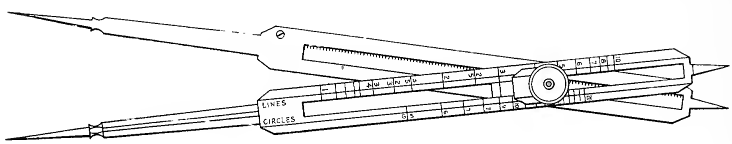


Fig. 31.—Proportional dividers.

ment consists essentially of two equal legs pointed at both ends and opening on an adjustable pivot, the position of which determines the ratio of the end openings between points. Distances are taken off with one pair of points and the other pair used to give the corresponding distance on the new drawing.

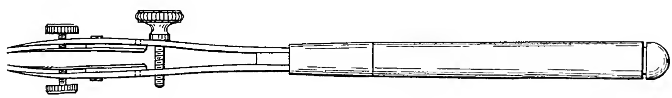


Fig. 32.—A border pen.

Border Pen.—Two parallel lines of equal or unequal weight may be readily ruled and duplicated by the use of a border pen (Fig. 32). Such a pen is also convenient for ruling parallel curved lines with the aid of a French curve.

Railroad Pen.—This instrument (Fig. 33a) is intended for use in ruling two parallel lines representing the rails of railroad track, but it has other uses as well.

Curve Pens.—The curve or "contour" pen (Fig. 33b) is used for the freehand drawing of continuous curved lines of uniform width. The nibs are offset from the center line of the shaft which is free to rotate in the handle of the instrument. In use the curve is traced with the

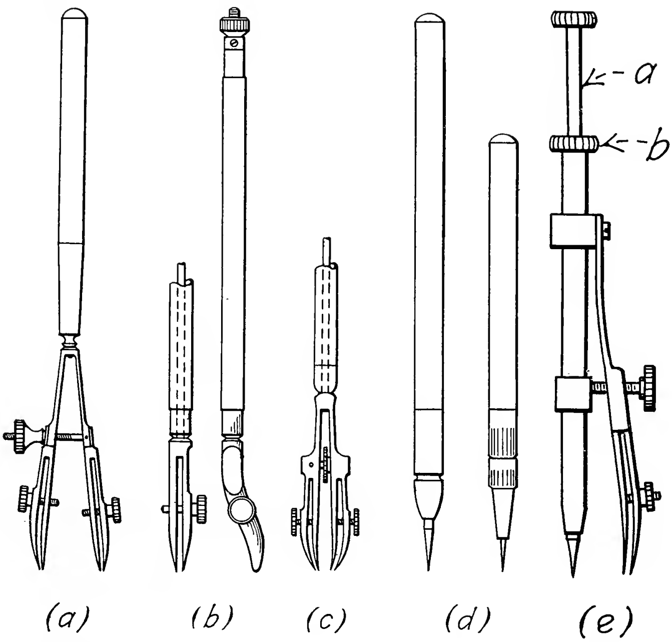


Fig. 33.—(a) Railroad pen, (b) curve pen, (c) double curve pen, (d) prickers, (e) drop pen.

handle held vertically and the nibs trailing. To work best (on tracing cloth especially) the nibs should be kept sharp so that there is no tendency to slip sidewise. The double curve pen (Fig. 33c) is a great convenience in drawing two freehand lines uniformly spaced, such as represent roads and trails on maps.

Pricker.—The most accurate results in transferring a distance from the scale to a drawing are attained when the points are marked by tiny punctures in the paper made by some sort of pricker (Fig. 33d), this instrument consisting simply of a fine steel point fixed in some sort of handle. The pricker shown at the left has a needle point screwed into place, while in the other the point is held by a small clutch and may be readily replaced if broken. A satisfactory substitute may be made by forcing part of a fine sewing needle into a small piece of soft wood to serve as a handle.

Drop Pen.—Where a large number of small circles of equal size must be inked, the use of a drop or "rivet" pen (Fig. 33e) is convenient. The needle point is on the shaft "a" which is held in position by the tips of the thumb and forefinger while the rotating sleeve carrying the pen is spun around by an impulse from the second finger applied at "b." The pen is lifted slightly while the needle point is being moved to a new center. Some drop pens have a pencil point that can be inserted in place of the pen, but most draftsmen draw the pencil circles freehand to save time.

Railroad Curves.—Railroad curves (Fig. 34) are used for drawing the circular arcs representing track curves on railroad maps. Such curves differ from French curves in that the arcs are circular, being of

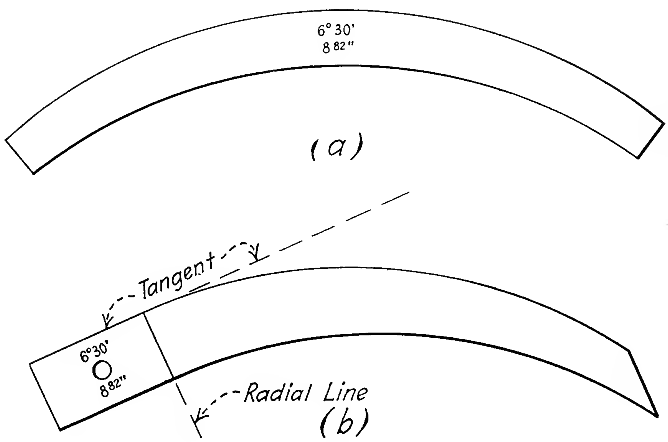


Fig. 34.—Railroad curves.

the proper radius to represent one certain degree of curvature. Railroad curves are made of cardboard, wood, hard rubber, celluloid or zinc, a set containing from ten to one hundred curves. Both curved edges are cut to the same radius, and each curve is marked with the radius in inches and the corresponding degree of curvature represented at the usual scale of 100 feet to an inch.

Freehand Lettering

The appearance of an engineering drawing depends largely on the quality and arrangement of the lettering placed on it by the draftsman. Lettering is not mechanical drawing, but it is essential that every mechanical draftsman have the ability to letter rapidly and neatly. This ability does not demand any marked artistic talent or any special proficiency as a penman. Practice along the right lines will make any draftsman a good letterer, provided he always strives for a more perfect result. Careless practice is worse than none at all.

The qualities most to be desired in the lettering of engineering drawings are legibility, neatness and speed. Legibility may be gained by adopting a simple style, such as the "Reinhardt," or "Engineering News" style, which is essentially that used throughout this text. Both legibility and neatness should follow a careful study of the letter forms and the correct methods of producing them. Speed, or the swing of the skilled draftsman, can only come with consistent practice.

The chief object of this chapter is to give a good insight into the correct formation of such styles of freehand lettering as are in common use in the drafting-rooms of today. The essential thing to be gained here is an accurate knowledge of the shape of the letters studied and the proper methods of constructing them.

Lettering is essentially freehand drawing. Mechanical aids in the formation of the various characters are the resort of the unskilled draftsman, and almost invariably result in lettering that is painfully inartistic.

Single-Stroke Lettering

The term "single-stroke lettering" does not mean that the complete letter is formed without raising the pencil or pen, but that only one passage of the pencil or pen point is needed to make each stroke used in forming the letter.

Guide Lines.—The height of the letters is considered as being divided into five equal spaces. All the capitals are drawn full five spaces high, while the body parts of the small letters are made only three. Three of the six horizontal guide lines (Fig. 36) are usually drawn as indicated in Fig. 35. For practice purposes, and to save time and secure greater accuracy, it is convenient to use some sort of ruled paper. Various sorts of paper specially ruled for lettering are available, but a piece of Plate "A" profile paper answers the purpose nicely. On this paper each vertical quarter-inch is divided into five equal spaces so that it is convenient to draw the letters one-fourth of an inch high. It is best in studying the letter forms to draw them somewhat larger than is customary on ordinary drawings. Guide lines should be drawn for all lettering. There are several lettering devices now available which make this operation a rapid and an accurate one.

Slope of Lettering.—Single-stroke lettering may be made either vertical or inclined. Both styles are in common use and most drafting rooms leave the choice to the draftsman. The vertical style of lettering is not used so generally as the inclined style. This is due chiefly to the fact that the average draftsman can do better work with the inclined style, and his employer naturally desires the best appearing drawings that his drafting force is capable of producing. A common argument for vertical lettering is that uniformity is easier of attainment with this style as there is only one vertical, while there are any number of slopes that may be used for lettering. However, the average draftsman soon demonstrates to his own satisfaction that slight irregularities in the slope given his inclined lettering are not so noticeable as are any departures from the vertical when the latter style is used. This is at least partly due to the fact that on most mechanical drawings the lines that are truly vertical are so numerous that the eye readily detects any deviation of the letter from the vertical. Inclined lettering has a slight advantage here in that it stands out better than does the vertical due to the contrast of the sloping characters with the horizontal and vertical lines of the drawing.

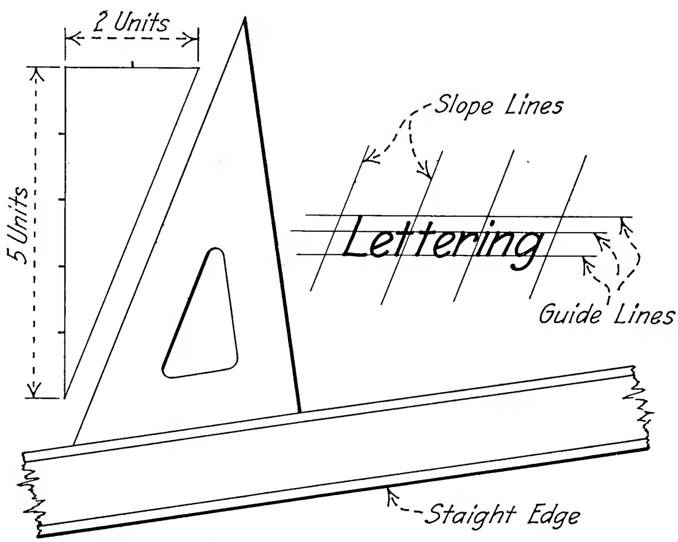


Fig. 35.—Method of drawing slope lines for lettering.

Some draftsmen, however, and particularly those that letter with the left hand, find that they can do better work with the vertical style. Then, too, nearly every draftsman will find occasions when it will be necessary for him to do some vertical lettering. One practice is to use the inclined lettering for notes, dimensions and general use, and the vertical style for reference letters, captions and titles.

Lettering with the Pen.—Before a new lettering pen is used it should be placed in the pen-holder and the point held for a moment in the flame of a match. This treatment burns off the coating with which the pens are covered to prevent their rusting, and will be found to cause them to take the ink more readily. Care should be taken not to draw the temper of the nibs by over-heating.

The use of too much ink on the lettering pen is a very common cause of blots and poor intersections. Even and clear-cut ink lines require a fairly light and even pressure on the pen point, together with frequent cleaning on a pen wiper.

Steel Pens for Lettering.—The choice of the proper pen to use for lettering depends on the draftsman's method of handling it as well as on the character of lines desired. Where there is a tendency to bear heavily on a pen one with stiff nibs is necessary, as the nibs should not be so flexible as to spread materially. Uniformity in width of stroke is essential, and such spreading tends to make the vertical strokes heavier than those made horizontally. Thus the character of the pen point should determine the weight of the strokes—not the pressure exerted on the nibs.

The following list suggests an assortment of lettering pens, grading from fine to coarse:

Joseph Gillott's No. 170
Joseph Gillott's "Extra Fine," No. 303
Joseph Gillott's "F," No. 404
Phinney and Co.'s "Spencerian," No. 1
Buxton & Skinner's "Cote Brilliante," No. 4
Leonardt & Co.'s "Ball Pointed," No. 516F

Spacing.—Beginners commonly space the letters of words too far apart and the words themselves too close together. The space between words and after commas should be sufficient to allow the insertion of a small letter "o" without crowding, while the space between sentences should be at least double this amount. Words placed too close tend to run together and thus confuse the eye of the reader. It should be kept in mind that placing the letters close together does not necessitate any cramping of the letter forms. The spacing between lines of lettering may vary from one-half to one and one-half times the height of the capital letters.

Inclined Single-Stroke Lettering.—Inclined lettering may be drawn at various slopes, but a slope of 2 to 5 (about 68°) is recommended. Slope lines at this angle are easily obtained by constructing a right-angled triangle using 2 and 5 units as the legs (Fig. 35), and such slope lines should be drawn lightly whenever a note of any length is to be placed on the drawing.

Inclined Capital Letters.—The study of the inclined capitals should proceed in the same order in which the letters are taken up in Fig 36. The completed form of each letter is given at the left, and the various strokes used in its construction indicated at the right. Note that the arrows give the direction in which each stroke is to be made, while the figures show the sequence of the various strokes. Most of the dash lines shown are slope lines (Fig. 35) which are parallel to the general slope of the lettering.

In general, all strokes are made downward or to the right as the nibs of the pen are apt to stick into the drawing surface when strokes are made upward or to the left. At present most engineering lettering in ink is done on tracing cloth, which presents a much smoother surface to the pen than does paper. For this reason it is often possible to simplify the construction of many of the letters so that fewer strokes are used than

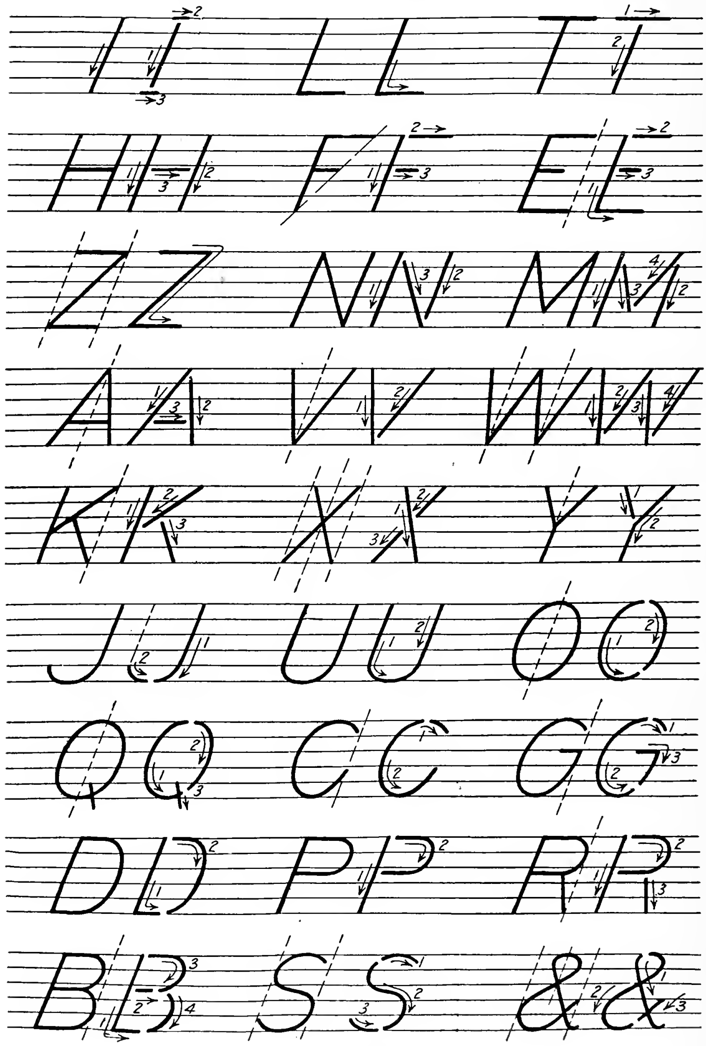


Fig. 36.—Inclined single-stroke capitals.

would be demanded by the rule just stated. In lettering with the pen on rough paper it may be found advisable to subdivide some of the strokes, using as a guide the rules given.

Two styles are shown for the capital "I." The simpler form should be used except when the capital is followed by the small letter "l," with which this form of the capital is identical.

The shape and construction of each letter should be carefully studied before practice is begun. In this way many mistakes may be avoided. Incorrect methods soon become habits and are very difficult to overcome. The position of the hand should not be shifted to draw the various strokes.

Notes lettered entirely in capitals are not easy to read, for the reason that each word so lettered loses its characteristic word form by which it is recognized in reading ordinary printed matter. Capitals are now ordinarily used only where they would properly occur. In captions and titles it is frequently desirable to use all capitals, and in such cases a better appearance is obtained if the initial letters of the important words are made slightly higher than the others (Fig. 37).

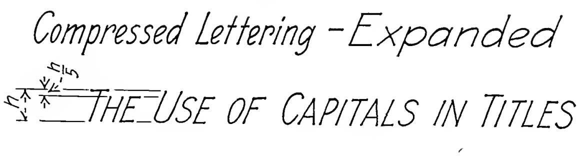


Fig. 37.

Inclined Small Letters.—In the construction of the small (or "lowercase") letters (Fig. 38) the stems of the tall letters are made the same height (five spaces) as the capitals, while the bodies of the letters are made three spaces high. The letter "t" is an exception, having a height of four spaces. The tail strokes of the letters "y," "j," "q," "g" and "p" extend two spaces below the bases of the other letters, and in studying these letters an extra guide line should be drawn two spaces below the others. The location of the dot which forms a part of the "i" and the "j" should be noted.

The letter "c" should be given very careful study for the reason that it is the important stroke in the construction of the seven letters following, the stroke being inverted in the case of "p" and "b."

Vertical Capital Letters.—The construction of the vertical capitals (Fig. 39) is practically the same as that given for the inclined. It will be found advisable to tip all the letters slightly to the left rather than allow them to lean even slightly to the right.

Vertical Small Letters.—While the vertical small letters (Fig. 40) are similar to the inclined in construction, it should be noted that the form used for the vertical "e" is not the same as that used for the inclined style. The style shown presents a better appearance with vertical lettering. The ellipses of the letters "o," "c," "e," etc., are tipped slightly to the left.

Figures.—The finishing of an ordinary working drawing requires a greater use of figures than of letters. For this reason extra emphasis should be placed on the study of the forms and construction of the figures (Figs. 41 and 42), which for the reason noted are made with as few strokes as possible.

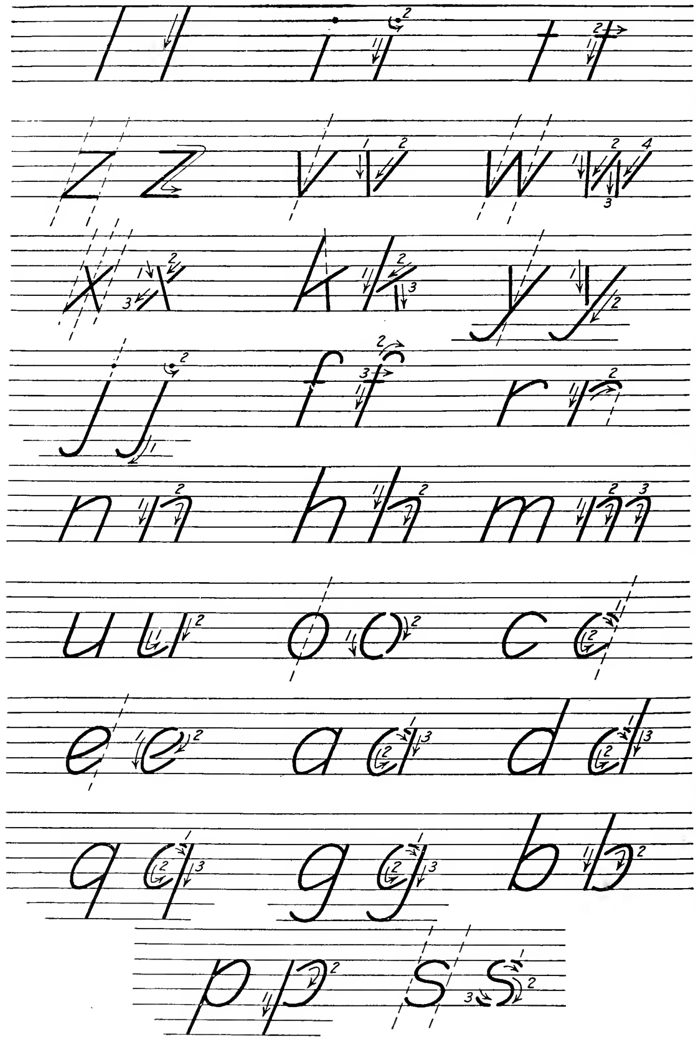


Fig. 38.—Inclined single-stroke small letters.

The Roman numerals present no difficulties, as they are merely combinations of the capital letters "I," "V" and "X." They are, however, made somewhat narrower in the present usage. The cross strokes on the upper and lower guide lines are frequently made incorrectly.

The relative sizes and placing of letters, figures, fractions, inch marks, etc., are indicated in Fig. 43.

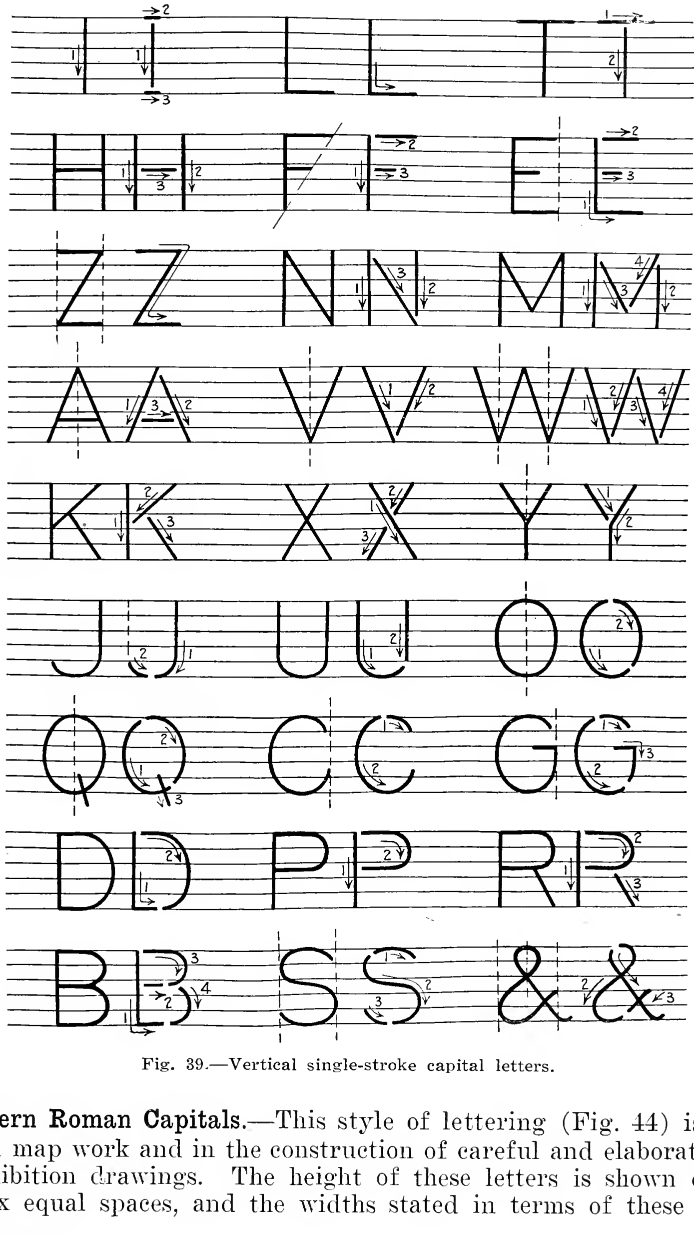


Fig. 39.—Vertical single-stroke capital letters.

Modern Roman Capitals.—This style of lettering (Fig. 44) is much used in map work and in the construction of careful and elaborate titles on exhibition drawings. The height of these letters is shown divided into six equal spaces, and the widths stated in terms of these spaces.

The straight, heavy stems are given a width of one space, while the shaded portions of the curves are made slightly wider.

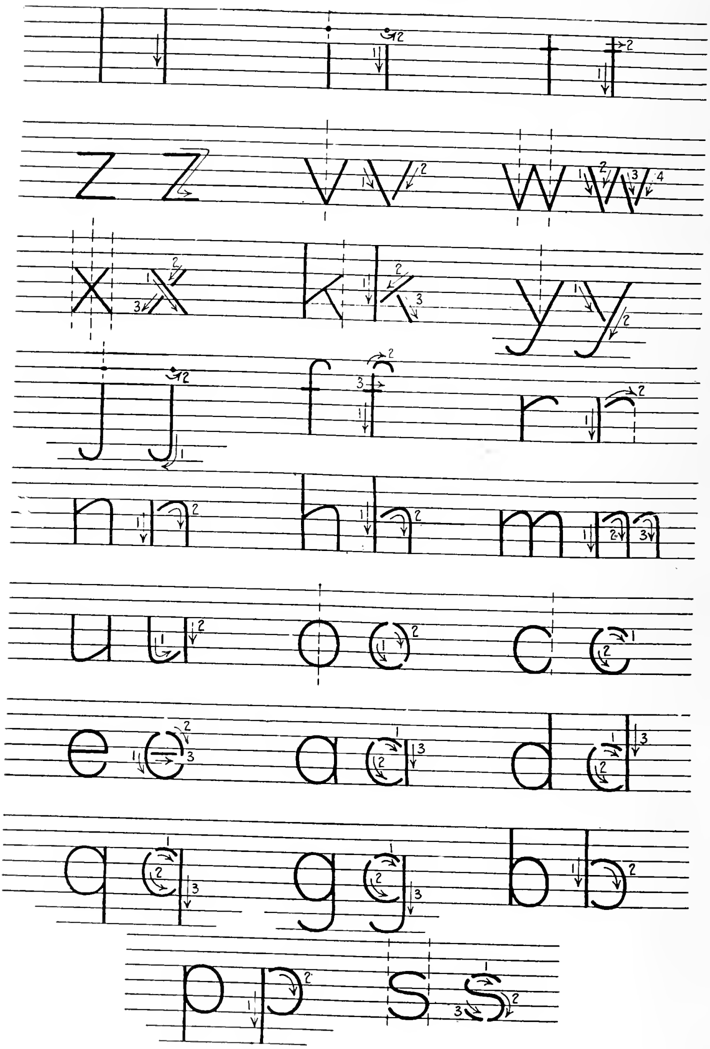


Fig. 40.—Vertical single-stroke small letters.

There are various exaggerations or corrections that are given the forms of many of these letters in order that they may seem properly proportioned. The horizontal stroke occurring at the middle height of the letters "H," "F," "E," "P," "R" and "B" is placed slightly more than three spaces above the bottom guide line. Also, the letters "E," "Z," "K," "X," "C," "G," "R," "B," and "S" are drawn narrower at the top than at the bottom. Unless these principles are observed the letters mentioned will look top-heavy.

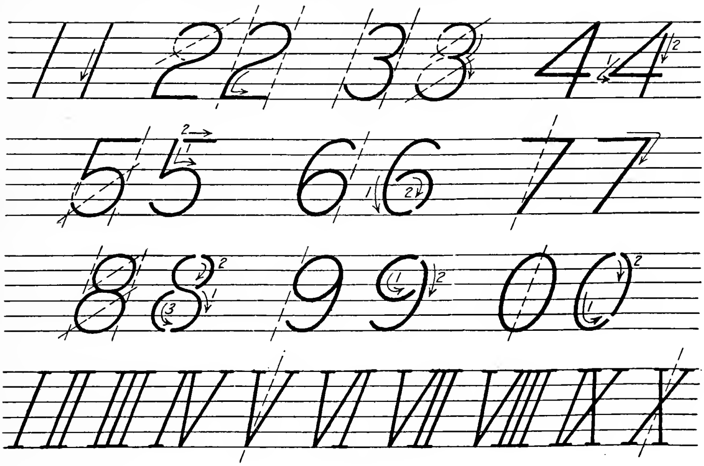


Fig. 41.—Inclined figures.

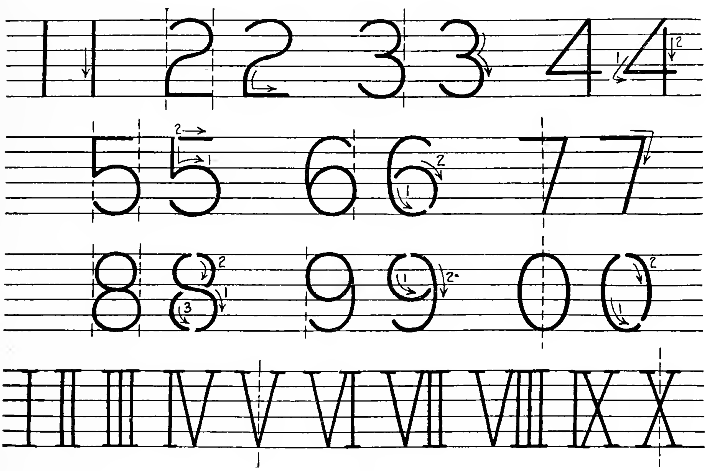


Fig. 42.—Vertical figures.

Another principle, common to the letters "J," "U," "O," "Q," "C," "G," "S" and the character "&," consists in extending the various curved outlines slightly over the top or bottom guide lines, as the case may be. If this correction is not applied these letters will not seem to be as high as the others.

The appearance of the letters "M," "A," "V" and "W" is improved if the sharp points common to these letters are extended a trifle beyond the extreme guide lines, and swung slightly away from the shaded side of the letter.

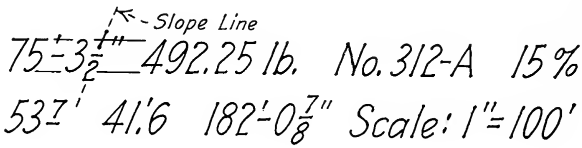


Fig. 43.

These letters are penciled in outline only, the heavy stems not being filled in until the letters are inked. The steps to be followed in sketching the letter "E" (Fig. 45a) illustrate the general procedure to be followed in drawing the straight-line letters. The correct form for the seriphs of the Modern Roman capitals is indicated in Fig. 45b.

The curved letters are sketched by drawing the outside curved outline first. The inside of the curve is then drawn as a straight line, the thickness of each curve being made slightly more than one space at the

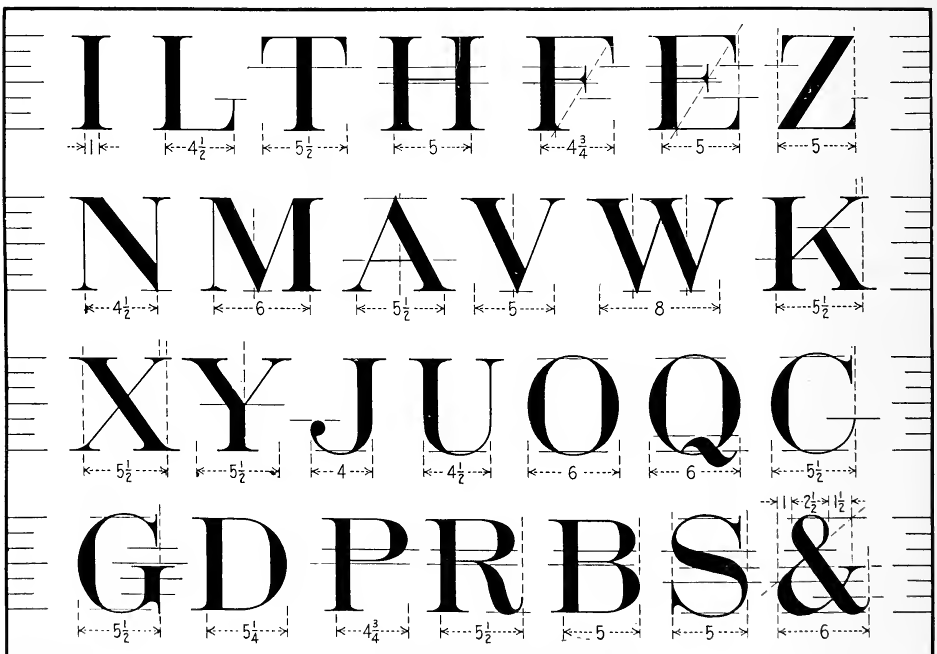


Fig. 44.—Modern Roman capitals.

widest part. The steps to be followed in sketching the letter "O" are shown in Fig. 45c. In forming the curves of the letters "B" and "R," the thick parts are kept from running together by making the outside curves somewhat pointed in outline (Fig. 45d).

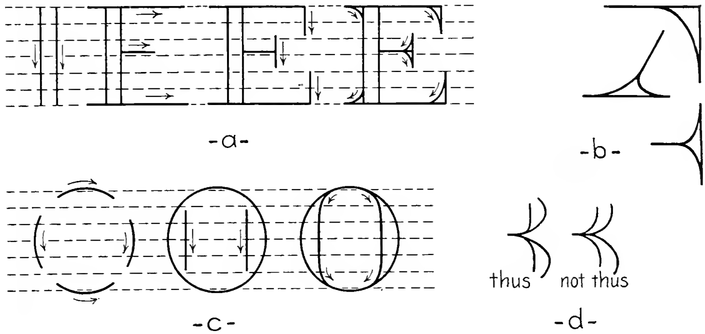


Fig. 45.—Construction of Modern Roman capitals.

The horizontal distances between the letters of a word should vary with the different letter combinations, the clear spaces included by the outlines of adjacent letters being kept approximately uniform in area.

In inking these letters one should proceed as in the pencil work. When the outlines are inked, all pencil marks are removed with a soft eraser. The wide stems of the letters are then filled in with a coarse writing pen or a ruling pen with the nibs nearly closed.

Fig. 46.

Roman Small Letters.—The small letters of the modern Roman alphabet (Fig. 46), together with the capitals (Fig. 44), may also be

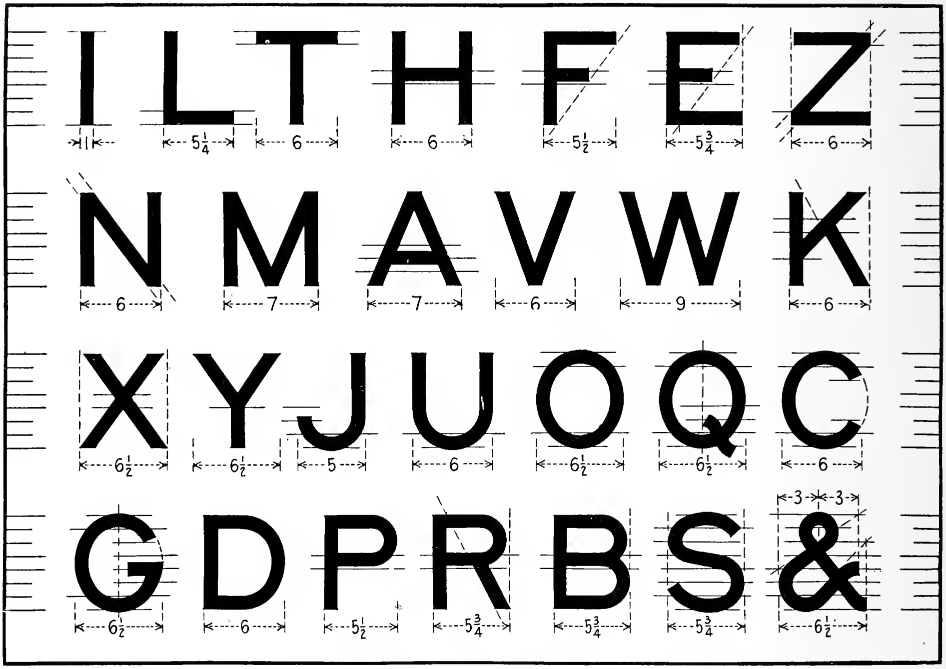


Fig. 47.—Block capitals.

drawn in the inclined or italic style, the forms of the letters otherwise remaining unchanged.

Stump Letters.—Stump letters (Fig. 46), a modified style of small italics, are often used with the italic Modern Roman capitals on maps and patent-office drawings. The heavy strokes of these letters, except in the case of very small letters, are first outlined and then filled in. While the hair lines may be made as part of the body stroke, it is generally advisable to form these with short down-strokes to the left. This avoids the tendency of the pen to catch, and also prevents dragging ink over the angles of the letters.

Block Letters.—The construction of the block capitals (Fig. 47), sometimes termed the Commercial Gothic alphabet, calls for some of the corrections applied in the construction of the Modern Roman alphabet. The cross-bars of the "H," "F," "E," "P," "R" and "B" are placed slightly above the middle height, while the letters "J," "U," "O," "Q," "C," "G," "S" and "&" all extend slightly beyond the limiting guide lines.

Block letters are penciled in outline and filled in solid when inked. All stems are made one space wide. A slight pointing of the sharp corners improves the appearance of these letters.

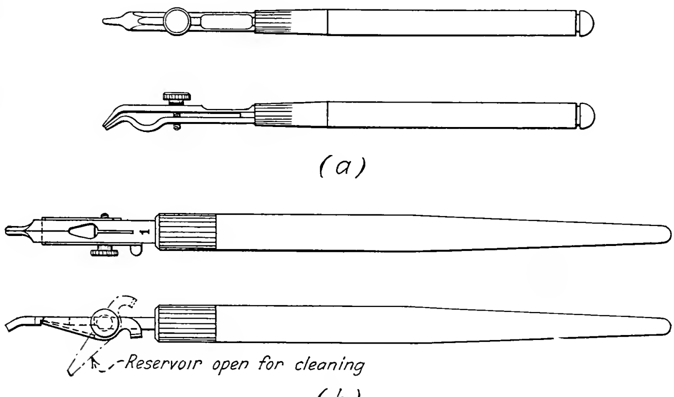


Fig. 48.—Block lettering pens.

Fig. 49.—Old Roman capitals.

The spacing of block letters should ordinarily be such that the area included by outlines of adjacent letters is about equal to one-third of the area used by the letter "M."

Single-Stroke Block Letters.—Heavy block letters may be drawn rapidly with single strokes made with special block-lettering pens (Fig. 48), or with special steel pen-points made with broad flattened points.

Old Roman Capitals.—The Old Roman letters form the basis of practically all of the lettering used in architectural drafting, and although rather difficult of execution they should be given careful study by anyone training for this class of work. In the Rennaissance alphabet (Fig. 49) the letters are made nine spaces high, with the light and heavy stems one-half a space and one space wide, respectively.

Fig. 50.—Single-stroke Roman.

In classical inscriptions, the letter "I" is customarily substituted for "J," and "V" for the letter "U," due to the fact that the letters "J" and "U" are comparatively modern additions to the alphabet.

The Old Roman letters are open to many modifications of form, which if made with due regard to proportions and composition give results that are varied and pleasing.

Single-Stroke Roman.—The single-stroke style shown in Fig. 50 (a and b) is derived from the Old Roman alphabet and retains much of its beauty and individuality. These simple letters may be formed rapidly and are much used by architects on working drawings. A modified style is indicated in Fig. 50c.

Orthographic Projection

If an object is viewed through a transparent plane (picture plane) and its outlines traced on the plane as seen, a perspective projection or drawing of the object will result (Fig. 51a). The size and shape of the outline thus projected will depend on the relative positions of the observer, the picture plane and the object. As all the rays or lines of sight from the object to the eye converge in one point (the point of sight), it is aparent that no line on the object will show or project in its true length unless it is actually in the picture plane. All lines behind the picture plane will be projected shorter than they are. This foreshortening of the lines of an object makes such a projection unsuitable for use as a working drawing, chiefly because the lines cannot readily be measured or dimensioned.

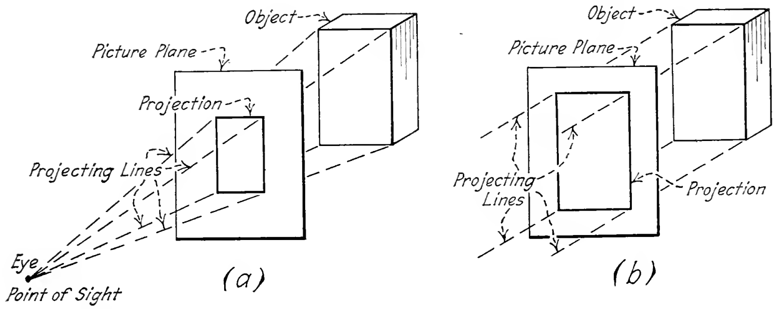


Fig. 51.—Perspective projection (a) and orthographic projection (b) compared.

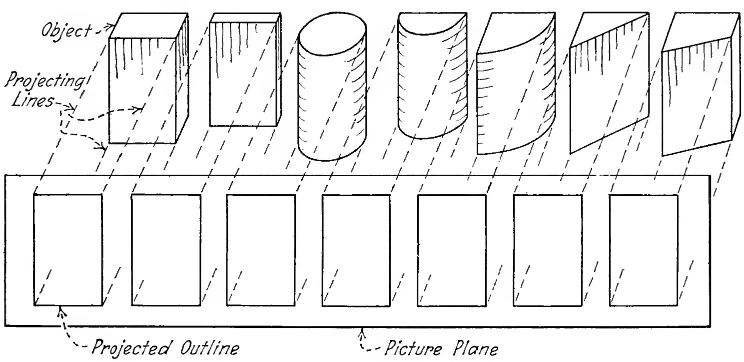


Fig. 52.—Dissimilar objects giving identical projections.

Orthographic Projection.—If the observer is considered as having moved an infinite distance away from the plane and the object, the lines of sight (projecting lines) locating the outline will become parallel

(Fig. 51b,) and every line parallel to the picture plane will project in its true length.

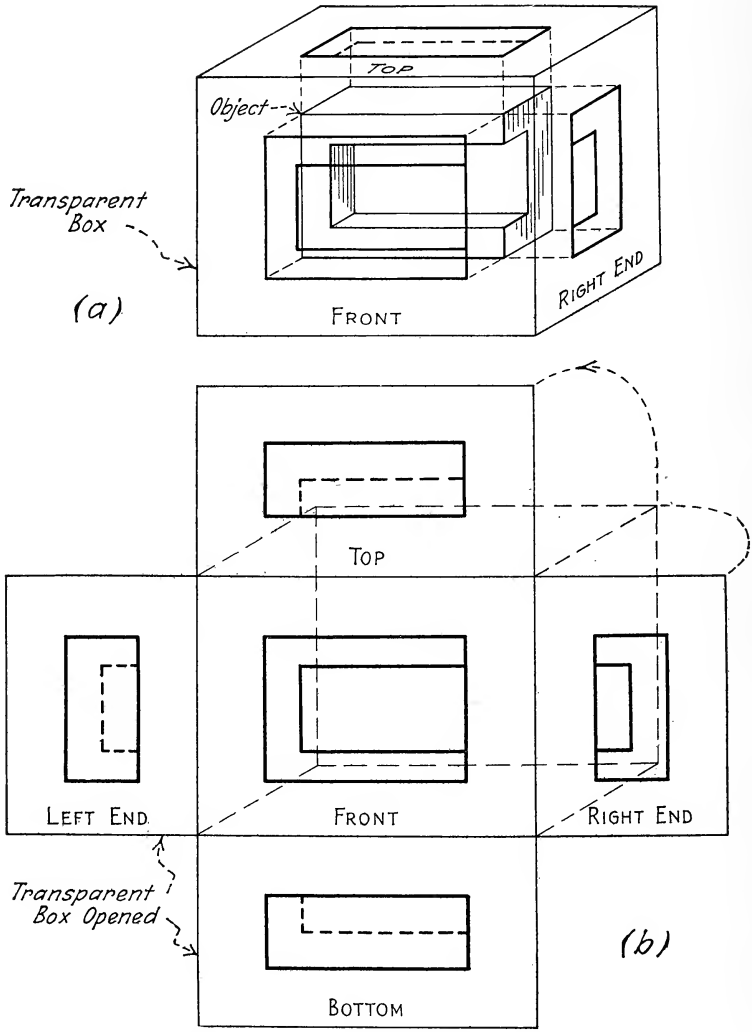


Fig. 53.—Theory of orthographic projection.

When projecting lines are parallel to each other, and also perpendicular to the picture plane, the projection or view obtained is an orthographic projection. Working drawings are made up of two or more such projections. The object is usually placed with one face parallel to the picture plane so that all lines on this face will project in their true length and relative positions. A second view is necessary to show the dimension of the object perpendicular to the picture plane (the plane of the drawing). Frequently a second view is necessary to define the shape of the object, as in the case of each of the objects shown in Fig. 52. These objects project as rectangles, identical in each case.

Arrangement of Views.—To get an understanding of the principles underlying the making and arrangement of additional views, consider the object to be inside of a rectangular box (Fig. 53a) having transparent sides, each of which may be taken as a picture plane for an orthographic projection or view. The object is so placed that its various faces are parallel to the sides of the box, so that the projections or views will project their true shape and size. The projections of invisible edges are always shown as dash lines.

The sides of the box are then opened out by swinging them away from the object, this giving the arrangement of the views indicated in Fig. 53b. In making the actual working drawings (Fig. 1b) the lines representing the edges of the imaginary box are omitted and only the necessary views (usually two or three) are drawn.

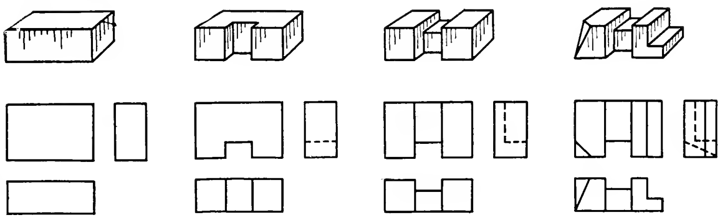


Fig. 54.—Orthographic projections.

Two groups of simple objects, together with their representations in orthographic projection, are shown for study in Figs. 54 and 55. The student should practice making freehand sketches of simple objects showing two or three views properly arranged.

Auxiliary Views.—Where a face of an object is not parallel to the picture plane on which it is projected, the resulting projection or view will be foreshortened or distorted.

In order to avoid this difficulty resort may be had to an auxiliary view. Such a view is a projection made on an imaginary picture plane taken parallel to the face to be projected. This is illustrated in Fig. 56 (a and b). In Fig. 56c the whole piece is shown in the auxiliary view, but where the piece is more complicated this view need only show the details of the inclined face.

Sectional Views.—Frequently the construction of an object may be shown more clearly if a portion of it is considered as having been cut away so as to show the interior. The cut is assumed to be made by an imaginary plane (57a) and the drawing so made as to represent the object as though it were so cut and the near or front portion removed. Thus the lower view in Fig. 57c is drawn to represent the object with the front portion cut away as in (b). The solid portions so cut are usually indicated by cross-section lines which may be varied to indicate in a conventional manner the various materials used (Fig. 58). The conventional method of designating a section and indicating just where it is taken is shown in Fig. 57c.

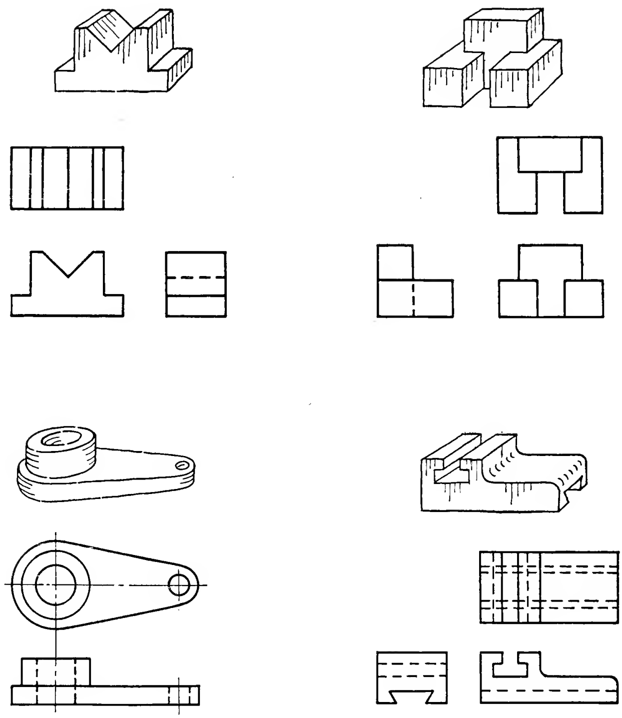


Fig. 55

Where a piece is symmetrical it is often convenient to show one-half in section (Fig. 59) and the other an outside view. Such a view is called a "half-section."

Revolved sections are frequently cut into ordinary views, as indicated in the detail drawing of the plug wrench (Fig. 60).

The conventional breaks shown in Fig. 61 are used in a manner similar to the revolved sections, and particularly when a piece with a uniform cross-section is too long to be shown to scale.

Intersections.—Most objects may be thought of as being made up of parts of various solids (such as spheres, cones, cylinders and prisms) joined together. The surfaces of any two of such solids intersect in what

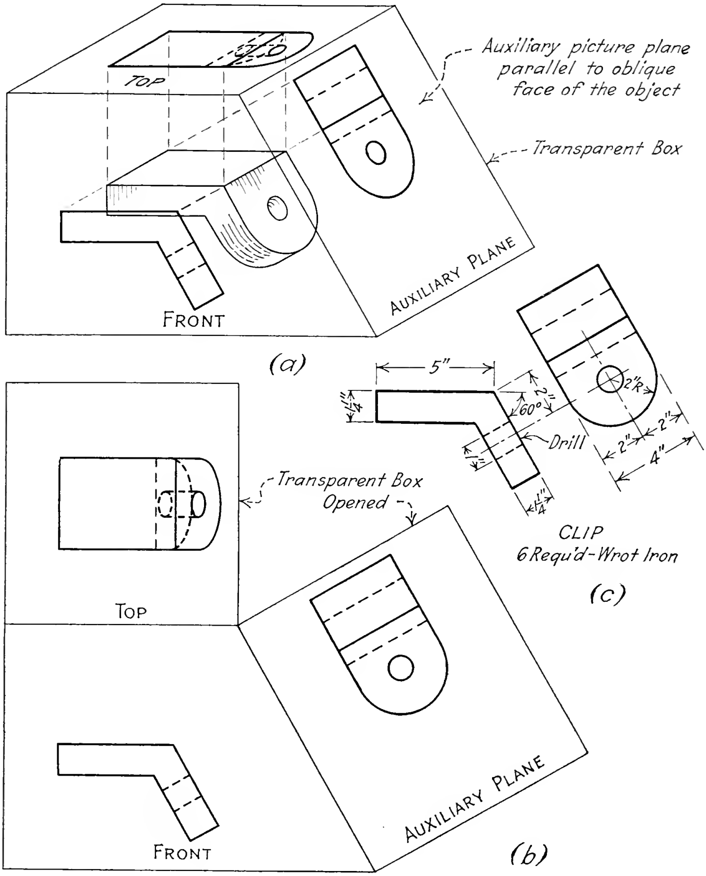


Fig. 56.—Auxiliary projections.

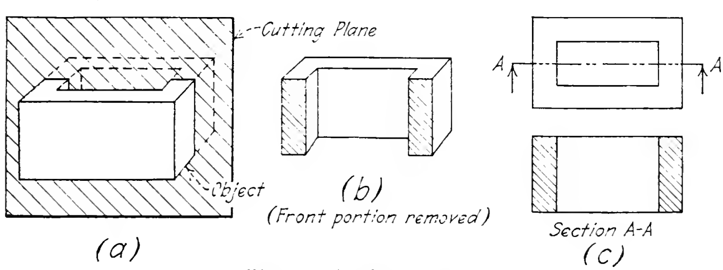


Fig. 57.—Sectional views.

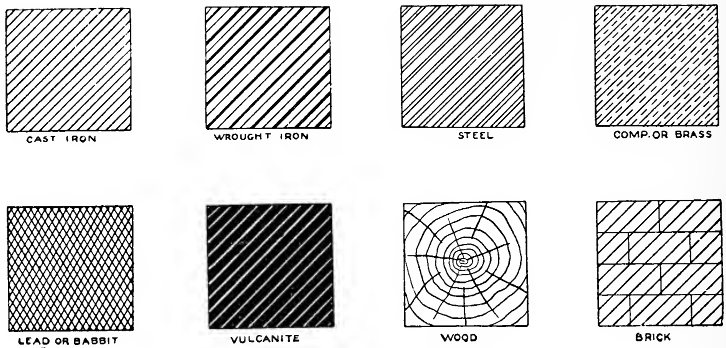


Fig. 58.—Cross hatching symbols.

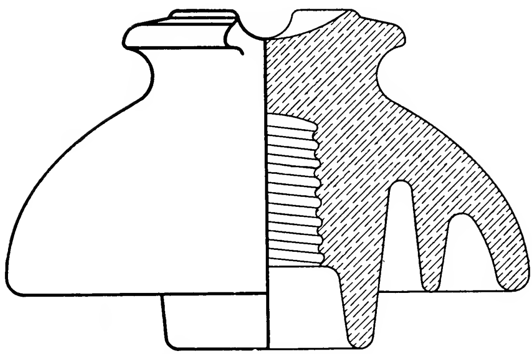


Fig. 59.—A half-section.

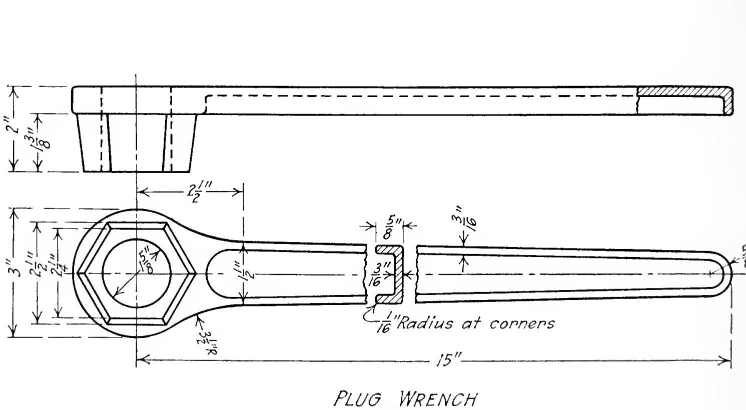


Fig. 60.—A detail drawing.

is termed a line of intersection, such a line being common to both surfaces.

In representing an object by orthographic views it is frequently necessary to obtain the projection of such lines of intersection. In general this can be done by so passing a series of imaginary planes through both surfaces that each plane will cut straight lines or circles from each.

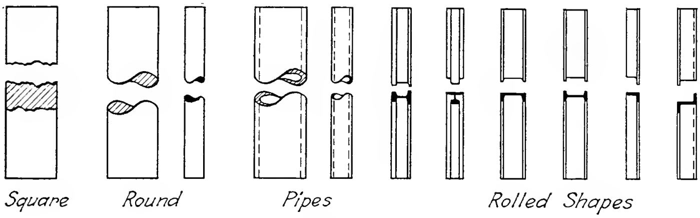


Fig. 61.—Conventional breaks.

These lines lying in the cutting plane will intersect in points common to both surfaces. A series of such points connected up will locate the line of intersection of the two surfaces.

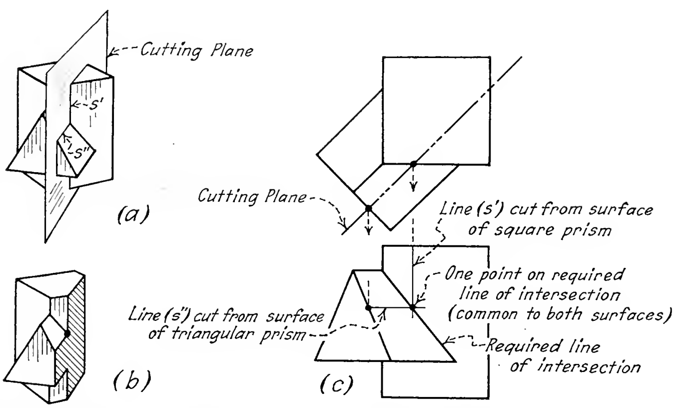


Fig. 62.—Method of finding points on the line of intersection of two surfaces.

The application of this method to finding the line of intersection of two prisms is illustrated in Fig. 62c. The cutting plane shown cuts a vertical line from the surface of the square prism, and a horizontal line from the surface of the triangular prism. These two lines intersect in a point which is common to the surfaces of both prisms and hence a point on the required line of intersection. The solution is shown pictorially in (a) and (b).

Two methods of finding the line of intersection of the surfaces of two cylinders are similarly illustrated in Fig. 63, while Fig. 64 shows similar methods applied to the intersection of a cylinder and a cone. The intersections of any of the numerous combinations of surfaces can be found by the application of this method.

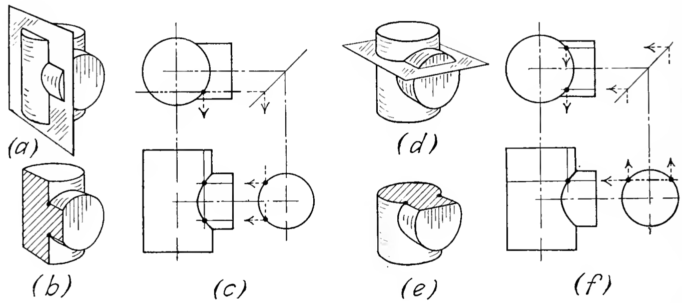


Fig. 63.—Two methods of finding points on the line of intersection of two cylinders.

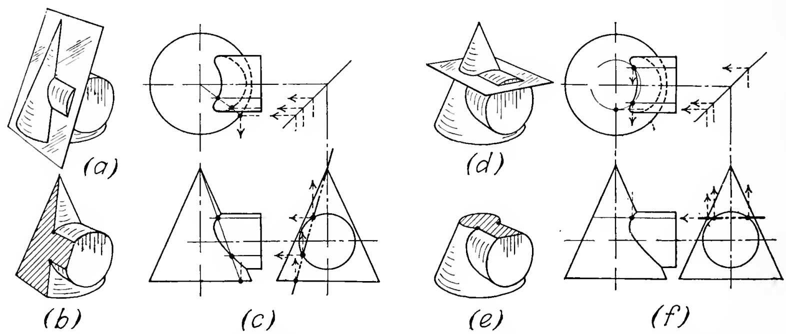


Fig. 64. Two methods of finding points on the line of intersection of a cone and a cylinder.

Working Drawings

A complete working drawing carries all the dimensions and other information that the workman needs in forming or finishing the piece or structure. It should not be necessary for the workman to take any dimensions from the drawing by scaling, or to do any computing to obtain them.

A working drawing of a separate part of any machine or structure is called a **detail drawing** (Figs. 1b and 60). A drawing which shows the various parts of a machine or structure in their assembled positions is called an assembly or an **assembled drawing** (Fig. 65). Such drawings have various uses and are characterized by a lack of detail dimensions—only the over-all and other important dimensions (such as to center lines) ordinarily appearing.

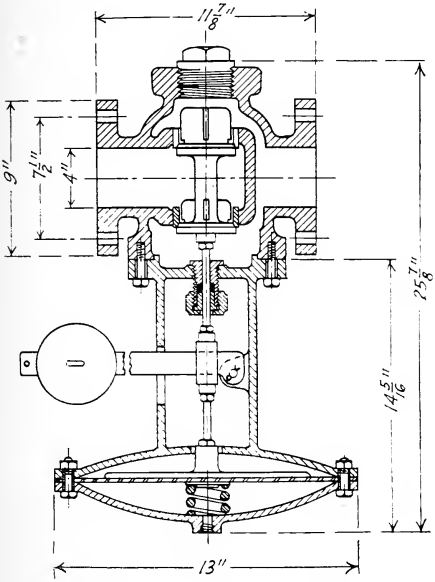


Fig. 65.—An assembled drawing.

Conventional Lines.—If all the lines used on a working drawing were drawn exactly alike, the drawing would not be easy to read. For this reason the lines used are varied in appearance so that they may be recognized readily. This may be done by varying the weight of the lines or by breaking them into various combinations of long and short dashes. The conventional lines shown in Fig. 66 are those commonly used on engineering drawings. Center lines should be penciled as continuous lines, these being changed to the conventional dot and dash line when inked or traced.

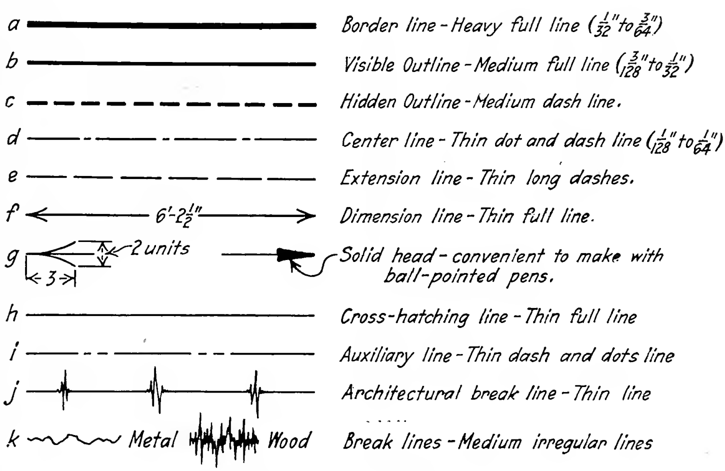


Fig. 66.—Conventional lines.

Order of Inking.—A systematic and logical procedure in inking drawings will result in a saving of time and better results.

In general, it is best to proceed in about the following order: center lines, small circles and circular arcs, large circles and circular arcs, irregular curved lines, straight horizontal lines, straight vertical lines, hidden circles and arcs, hidden straight lines, dimension lines, dimensions, notes, section lines, the title and the border lines.

Tracing cloth shrinks and expands to such an extent (due to atmospheric changes) that it is a good plan when tracing a large drawing to finish one view at a time or to work on only such a portion of the drawing as can be finished the same day. This plan largely avoids the difficulty of getting the various lines previously inked to agree with the drawing.

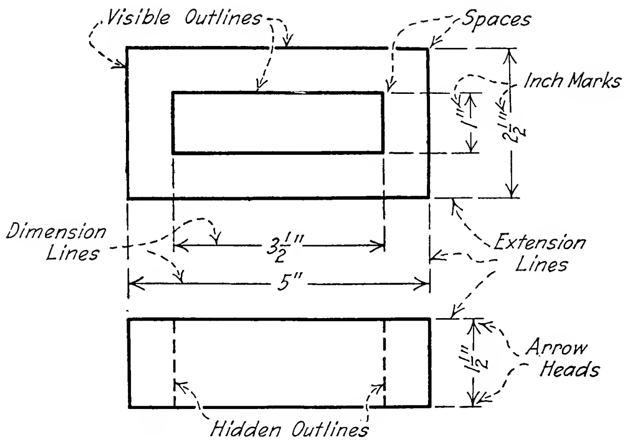


Fig. 67.—Use of conventional lines.

Dimensioning.—Dimensions are indicated on working drawings by means of figures placed in line with and between double arrows (Fig. 66f), the points of which touch the outlines or extension lines limiting the measurement (Fig. 67). Sometimes dimension lines are inked in red with figures and arrowheads (Fig. 66g) in black, but the use of colored inks is neither general nor recommended. Extension lines (Figs. 66e and 67) may be full lines or dash lines. Dimension lines are usually broken for the insertion of the figures except in structural steel drafting, where it is customary to place the figures above the dimension lines.

The figures indicating feet and inches should be separated by a dash in every case, thus, 1′—4½″. If written 1′4½″ the dimension is apt to be read as 14½″. Dimensions of even feet are indicated thus, 6′—0″. In some classes of work drawings are dimensioned entirely in inches, and in such cases the inch-marks are frequently omitted.

Various methods and devices of use in arranging and indicating dimensions are shown in Fig. 68. The satisfactory placing of the figures depends on the space available and the ingenuity of the draftsman. No system of arranging dimensions is applicable to all conditions. Every effort should be made to place on the drawing in an orderly arrangement just the dimensions that will be needed in forming the piece.

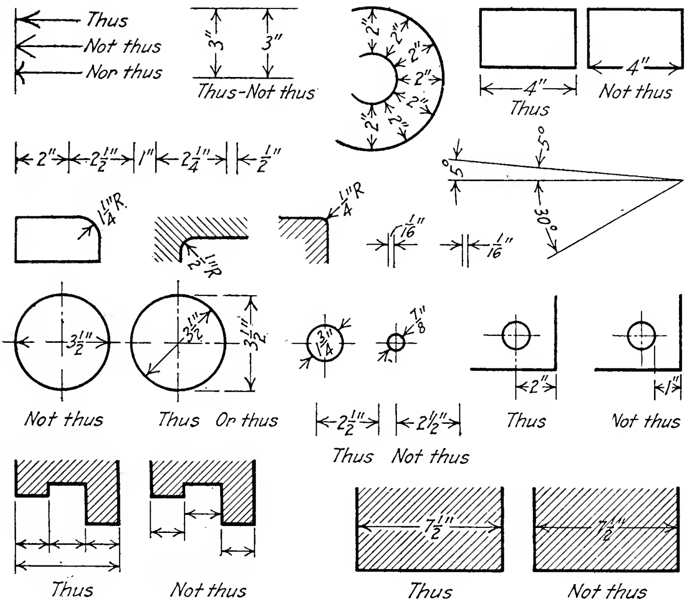


Fig. 68.—Arrangement of dimensions.

Some knowledge of the shop methods to be used is therefore necessary in order to dimension a piece properly. It is well for the draftsman to imagine himself about to construct the piece, and then mentally to trace through the various operations necessary to produce it. Then he is in the proper frame of mind to supply the necessary information in the clearest and most convenient manner.

The view which most clearly defines the piece should be selected and dimensioned first. The more important dimensions should be indicated first, all similar dimensions being put on at the same time. Flat pieces should be dimensioned by placing all the dimensions but the thickness on the outline view.

A careful study of Fig. 68 and the various dimensioned drawings shown in this publication will familarize the student with good practice in dimensioning. The following suggestions should always be kept in mind:

1. Clearness and legibility are essential. These may be secured by neatness in arrangement and care in forming arrowheads and figures, and by avoiding any crowding of dimensions.
2. Dimensions should not be repeated on different views without some special reason.
3. Finished surfaces should be located from other finished surfaces or from center-lines.
4. Dimensions should be placed so that they may be read from the bottom or the right-hand edge of the drawing (Fig. 68).
5. All notes should read from the bottom edge.

Standard Details.—Such small details as have been standardized do not require complete dimensioning. This may apply to such details as screws, tapers, piping, wire, sheet-metal, rope, chain, pins and rolled steel sections.

Finish.—Where any chance for confusion exists as to the surface finish to be given to any part, the finish should be carefully indicated by means of a note and an arrow leading to the surface referred to.

The usual finish indications are as follows: Rough, Rough-Turned, Ground, Polished, Cored, Drilled, Reamed, Loose Fit, Scraped, Chipped and Spot-Faced.

The letter "f" is frequently used as an abbreviation of the word "Finish." The manner of its use is indicated in Fig. 1b.

Notes.—Explanatory notes should be added to a drawing whenever the drawing can be made clearer by their presence. Frequently a carefully worded note saves time by making the drawing of another view unnecessary. Brevity of wording is desirable so long as the exact meaning is clearly stated.

No.	Name of Part	No. Req'd.	Material	Remarks	Dr. No.
2485-1	Upper Shear	1	Tool Steel	Harden & Grind	2485
2485-2	Upper Stripper	1	" "	" "	2485
2485-3	Lower Shear	2	" "	" "	2485
2485-4	Lower Stripper	2	" "	" "	2485
2486-1	Upper Stripper Spring	1	Spring St.		2486

Fig. 69.—A bill of material.

Bills of Material.—Working drawings frequently carry a tabulated form known as a "bill of material" which states the names and the number of each of the various pieces needed to make up one complete machine or structure. The items of information included vary considerably, but the form shown in Fig. 69 may be taken as typical.

Title.—Every drawing should carry a title of some sort. In its simplest form a title should contain the title proper, the name of the draftsman and the date. Titles may be open or boxed, both styles being illustrated in Fig. 70. Titles on engineering drawings should be simple in style and arrangement.

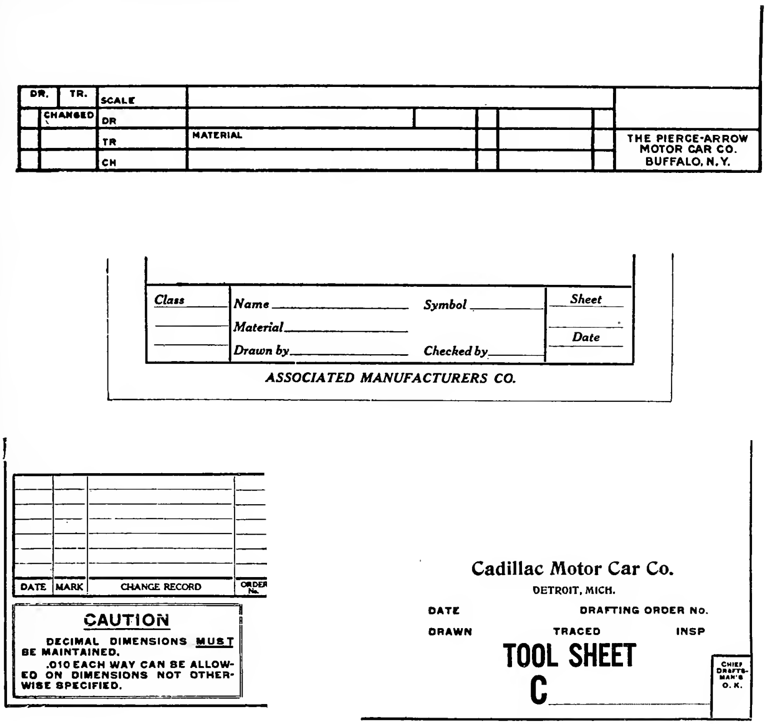


Fig. 70.—Various title forms.

Some concerns having many drawings save expense and secure greater uniformity and better appearance by printing the titles on their tracings with type. Sometimes only the standard portion of the title is printed, the variable portion being added free-hand by the draftsman.

Screw Threads.—The sharp edge of a screw thread is a curve known as a helix (Fig. 71q), and its projection on a plane parallel to its center-line is a curved line. Ordinarily straight lines are substituted for these curves, the ordinary V-thread being drawn as in Fig. 71a.

As the drawing of individual threads takes too much time, threads are usually indicated on working drawings by some one of the various conventional methods shown in Fig. 71. Where the lines representing the edges of threads are drawn perpendicular to the center-line, the thread is assumed to be right-hand unless otherwise specified.

Bolts and Nuts.—In Fig. 72 are shown the dimensions and the conventional methods of drawing U. S. standard bolts and nuts.

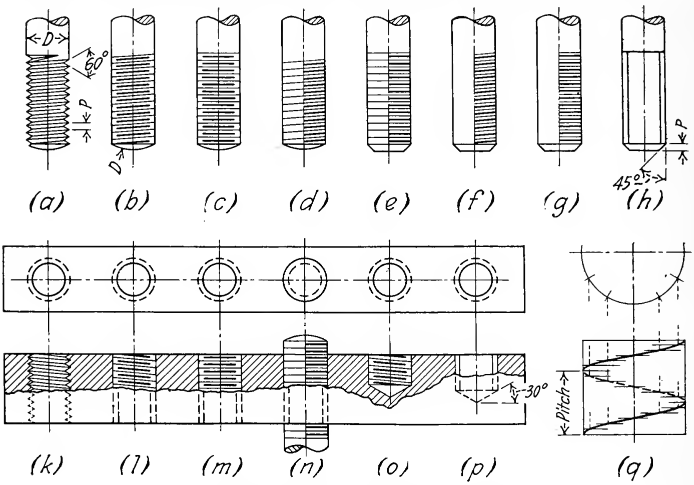
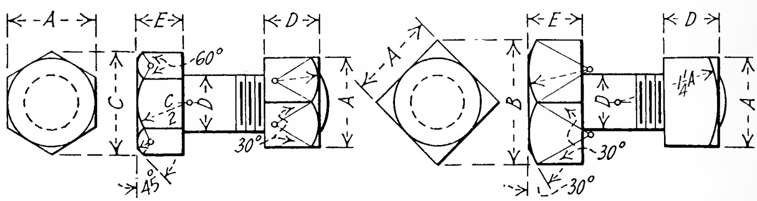


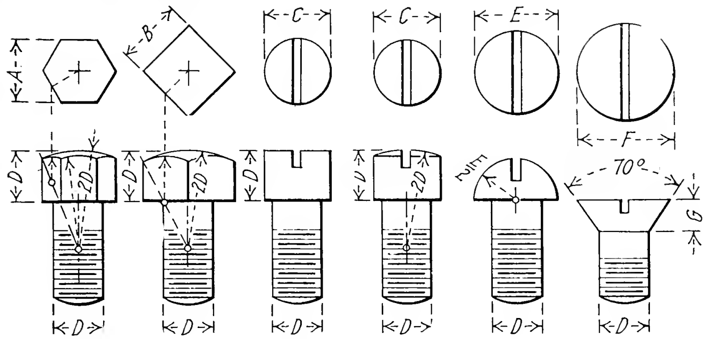
Fig. 71.—Conventional representation of threads.



Bolt Diam. D	Th'ds per Inch	Root Diam.	Short Diam. A	Long Diam. Square B	Long Diam. Hex. C	Thickness Nut D	Thickness Head E	Bolt Diam. D	Thds. per Inch	Root Diam.	Short Diam. A	Long Diam. Square B	Long Diam. Hex. C	Thickness Nut D	Thickness Head E
1/4	20	0.185	1/2	0.707	0.578	1/4	1/4	1 1/2	6	1.283	2 3/8	3.358	2.743	1 1/2	1 3/16
5/16	18	0.240	19/32	0.840	0.686	5/16	19/64	1 5/8	5 1/2	1.389	2 9/16	3.623	2.960	1 5/8	1 9/32
3/8	16	0.294	11/16	0.972	0.794	3/8	11/32	1 3/4	5	1.490	2 3/4	3.889	3.176	1 3/4	1 3/8
7/16	14	0.345	25/32	1.105	0.902	7/16	25/64	1 7/8	5	1.615	2 15/16	4.154	3.393	1 7/8	1 15/32
1/2	13	0.400	7/8	1.237	1.011	1/2	7/16	2	4 1/2	1.711	3 1/8	4.419	3.609	2	1 9/16
9/16	12	0.454	31/32	1.370	1.119	9/16	31/64	2 1/4	4 1/2	1.961	3 1/2	4.949	4.043	2 1/4	1 3/4
5/8	11	0.507	1 1/16	1.502	1.227	5/8	17/32	2 1/2	4	2.175	3 7/8	5.479	4.476	2 1/2	1 15/16
3/4	10	0.620	1 1/4	1.768	1.444	3/4	5/8	2 3/4	4	2.425	4 1/4	6.010	4.909	2 3/4	2 1/8
7/8	9	0.731	1 7/16	2.033	1.660	7/8	23/32	3	3 1/2	2.629	4 5/8	6.540	5.342	3	2 5/16
1	8	0.838	1 5/8	2.298	1.877	1	13/16	3 1/4	3 1/2	2.879	5	7.070	5.775	3 1/4	2 1/2
1 1/8	7	0.939	1 13/16	2.563	2.093	1 1/8	29/32	3 1/2	3 1/4	3.100	5 3/8	7.600	6.208	3 1/2	2 11/16
1 1/4	7	1.064	2	2.828	2.310	1 1/4	1	3 3/4	3	3.317	5 3/4	8.131	6.641	3 3/4	2 7/8
1 3/8	6	1.158	2 3/16	3.093	2.527	1 3/8	1 3/32	4	3	3.567	6 1/8	8.661	7.074	4	3 1/16

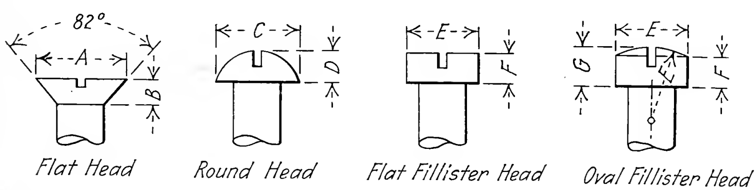
Fig. 72.—Dimensions of U. S. standard bolts and nuts.

Cap Screws.—The method of drawing the various styles of cap screws, together with a table of dimensions, is shown in Fig. 73. It should be noted that the heads are of smaller diameter and thicker than those of standard bolts.



D	A	B	C	E	F	G	D	A	B	C	E	F	G	D	A	B	C
1/8			3/16	7/32	1/4	3/32	7/16	5/8	9/16	5/8	3/4	13/16	17/64	7/8	1 1/8	1 1/8	1 1/8
3/16			1/4	5/16	3/8	9/64	1/2	3/4	5/8	3/4	13/16	7/8	17/64	1	1 1/4	1 1/4	1 1/4
1/4	7/16	3/8	3/8	7/16	15/32	5/32	9/16	13/16	11/16	13/16	15/16	1	5/16	1 1/8	1 3/8	1 3/8	
5/16	1/2	7/16	7/16	9/16	5/8	7/32	5/8	7/8	3/4	7/8	1	1 1/8	23/64	1 1/4	1 1/2	1 1/2	
3/8	9/16	1/2	9/16	5/8	3/4	17/64	3/4	1	7/8	1	1 1/4	1 3/8	7/16				

Fig. 73.—Dimensions of cap screws.



No.	Diam.	Thds.	A	B	C	D	E	F	G	No.	Diam.	Thds.	A	B	C	D	E	F	G
0	.060	80	.112	.030	.106	.042	.0894	.0376	.0496	12	.216	28	.424	.120	.394	.151	.3452	.1405	.1868
1	.073	72	.138	.037	.130	.051	.1107	.0461	.0609	14	.242	24	.476	.135	.443	.169	.3879	.1577	.2097
2	.086	64	.164	.045	.154	.060	.1320	.0548	.0725	16	.268	22	.528	.150	.491	.188	.4305	.1748	.2325
3	.099	56	.190	.052	.178	.069	.1530	.0633	.0838	18	.294	20	.580	.164	.539	.206	.4731	.1920	.2554
4	.112	48	.216	.060	.202	.078	.1747	.0719	.0953	20	.320	20	.632	.179	.587	.224	.5158	.2092	.2783
5	.125	44	.242	.067	.226	.087	.1960	.0805	.1068	22	.346	18	.684	.194	.635	.242	.5584	.2263	.3011
6	.138	40	.268	.075	.250	.097	.2170	.0890	.1180	24	.372	16	.736	.209	.683	.260	.6010	.2435	.3240
7	.151	36	.294	.082	.274	.106	.2386	.0976	.1296	26	.398	16	.788	.224	.731	.279	.6437	.2606	.3469
8	.164	36	.320	.090	.298	.115	.2599	.1062	.1410	28	.424	14	.840	.239	.779	.297	.6863	.2778	.3698
9	.177	32	.346	.097	.322	.124	.2813	.1148	.1524	30	.450	14	.892	.254	.827	.315	.7290	.2950	.3927
10	.190	30	.372	.105	.346	.133	.3026	.1234	.1639										

Fig. 74.—Dimensions of machine screws.

Machine Screws.—The proportions of the various sizes and styles of machine screws are shown in Fig. 74. Machine screws are specified by gage numbers as indicated.

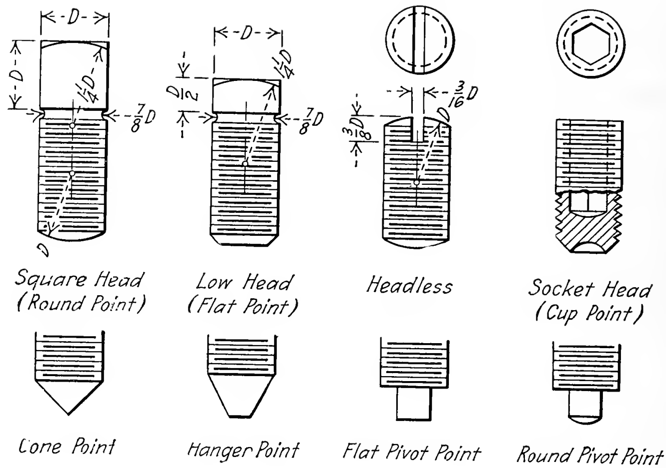
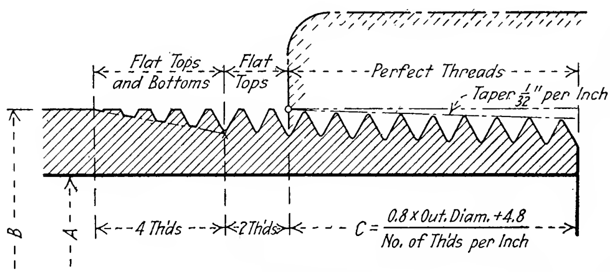


Fig. 75.—Dimensions of set screws.



Diameters			Thds per Inch	Internal Area	Distance Pipe Enters C	Diameters			Thds per Inch	Internal Area	Distance Pipe Enters C
Nominal Inside	Actual Inside A	Actual Outside B				Nominal Inside	Actual Inside A	Actual Outside B			
$\frac{1}{8}$	0.270	0.405	27	0.057	0.19	3	3.067	3.500	8	7.383	0.95
$\frac{1}{4}$	0.364	0.540	18	0.104	0.29	$3\frac{1}{2}$	3.548	4.000	8	9.887	1.00
$\frac{3}{8}$	0.494	0.675	18	0.191	0.30	4	4.026	4.500	8	12.730	1.05
$\frac{1}{2}$	0.623	0.840	14	0.304	0.39	$4\frac{1}{2}$	4.508	5.000	8	15.961	1.10
$\frac{3}{4}$	0.824	1.050	14	0.533	0.40	5	5.045	5.563	8	19.986	1.16
1	1.048	1.315	$11\frac{1}{2}$	0.861	0.51	6	6.065	6.625	8	28.890	1.26
$1\frac{1}{4}$	1.380	1.660	$11\frac{1}{2}$	1.496	0.54	7	7.023	7.625	8	38.738	1.36
$1\frac{1}{2}$	1.610	1.900	$11\frac{1}{2}$	2.036	0.55	8	7.982	8.625	8	50.027	1.46
2	2.067	2.375	$11\frac{1}{2}$	3.356	0.58	9	8.937	9.625	8	62.720	1.57
$2\frac{1}{2}$	2.468	2.875	8	4.780	0.89	10	10.019	10.750	8	78.823	1.68

Fig. 76.—Dimensions of standard steel and wrought-iron pipe.

Set Screws.—In Fig. 75 are shown the various styles and proportions of set screws used in machine work. Other combinations of the various heads and points shown may be used.

Standard Pipe.—The threads on U. S. standard steel and wrought-iron pipe differ from the standard V-thread as indicated in detail in Fig. 76. The various dimensions of value to the draftsman are stated in tabular form.

DECIMAL EQUIVALENTS OF FRACTIONS OF AN INCH

1/64	.015625	17/64	.265625	33/64	.515625	49/64	.765625
1/32	.03125	9/32	.28125	17/32	.53125	25/32	.78125
3/64	.046875	19/64	.296875	35/64	.546875	51/64	.796875
1/16	.0625	5/16	.3125	9/16	.5625	13/16	.8125
5/64	.078125	21/64	.328125	37/64	.578125	53/64	.828125
3/32	.09375	11/32	.34375	19/32	.59375	27/32	.84375
7/64	.109375	23/64	.359375	39/64	.609375	55/64	.859375
1/8	.125	3/8	.375	5/8	.625	7/8	.875
9/64	.140625	25/64	.390625	41/64	.640625	57/64	.890625
5/32	.15625	13/32	.40625	21/32	.65625	29/32	.90625
11/64	.171875	27/64	.421875	43/64	.671875	59/64	.921875
3/16	.1875	7/16	.4375	11/16	.6875	15/16	.9375
13/64	.203125	29/64	.453125	45/64	.703125	61/64	.953125
7/32	.21875	15/32	.46875	23/32	.71875	31/32	.96875
15/64	.234375	31/64	.484375	47/64	.734375	63/64	.984375
1/4	.25	1/2	.5	3/4	.75	1	1.0

Fig. 77.

Decimal Equivalents.—A table of decimal equivalents of the various fractional parts of an inch is inserted (Fig. 77) for the convenience of the student. The decimal equivalents for each sixteenth of an inch should be memorized.

Reproduction of Drawings

The tracings which the draftsman makes from his drawings are not suitable for shop use. They are permanent records and are seldom allowed to leave the drafting room, as they would be damaged and perhaps lost if sent to the shops. The necessary reproductions of the tracings that are needed in the shop and elsewhere may be made in various ways.

Blueprinting.—The cheapest process and the one in common use is called "blueprinting," this being simply a photo-printing process by which any number of copies can be made from one tracing. Tracings made on tracing cloth or tracing paper with a soft pencil can be blue-printed, but better results are secured from tracings inked in the usual manner.

Blueprints are made on white paper or cloth which has one side coated with a chemical sensitive to light. When fresh the sensitized side is of a pale yellowish-green color which with age, or on exposure to the light, turns a greyish-blue. If an unexposed piece of fresh paper is washed this coating is removed, leaving only the white paper; while a piece properly exposed to the light will turn a deep blue when similarly treated. In blueprinting a tracing, the opaque ink lines protect the coating underneath from the action of the light while the background is being exposed.

In making a blueprint the inked side of the tracing is placed against the glass of the printing frame (Fig. 78) and the sensitized side of the

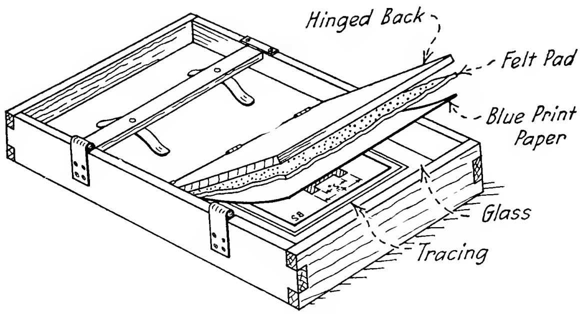


Fig. 78.—A printing frame.

blueprint paper against the tracing. The back of the printing frame is then locked in position to hold the tracing and the paper firmly in contact, and the glass side of the frame exposed to sunlight from one-half minute to several minutes, depending on the light and the speed or sensitiveness of the paper. The paper is then removed from the frame and washed in clear water for several minutes to fix the blue background and to wash the lines to a clear white. Prints hurriedly washed will fade badly on exposure to strong light. Prints may then be hung up to dry, or may first be dipped in a weak sodium bichromate solution. This operation improves the color and clearness of the prints and should be followed by a rinsing in clear water. The prints should be hung with the lower edge at an angle with the horizontal, so that the water will drain off at the lowest corner. Wet prints should be kept out of strong light and where the air can circulate freely. Drying can be materially hastened if the excess moisture is removed from the print by means of a rubber squeegee such as is used in window washing.

It should be noted that this process, photographically speaking, produces a negative in that the black lines of the tracing are changed to white lines on a dark (blue) background. Changes on blueprints may be made by the use of white and blue pencils, or the blue of the background can be bleached white by using an alkaline solution in the pen—such as washing soda with a little gum arabic added to prevent spreading. The practice of changing blueprints is not one to be recommended, as it is better to make any desired changes on the tracing and then to make new prints carrying a new date to indicate that a revision has been made.

Slow-printing paper keeps better and makes better prints than the rapid papers. Fresh paper prints more slowly than old but washes more quickly and will give whiter lines.

A good blueprint can be made from typewritten copy made on thin paper with black carbon-paper placed both in front and behind. Inked drawings on thick paper may be printed readily if transparentized with oil, hot paraffin, or, temporarily, with benzine.

Where much blueprinting is done, electric printing machines are convenient and make the process independent of weather conditions. These machines may be had in many forms, varying from those printing separate sheets to those which print on continuous rolls of paper and automatically wash, "potash," dry, iron and reroll the paper. Every large city has its printing concerns, and it is more economical for firms requiring only a moderate amount of blueprinting to patronize these establishments than to maintain their own printing plant.

Blue-line and Brown-line Prints.—Blueprint "positives" may be made by first printing a negative on thin Van Dyke paper or cloth which gives white lines on a dark-brown and opaque background. This negative is printed and washed in the same manner as an ordinary blueprint. It is then placed in a "hypo" or fixing bath for a moment, this being followed by a rinsing in water before the negative is dried. The blueprint positive, or "blue-line" print, is made by blueprinting in the usual manner, using the Van Dyke negative instead of a tracing. If desired the positive may be printed on Van Dyke paper, this process giving dark-brown lines on a white ground. Such prints are considerably more expensive than blueprints, but have important advantages in some cases.

Direct Positive Prints.—Certain printing papers may be obtained which produce blue-line or black-line positives with one printing. While these papers are relatively expensive, slow printing and frequently of poor keeping qualities, their use is a decided convenience under certain conditions. Most of these papers require no special developing solutions, being handled like blueprint paper.

Photography.—Tracings are frequently photographed, usually to a reduced size, and photographic prints made from the negatives. Such photographic reproductions of large drawings are a decided convenience to men in the field on account of the reduction in size of the sheets. This process, however, is relatively expensive.

Direct Photography.—Copies of drawings, blueprints, etc., may be made by means of a special type of camera containing a prism so placed as to prevent the usual reversal of image in the negative. The negative is used as the reproduction, with the usual color reversal of light and dark. A blueprint, when thus reproduced, has dark lines on a light background. The Photostat, Rectigraph and Cameragraph are the trade names of machines making use of this principle.

Gelatine Process.—Drawings may be reproduced on tracing cloth or on paper by a special process in which a special "matrix" print is first made on a blueprint machine and then transferred to a flat gelatine surface. The impression is then inked, and the copies or prints rubbed into contact and pulled from it. The "Janney," "Lithoprint" and "Eureka" processes are of this nature.

Drafting Room Geometry

A knowledge of certain principles of geometry is essential to the mechanical draftsman. Purely geometrical constructions are such as may be made with a pair of compasses and a straight edge, but the draftsman, with his instruments, has special and less laborious methods of accomplishing many of these operations. For example, a line parallel to a given line may be constructed geometrically as indicated in Fig. 79a, while the draftsman's method of doing this has been shown in Fig. 7a.

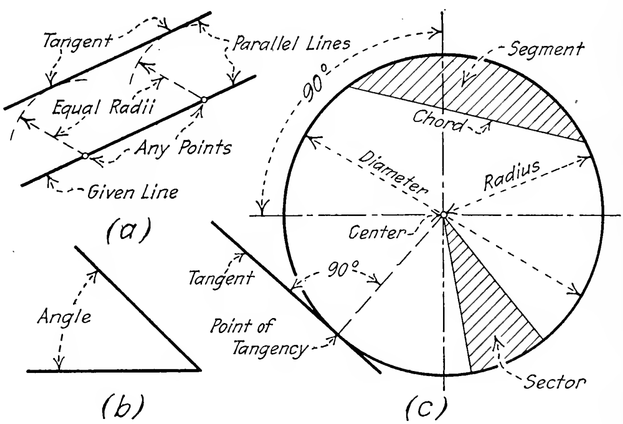


Fig. 79.

Circle.—A circle is a closed curved line every point of which is the same distance (radius) from a fixed point (center) within. Any two lines radiating from the center cut off a part of a circle (arc) and form an angle (Fig. 79b), each being measured in degrees, 360 of which are contained in a circle. Thus, a right angle is one-fourth of a circle (Fig. 79c), or 90 degrees (90°), and may be constructed by drawing two perpendicular lines (Figs. 7b and 7c). A line tangent to a circle (Fig. 79c) at any given point is perpendicular to a radial line through the point.

Triangles.—Plane figures having three straight sides are called triangles (Fig. 80a). The sum of the three inside angles of a triangle is always equal to 180°.

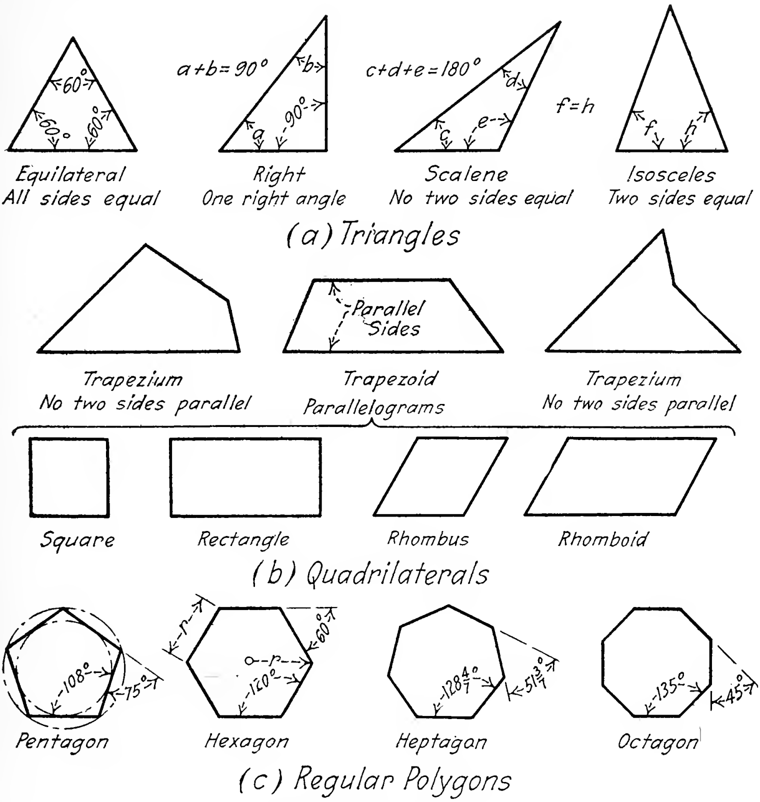


Fig. 80.—Triangles, quadrilaterals and polygons.

Quadrilaterals.—Any plane figure having four straight sides is called a quadrilateral. The common sorts of quadrilaterals are shown in Fig. 80b.

Polygons.—The equilateral triangle and the square are regular polygons. Other regular polygons are shown in Fig. 80c. All regular polygons can be constructed within or tangent to a circle, as is indicated in the case of the pentagon.

Solids.—Some of the solids commonly used are indicated in Fig. 81. A sphere is a solid included within a surface which is at every point equidistant from an internal point (center). Both prisms (Fig. 81a) and cylinders have bases which are parallel and equal. When a portion is cut away by a plane not parallel to the bases such solids are said to be truncated. When a cone or pyramid is similarly cut by a plane parallel to its base, the portion between the bases is known as a frustum (Fig. 81b).

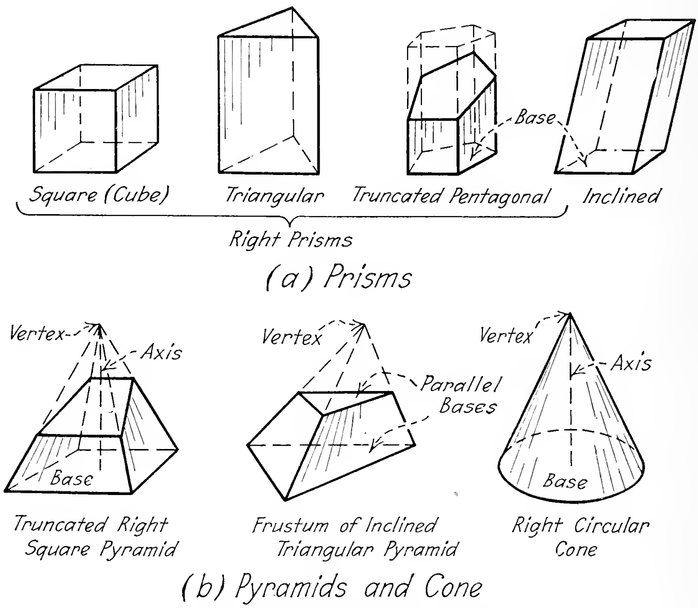


Fig. 81.—Prisms, pyramids and cones.

To Bisect a Line.—(Fig. 82a.)—(Geometrical Method.) Given the line AB. Use any radius R, with A and B as centers. Connect the arc intersections (C and D) with a line cutting AB at E. Then AE=BE. (A Draftsman's Method.) Use the triangles against a straight-edge placed parallel to the line (Fig. 82b), drawing three lines in the order indicated. Then AC=BC.

To Divide a Line into Equal Parts.—(Fig. 83.) Given the line AB to be divided into seven equal parts. Select a suitable scale, placing it as indicated and marking the points C to 6 so as to have seven equal spaces. If preferred, seven equal spaces of convenient length may be stepped off with the dividers along any line AC.

Draw the line BC. Then through points 1 to 6 draw lines parallel to BC, using the triangles (Fig. 7a). The intersections with AB will form the desired divisions.

To Bisect an Angle.—(Fig. 82c.) Given the angle AOB. With O as a center and any radius R_1 strike an arc to obtain intersections C and D. With C and D as centers and any radius R_2 strike arcs intersecting at E. Then line EO is the bisector.

To Reconstruct an Angle.—(Fig. 82d.) Given the angle AOB. Draw the line O′B′. With any radius R_1 strike arcs from O and O′. Make C′D′=CD (R_2) and draw O′A′ through D′.

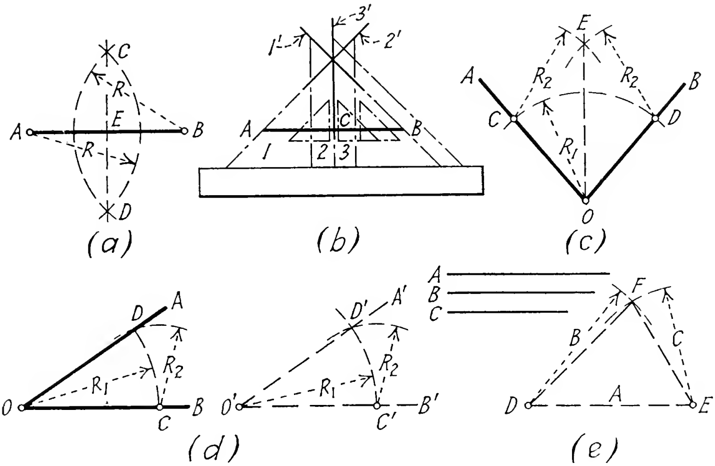


Fig. 82.

To Construct a Triangle.—(Fig. 82e.) Given the sides B and C as radii strike arcs intersecting at F. Draw DF and EF.

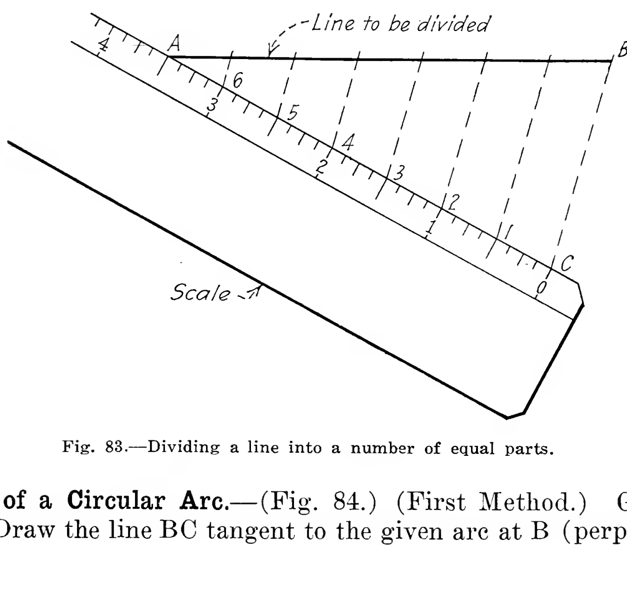


Fig. 83.—Dividing a line into a number of equal parts.

Length of a Circular Arc.—(Fig. 84.) (First Method.) Given the arc AB. Draw the line BC tangent to the given arc at B (perpendicular to the radius). Set the dividers to a suitable spacing and, starting at A, step off equal spaces until a point is reached just beyond B. Without

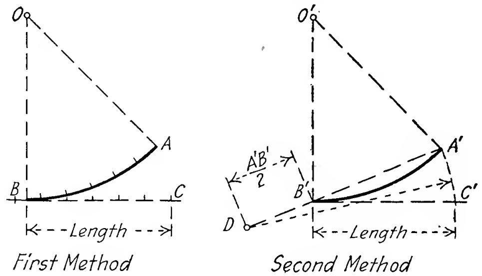


Fig. 84.—Finding the length of a circular arc.

lifting the dividers step off the same number of spaces in a reverse direction along the tangent BC. Then BC is the required length, the theoretical accuracy depending on the length of the chord used. (Second

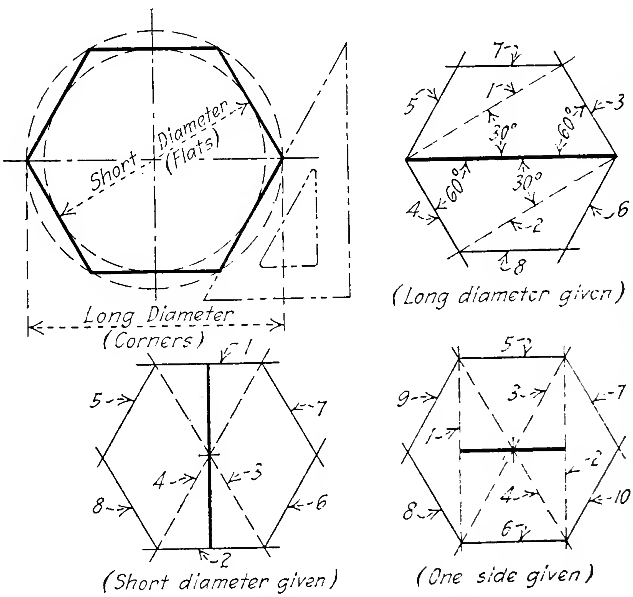


Fig. 85.—Construction of regular hexagons.

Method). Draw the line B′C′ tangent to given arc A′B′ at B′. Draw the chord A′B′, extending it one-half its length to D. With D as a center and DA′ as a radius strike an arc to cut the tangent line at C′. Then B′C′ is the required length. This construction should not be used when the angle AOB is greater than 60°.

The Regular Hexagon.—(Fig. 85.) There are various methods of constructing the hexagon. Usually the draftsman is given the distance across the flats or the distance across the corners, either of which may be used as the diameter of a circle drawn with its center at the intersection of the center lines. The hexagon may then be readily constructed within or tangent to this circle, using the 30°-60° triangle as indicated. Other methods of constructing the hexagon, using only this triangle, are also indicated—the given dimension in each case being shown as a heavy line, and the sequence for drawing the lines indicated by the figures.

Tangent Arcs.—(Fig. 86.) When a circular arc is tangent to a straight line the point of tangency will be on a line drawn through the

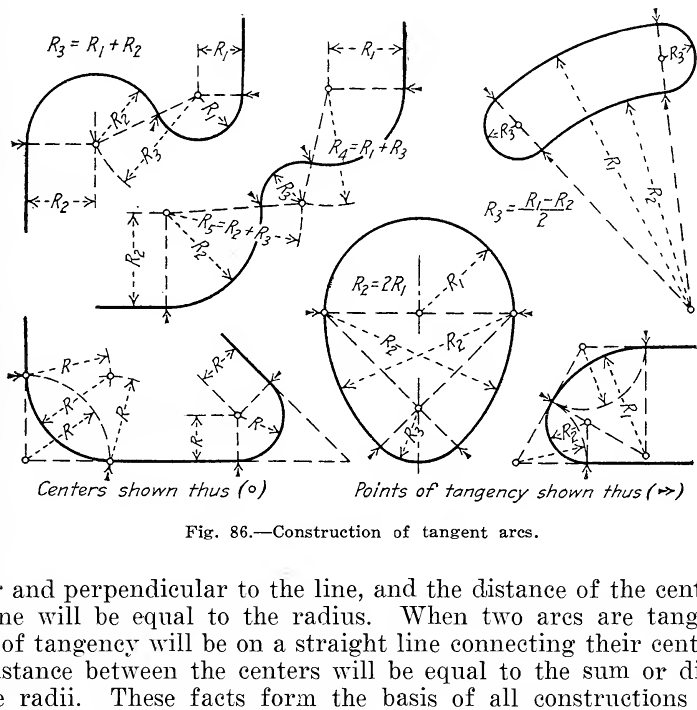


Fig. 86.—Construction of tangent arcs.

center and perpendicular to the line, and the distance of the center from the line will be equal to the radius. When two arcs are tangent, the point of tangency will be on a straight line connecting their centers, and the distance between the centers will be equal to the sum or difference of the radii. These facts form the basis of all constructions used to locate centers for drawing arcs. A number of such constructions involving tangent arcs are shown in the illustration.

The Ellipse.—(Fig. 87.) An ellipse is a closed curve so drawn that the sum of the distances from any point on the curve to each of two fixed points (foci) is the same. Each of these fixed points is called a focus. As every projection of a circle viewed obliquely is an ellipse, this curve must be drawn frequently. The major and minor axes are usually known and may be measured off on the center lines. If desired the foci may be located in the manner indicated (Fig. 87a) and a sufficient number of points to define the curve located by intersecting arcs struck from the foci as centers. The "trammel" method (Fig. 87b) is a neater one for the draftsman as it requires no construction lines. On a straight slip of paper three points (E, F and G) are marked so that EF equals half the minor axis, while EG equals half the major. If the trammel is moved, keeping the points F and G on the major and the

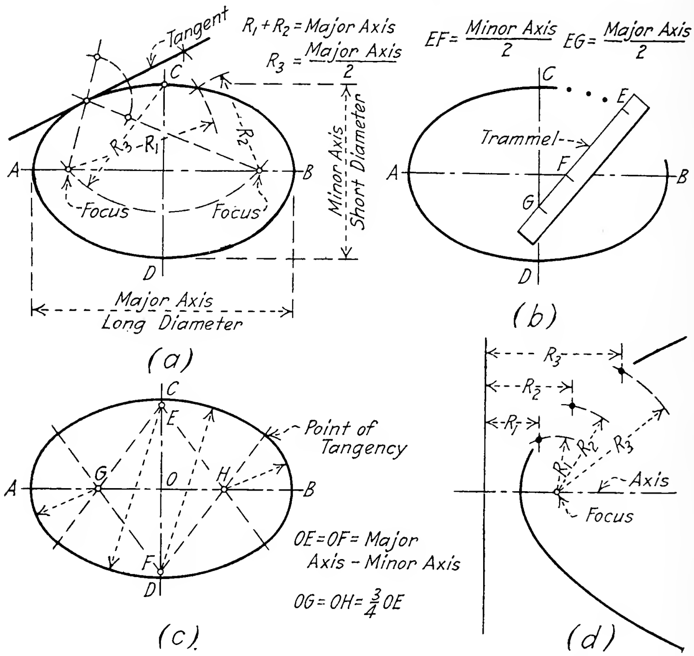


Fig. 87.—Construction of the ellipse and the parabola.

minor axes, respectively, the point E will locate points on a true ellipse. A light line should be sketched through the series of points thus found, and the curve drawn in accurately with the assistance of a French curve.

Frequently it is sufficiently accurate to approximate the ellipse by substituting circular arcs for the true curve. Thus, having the axis given (Fig. 87c), lay off OE an OF each equal to the length of the major axis less the minor axis. Make OG and OH each equal to three-fourths of OE. Use the points E, F, G and H as centers for the four circular arcs as indicated.

The Parabola.—(Fig. 87d.) The parabola is an open curve so drawn that each point on the curve is equidistant from a fixed point (focus) and a straight line (directrix). Points on the curve may be found by assuming various values for R, as indicated in the illustration.