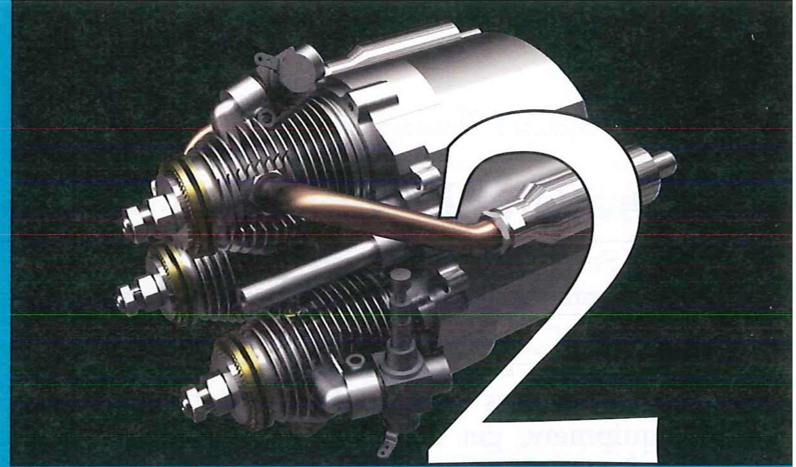
Traditional Drafting Equipment and Drawing Techniques



Learning Objectives

After studying this chapter, you will be able to:

- Identify and describe how to use basic drafting tools.
- List and explain the types of lines in the Alphabet of Lines.
- Describe how to make drawings to scale.
- Use drafting tools and basic drawing techniques to make drawings.

Technical Terms

Alphabet of Lines
Architect's scale
Beam compass
Border lines
Bow compass
Break lines
Centerlines
Civil engineer's scale
Combination scale
Compass
Construction lines
Cutting plane
Cutting-plane lines
Datums
Dimension lines
Dividers
Drafting machine
Drafting media
Drafting templates
Drawing board
Drawing pencils
Electric eraser
Erasers
Erasing shield
Extension lines
French curve
Friction-joint compass
Full-divided scale
Ghosting
Hidden lines
Instrument drafting
Irregular curves
Leaders
Mechanical engineer's scale
Metric scale
Object lines
Open-divided scale
Parallel straightedge
Phantom lines
Pointing
Polyester film
Proportional dividers
Protractor
Scale
Section lines
Technical pen
Title block
Tracing paper
Triangles
T-square
Vellum

The purpose of an engineering or technical drawing is to convey information about a part or assembly as clearly and simply as possible. The process of making technical drawings using instruments, templates, scales, and other mechanical equipment is called ***instrument drafting***. Computer-based drafting is accomplished using a computer-aided drafting (CAD) system. CAD tools and drawing methods are discussed in Chapters 3 and 4.

Today, the production and servicing of industrial components requires careful preparation of drawings. The purpose of this chapter is to enable you to gain a knowledge of basic drawing instruments and to instruct you in their proper use and care. After you have become familiar with these basic tools, you can easily acquire skill with more specialized instruments used in drafting. Some of the instruments needed for technical drawing are shown in **Figure 2-1**.

Figure 2-1. Basic instruments used in drafting. (Koh-I-Noor Rapidograph, Inc.)

Drafting Equipment

Some schools furnish drafting equipment for their students. Others require that students purchase their own. Good instruments are expensive, but it is wise to invest in quality items. Unless you are familiar with drafting equipment, get the advice of your instructor before making a purchase. The equipment and supplies listed below are adequate for most drafting work.

Instruments

- Small compass with pen attachment
- Large compass with pen attachment
- Lengthening bar
- Friction joint dividers
- Lead holder
- Box of leads
- Technical pen
- Screwdriver

Other Equipment

- Drawing board or drawing table
- T-square (24″ plastic edge)
- 30°-60° triangle (10″)
- 45° triangle (8″)
- Architect's and engineer's scales
- Lettering device
- Protractor
- Irregular or French curve
- Circle and ellipse templates
- Erasing shield
- Vinyl eraser
- Dusting brush
- Sketch pad
- Drawing paper, tracing paper, or vellum
- Drafting tape
- Drafting pencils or mechanical lead holder
- Sandpaper pad, file, or pencil pointer

Drawing Boards

A ***drawing board*** provides a surface for drafting. Traditional drawing boards are made in standard sizes of 12″ × 18″, 18″ × 24″, 24″ × 36″, and 30″ × 42″. Most boards are white pine or basswood, **Figure 2-2**, or plywood with a vinyl cover. They may have cleated ends to restrain warping. For those who still draft manually, drafting tables that have drawing-board tops are used most often. These tables are usually larger and have a drafting machine or straightedge permanently attached.

T-Square

The ***T-square*** is a traditional manual drafting instrument, **Figure 2-3**. It is manufactured from wood, metal, plastic, or a combination of these materials. The T-square slides along one edge of the drafting board and is used to draw horizontal lines. It also provides an edge against

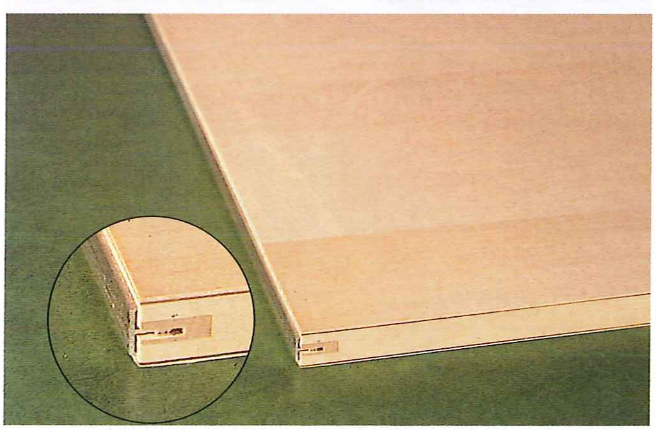


Figure 2-2. Traditional drawing board with cleated ends.

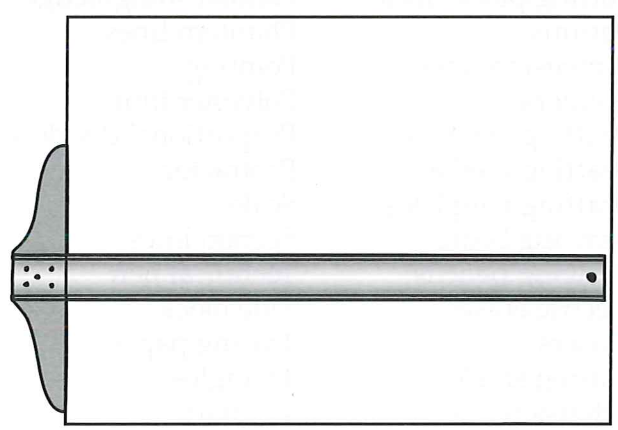


Figure 2-3. A T-square is used to draw straight lines.

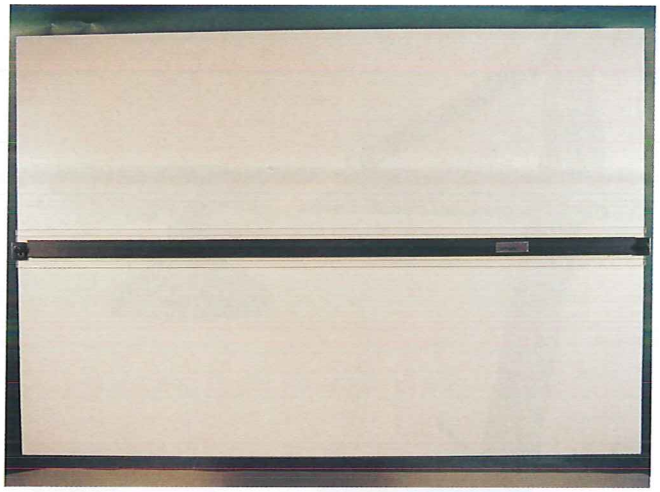


Figure 2-4. A drafting board may be equipped with a parallel straightedge.

which triangles are placed to draw vertical and inclined lines. A T-square is used when a drafting machine is not available.

Parallel Straightedge

Drawing boards and tables may be equipped with a *parallel straightedge*, **Figure 2-4**. The straightedge is preferred for large drawings and for vertical board work. It is easily manipulated and retains its parallel position.

The straightedge may be moved up or down the board. It is supported at both ends by a cable that operates over a series of pulleys, keeping the straightedge parallel.

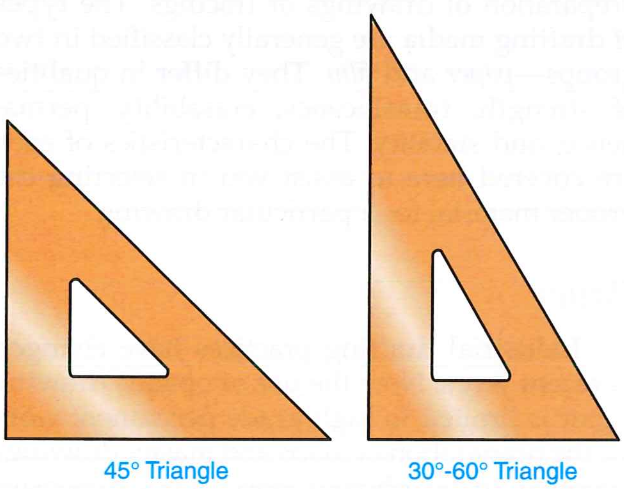


Figure 2-5. Transparent plastic triangles are available in many sizes. The 45° and 30°-60° types are most common.

Triangles

Triangles are used to draw vertical and inclined lines. The most commonly used drafting triangles are the 45° and 30°-60° types, **Figure 2-5**. They are made of transparent plastic, and their size is designated by the height of the triangle. They may be purchased in sizes from 4″ to 18″.

Special purpose triangles are made to help draw guidelines for lettering, lay out roof pitches, and complete intricate angular work, **Figure 2-6**.

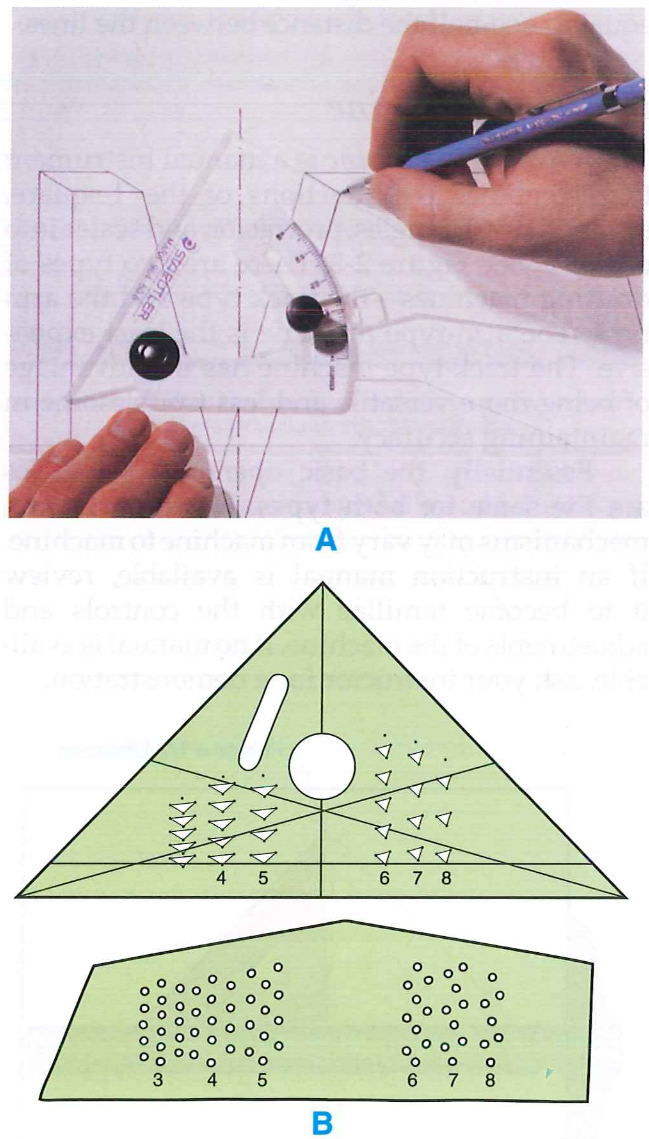


Figure 2-6. Special purpose triangles. A—An adjustable triangle is used for complex angular work. (Staedtler Mars GmbH & Co.) B—Some lettering guides have special alignment angles.

An adjustable triangle permits the laying off of any angle from 0° to 90°.

Occasionally check all triangles for nicks by running your fingernail along the edges. Such defects are caused by hitting the triangles against sharp edges, dropping them, or using them as a guide for a knife in cutting or trimming. Minor defects, nicks, or misalignment can be corrected by sanding the edge with fine abrasive paper wrapped around a block of wood.

Test a triangle for accuracy by drawing a vertical line. Reverse the triangle and draw a second line, starting at the same point, **Figure 2-7**. If the lines coincide, the triangle is true. If not, the error is equal to one-half the distance between the lines.

Drafting Machine

A ***drafting machine*** is a manual instrument that combines the functions of the T-square, straightedge, triangles, protractor, and scales into one tool. See **Figure 2-8**. There are two types of drafting machines—the track type and the arm type. The arm-type machine is the least expensive. The track-type machine has the advantage of being more versatile and less troublesome in maintaining accuracy.

Essentially, the basic operating principles are the same for both types. However, control mechanisms may vary from machine to machine. If an instruction manual is available, review it to become familiar with the controls and adjustments of the machine. If no manual is available, ask your instructor for a demonstration.

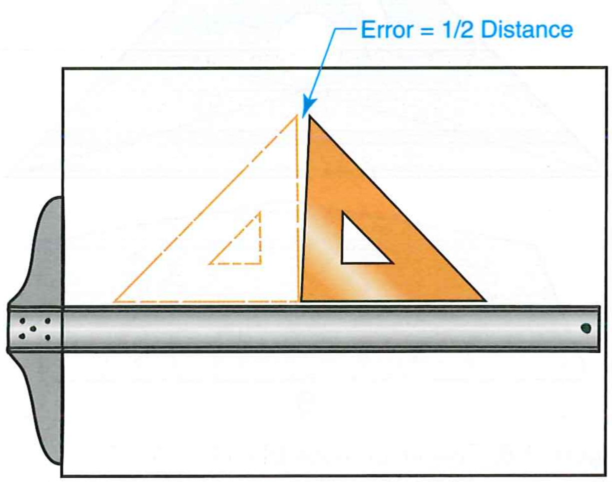


Figure 2-7. Check triangles for trueness. The error will be one-half the distance between the lines.

Figure 2-8. A track-type drafting machine. (Vemco Corporation)

Alignment of the drafting machine should be checked periodically by comparing results with previously drawn horizontal and vertical lines. When differences occur, check the board mounting clamps, scale chuck clamps, and the baseline protractor clamp. If these are in order, check the maintenance manual for the machine or check with your instructor.

Drafting Media

Drafting media are materials used in the preparation of drawings or tracings. The types of drafting media are generally classified in two groups—*paper* and *film*. They differ in qualities of strength, translucency, erasability, permanence, and stability. The characteristics of each are covered here to assist you in selecting the proper material for a particular drawing.

Paper

Industrial drafting practices have changed in recent years. Now the use of opaque drawing paper is limited to high-grade permanent work for the preparation of maps and master drawings intended to be photographed. Less expensive paper is used for beginning drafting classes in schools. Even here, however, the tendency is to use inexpensive types of translucent materials.

Opaque drawing sheets are available in cream, light green, blue tint, and white. White paper is preferable for drawings to be photographed later. Light-colored paper reduces eye strain and is less likely to soil.

Drawing sheets are available in standard US Customary and metric sizes. In both systems, letter designations are used to identify sheet sizes. Two series of US Customary sizes are recognized as standard. These series are based on the standard sizes of 8 1/2″ × 11″ and 9″ × 12″. The series consist of multiples of each size, **Figure 2-9A**. Metric drawing sheet sizes are shown in **Figure 2-9B**.

Tracing Paper

Tracing paper is a translucent drawing paper. Its name was derived from the practice of first making a drawing in pencil on opaque paper, then "tracing" it in ink on an overlay sheet of translucent paper.

Today, however, the more common practice is to develop the master drawing in pencil directly on tracing paper from which reproductions can be made (eliminating the time and expense of preparing a "tracing"). Inking is reserved primarily for permanent drawings or for photographic reproduction work.

Tracing paper (as differentiated from vellum, described below) is natural paper that has no additives to make the paper transparent. Natural paper made fairly strong and durable is not very transparent. Paper with high transparency is only moderately durable.

Vellum

Vellum is referred to as transparentized or prepared tracing paper. Vellum sheets provide strength, transparency, durability (in handling and folding), and erasability without ***ghosting*** (where erased lines show through).

Vellum sheets are made of 100% rag content and impregnated with a synthetic resin to provide high transparency. They are available in white or blue tint and are highly resistive to discoloration and brittleness due to age. The working qualities of vellum make it more commonly used in industry than tracing paper even though it is more expensive than tracing paper.

Polyester Film

Polyester film is a newer development in drafting media. It is more durable than vellum. With the exception of cost, it has the best qualifications for a drawing medium. It provides dimensional stability, strong resistance to tearing, easy erasing (with a soft eraser or erasing fluid), and high transparency. It is waterproof and will not discolor or become brittle with age.

Polyester film has an excellent working surface for pencil, ink, or printing devices. Many industries feel that the added cost of this medium is offset by its advantages, including the ease with which changes can be made.

US Customary System			
Multiples of 8 1/2″ × 11″ Size		Multiples of 9″ × 12″ Size	
Letter Designation	Sheet Size	Letter Designation	Sheet Size
A	8 1/2 × 11	A	9 × 12
B	11 × 17	B	12 × 18
C	17 × 22	C	18 × 24
D	22 × 34	D	24 × 36
E	34 × 44	E	36 × 48

A

Metric System		
Designation	Sheet Size (millimeters)	Sheet Size (inches)
A4	210 × 297	8.27 × 11.69
A3	297 × 420	11.69 × 16.54
A2	420 × 594	16.54 × 23.39
A1	594 × 841	23.39 × 33.11
A0	841 × 1189	33.11 × 46.81

B

Figure 2-9. Standard US Customary and metric sheet sizes.

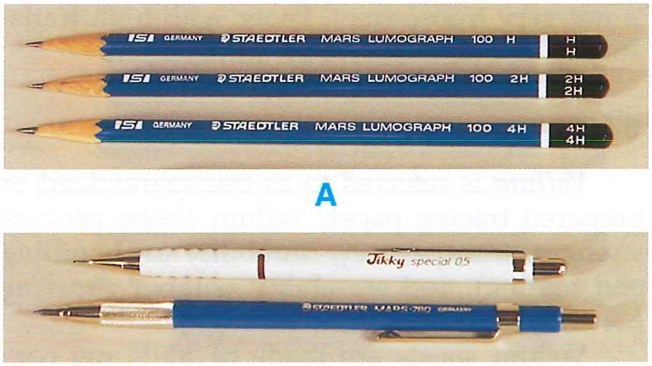


Figure 2-10. Drawing pencils used in drafting. A—Wooden pencils are available in different grades of hardness. B—Mechanical lead holders are available in different lead sizes.

Fastening the Drawing Sheet to the Board

The drawing sheet should be positioned on the drawing board or table so that it is accessible and comfortable. When it is positioned correctly, fasten the upper corners of the sheet with drafting tape so that it is aligned properly with the T-square or drafting machine. Smooth the sheet out to the corners and fasten the lower corners.

When a drafting machine is being used, the drawing sheet may be placed at a slight angle. This provides a more "natural" drawing and lettering position than the horizontal position necessary when using a T-square.

Drawing Pencils

Drawing pencils are manufactured in a variety of types, **Figure 2-10**. The following types are common.

- Standard wooden pencils.
- Rectangular leads with a wedge point.
- Mechanical lead holders in standard lead sizes.
- Fractional millimeter lead sizes called *thin leads.*

Although more expensive, refill pencils are convenient to use. They remain the same length and save the time required in sharpening wooden pencils.

Leads used in drawing pencils are manufactured by a special process designed to make them strong and capable of producing sharp, even-density lines. Drawing leads are graded in 18 degrees of hardness from 7B (very soft) to 9H (very hard).

The softer grades of pencil leads (2H, 3H, and 4H) deposit more graphite on the paper and produce more opaque lines. However, many drafters prefer to use the harder grades because they produce sharper lines and do not smudge as readily during the drafting process.

Special pencil leads with a plastic base are manufactured for use on polyester film. They come in five grades of hardness from K1 (very soft) to K5 (very hard).

Sharpening the Pencil

When sharpening wooden pencils, first remove enough wood to expose 3/8″ of lead on the end opposite the grade marking, **Figure 2-11**.

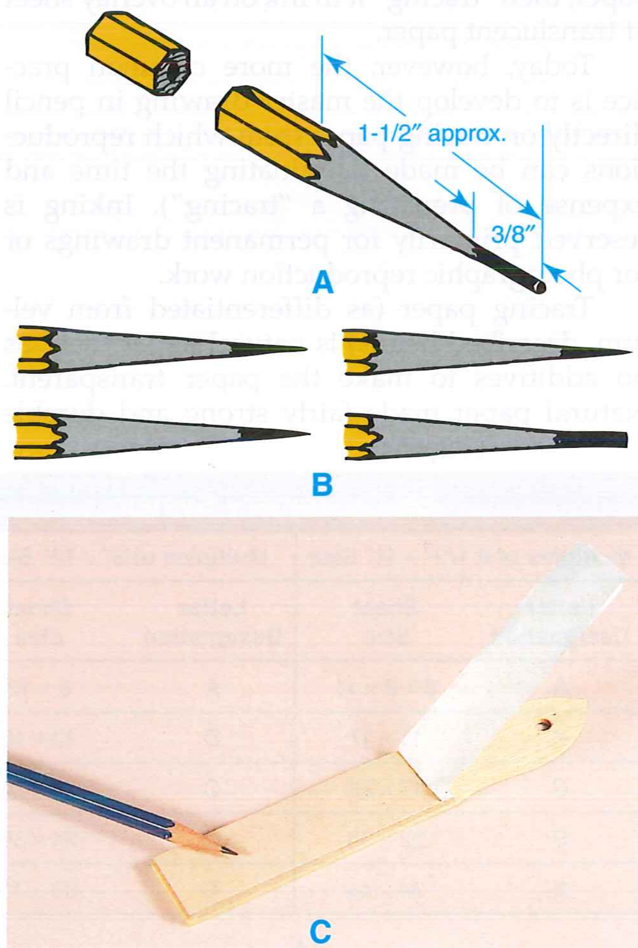


Figure 2-11. Sharpening a wooden pencil. A sanding pad (at C) can be used for final shaping (pointing).

Use a knife or a drafter's pencil sharpener with special cutters that will remove wood only, **Figure 2-12**. If a knife is used, exercise care to prevent nicking the lead, causing it to break under pressure of use. For final shaping, finish the point on a piece of scrap paper or use a lead pointer (such as a sandpaper pad). This is known as ***pointing***.

Lead in standard size lead holders should be extended slightly beyond the normal use position for pointing. Thin leads do not require pointing. After pointing, remove all excess graphite dust from the pencil point by wiping it on a felt pad or soft cloth.

Two types of points are used on drafting pencils—conical and wedge. A *conical point* is used for general line work and lettering. It is shaped in a lead pointer, on a sandpaper pad, or with a file.

A *wedge point* is used for drawing long, straight lines because it holds a point (edge) longer than the conical point. Shape the point on a sandpaper pad or file by dressing the two sides to produce a sharp edge. Finish on scrap paper and remove the excess graphite dust.

To maintain a neat work area and produce clean drawings, do not sharpen the pencil over your drawing or instruments. Before storing tools, remove the graphite dust from the sandpaper pad or file by tapping it lightly against the inside of a wastebasket.

Figure 2-12. Drafter's pencil sharpeners look like regular pencil sharpeners, but they remove only the wood and leave the lead.

As shown in **Figure 2-13**, lines are drawn thick or thin. For manual drafting, the ASME standard recommends an approximate 2:1 line width ratio of thick lines to thin. Recommended minimum line widths are 0.6 mm (for thick lines) and 0.3 mm (for thin lines). For CAD drafting, a uniform line width for all lines is acceptable. All lines on drawings should be dense and black, regardless of width, as thin pencil lines tend to "burn out" during the reproduction process of making prints. Any variation in lines should be in width and character only. Pencil lines are likely to be slightly thinner than corresponding ink lines. However, pencil lines should be as thick as practical to provide acceptable reproductions.

Alphabet of Lines

The American Society of Mechanical Engineers (ASME) has developed a standard for lines that is accepted throughout industry. Known as the ***Alphabet of Lines***, this standard is designed to give universal meaning to the lines of a drawing, **Figure 2-13**.

The lines in the Alphabet of Lines are used to describe shape, size, hidden surfaces, interior detail, and alternate positions of parts. The conventions shown in **Figure 2-13** should be studied carefully, and each drawing produced should conform to this standard. Note that the lines differ in *width* (sometimes referred to as thickness or weight). They also differ in character. Each is easily distinguishable from another. Each conveys a particular meaning on the drawing. The use of these lines on a drawing is illustrated in **Figure 2-14**.

Object Lines

Object lines are also known as *visible lines*. They are used to outline the visible edges or contours of the object that can be seen by an observer. Object lines should stand out sharply when contrasted with other lines on the drawing. They should be the darkest lines on the drawing, with the exception of the border.

Hidden Lines

Hidden lines indicate edges, surfaces, and corners of an object that are concealed from the view of the observer. They are thin lines made up of short dashes, evenly spaced. The dashes are approximately 1/8" long and the spaces are approximately 1/32" long. They may vary slightly with the size of the drawing.

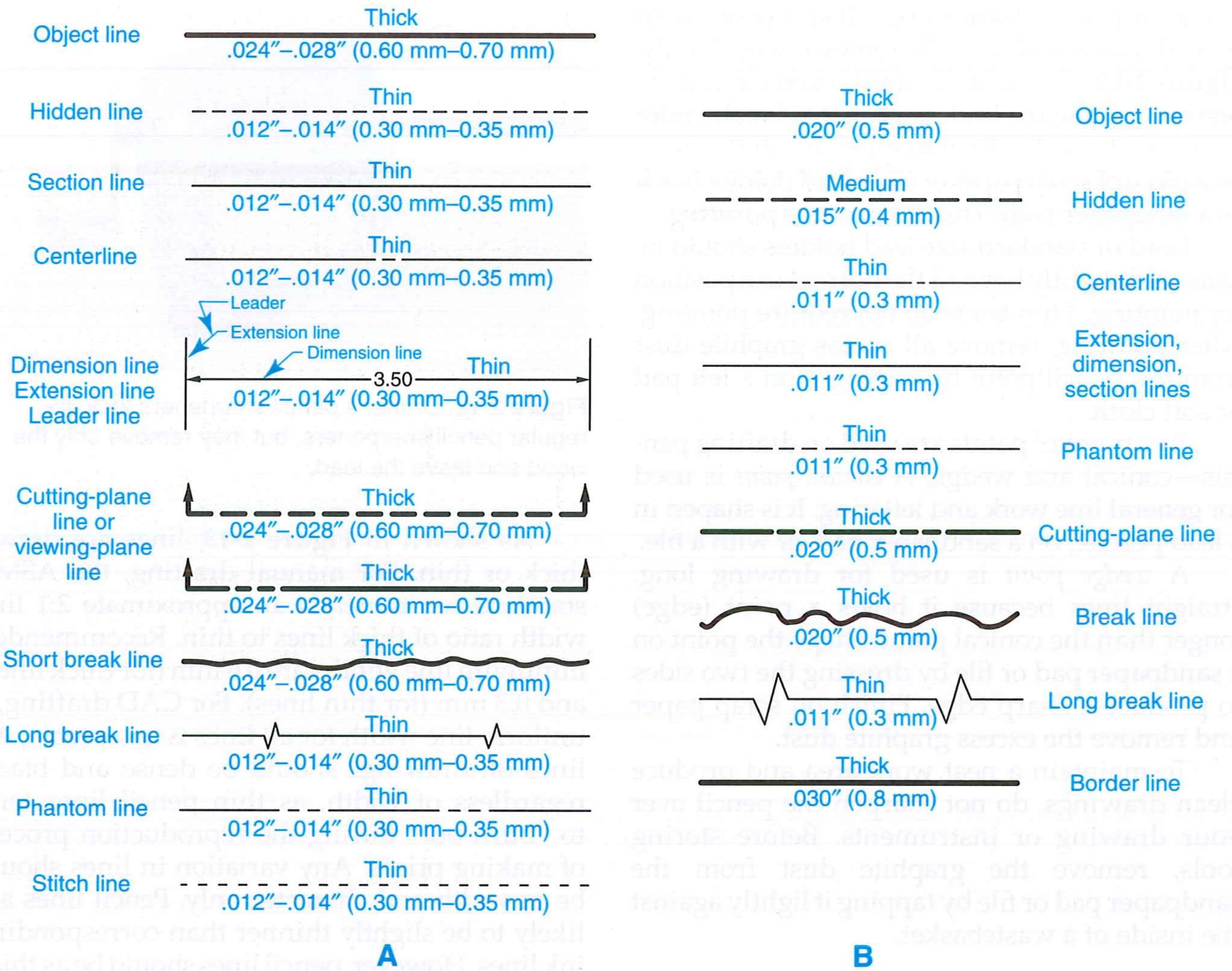


Figure 2-13. A—In the Alphabet of Lines, two line weights (thick and thin) are used for drawing lines. (American Society of Mechanical Engineers) B—A nonstandard Alphabet of Lines that uses a third line weight for hidden lines.

Hidden lines start and end with a dash. They make contact with object lines or other hidden lines from where they start or end, **Figure 2-15A**. If the hidden line is a continuation of an object line, then a gap is shown, **Figure 2-15B**. A gap is also shown when a hidden line crosses but does not intersect another line, **Figure 2-15C**. Dashes should join at corners, and arcs should start with dashes at tangent points, **Figure 2-15D** and **2-15E**.

Hidden lines should be omitted wherever they are not needed for clarity. By omitting hidden lines when not needed, very complex drawings will be easier to read. However, until you gain experience in drafting, you should include all required lines unless otherwise directed by your instructor.

Section Lines

Section lines are sometimes referred to as crosshatching. These lines represent surfaces exposed by a ***cutting plane*** (an invisible plane passing through an object). Section lines are usually drawn at an angle of 45° with a sharp 2H pencil, **Figure 2-16**. If more than one object is sectioned on the same drawing, vary the angle and direction of the section lines to demonstrate the different parts. Draw the lines dark and thin to contrast with the heavier object lines. On average size drawings, space the lines by eye about 1/16″ apart. On small drawings, use 1/32″ spacing. On large drawings, use 1/8″ spacing. Spacing of section lines should be uniform.

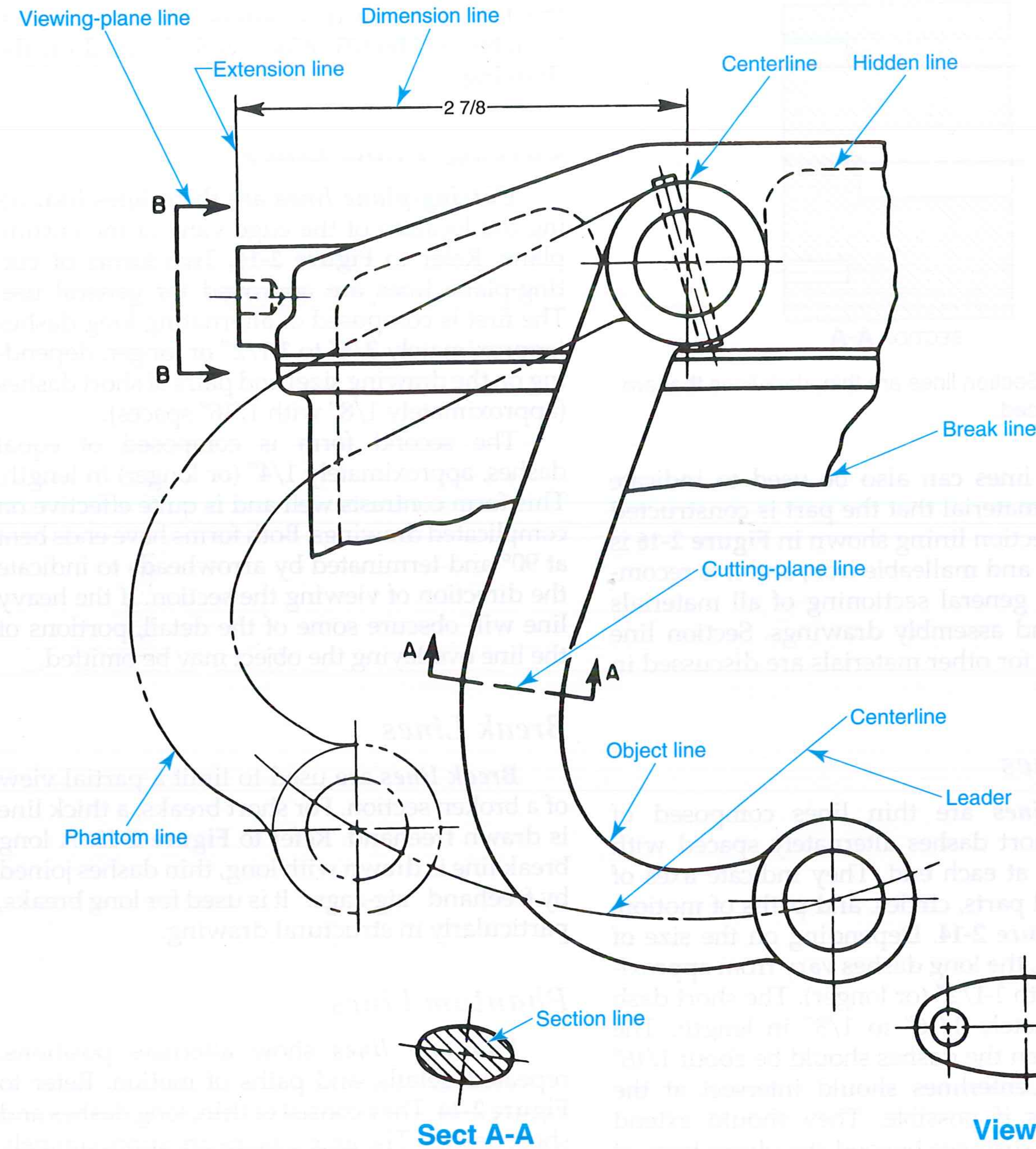


Figure 2-14. Standard line conventions. (American Society of Mechanical Engineers)

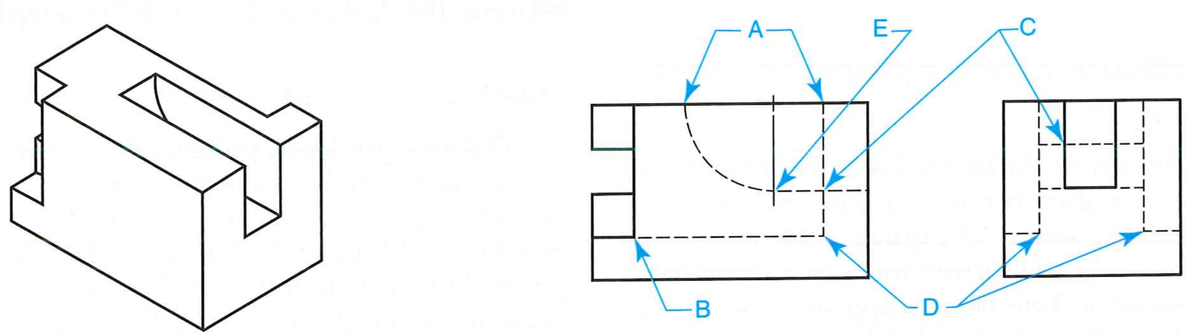


Figure 2-15. Drawing conventions for hidden lines.

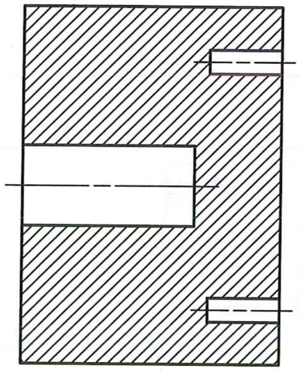


Figure 2-16. Section lines are thin, dark lines that are uniformly spaced.

Section lines can also be used to indicate the type of material that the part is constructed from. The section lining shown in **Figure 2-16** is for cast iron and malleable iron, and it is recommended for general sectioning of all materials on detail and assembly drawings. Section line conventions for other materials are discussed in Chapter 10.

Centerlines

Centerlines are thin lines composed of long and short dashes alternately spaced with a long dash at each end. They indicate axes of symmetrical parts, circles, and paths of motion. Refer to **Figure 2-14**. Depending on the size of the drawing, the long dashes vary from approximately 3/4″ to 1-1/2″ (or longer). The short dash is approximately 1/16″ to 1/8″ in length. The space between the dashes should be about 1/16″ in length. Centerlines should intersect at the short dashes if possible. They should extend only a short distance beyond the object lines of the drawing, unless needed for dimensioning or other functions.

Dimension Lines, Extension Lines, and Leaders

Dimension lines indicate the extent and direction of dimensions and are terminated by arrowheads. Refer to **Figure 2-14**. ***Extension lines*** indicate the termination of a dimension. The extension line begins approximately 1/16″ from the object and extends to 1/8″ beyond the last arrowhead. ***Leaders*** are lines drawn to notes or identification symbols used on the drawing.

Cutting-Plane Lines

Cutting-plane lines are thick lines indicating the location of the edge view of the cutting plane. Refer to **Figure 2-14**. Two forms of cutting-plane lines are approved for general use. The first is composed of alternating long dashes (approximately 3/4″ to 1-1/2″ or longer, depending on the drawing size) and pairs of short dashes (approximately 1/8″ with 1/16″ spaces).

The second form is composed of equal dashes, approximately 1/4″ (or longer) in length. This form contrasts well and is quite effective on complicated drawings. Both forms have ends bent at 90° and terminated by arrowheads to indicate the direction of viewing the section. If the heavy line will obscure some of the detail, portions of the line overlaying the object may be omitted.

Break Lines

Break lines are used to limit a partial view of a broken section. For short breaks, a thick line is drawn freehand. Refer to **Figure 2-13**. A long break line is drawn with long, thin dashes joined by freehand "zig-zags." It is used for long breaks, particularly in structural drawing.

Phantom Lines

Phantom lines show alternate positions, repeated details, and paths of motion. Refer to **Figure 2-14**. They consist of thin, long dashes and short dashes. The long dashes are approximately 3/4″ to 1-1/2″ in length. They are alternated with pairs of short dashes 1/8″ in length. The space between the dashes is about 1/16″ in length.

Datum Dimensions

Datums are lines, points, and surfaces that are assumed to be accurate. They are placed on drawings as datum dimensions since they may be used for exact reference or location purposes. Datum symbols and dimensioning and tolerancing standards are used to describe such information. Datum symbols use thin lines and have the same characteristics as other lines used in dimensioning.

Construction Lines

Construction lines are very light, gray lines used to lay out all work. They should be light enough on a drawing so they will not reproduce when making a print. On drawings for display or reproduction, they should not be visible beyond an arm's length.

Border Lines

Border lines, while actually not a part of the ASME standard, are used as a "frame" for the drawing. These lines are the heaviest of all lines on a drawing. Refer to **Figure 2-13.**

Erasing and Erasing Tools

It would be desirable to make a drawing without erasing. However, mistakes do happen and changes in existing drawings must frequently be made.

Erasing is a technique that the drafter must perfect to do good work. Much erasing time and damage to drawings may be saved by drawing all lines first as construction lines. The lines can be "heavied-in" for final finish.

Two types of ***erasers*** are useful in drafting: the firm textured rubber eraser for erasing ink lines, and the soft vinyl eraser for erasing pencil lines and cleaning drawings, **Figure 2-17.** Erasers containing gritty abrasives (such as ink erasers) should not be used. These will damage the drawing surface and produce ghosting on reproductions. ***Ghosting*** is a smudged area on a copy of a drawing caused by damage from erasing or mishandling.

Steel erasing knives should not be used for general line erasing. They are useful in removing ink lines that have overrun, are too wide, or have been made by error. They must be kept sharp. Use them with a light sideways stroke. Special nonabrasive vinyl erasers and erasing fluids are used on polyester film.

Erasing Procedure

When making erasures with a soft vinyl eraser, follow this procedure:

1. Clean the eraser by rubbing it on a scrap of paper.
2. With your free hand, hold the drawing securely to avoid wrinkling.
3. Rub the eraser lightly back and forth to erase the detail or line.
4. For erasing deeply grooved pencil or ink lines, place a triangle under the paper for backing.
5. If necessary to protect details close by, use an ***erasing shield,*** **Figure 2-18.** (A piece of stiff paper will serve if an erasing shield is not available.)
6. Clean the drawing with the eraser before final finishing of lines.

Figure 2-17. Red rubber and soft vinyl erasers are recommended for drafting.

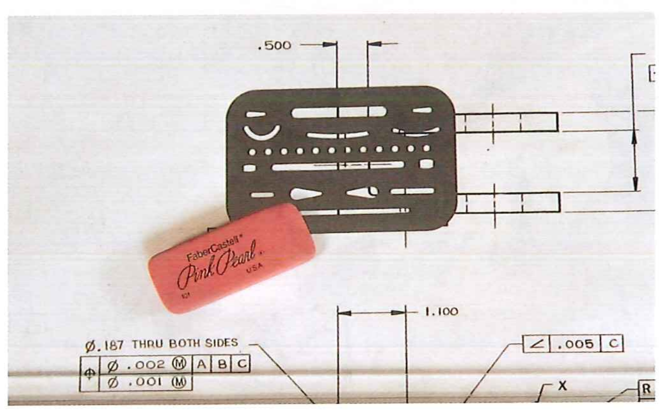


Figure 2-18. An erasing shield can be used to protect parts of a drawing that are not to be removed.

Figure 2-19. Frequent use of a dust brush will help keep your drawing clean.

7. Remove erasure dust with a dust brush or soft cloth, **Figure 2-19**.
8. After cleaning the front of the drawing, turn the drawing over and inspect the back for dirt that may have been transferred from the drawing board to the back of the drawing.

Electric Erasers

Most industries today, because of frequent alterations in product design, find it necessary to make changes on existing drawings. Improvements in drafting media, as well as the ***electric eraser***, make changes a simple matter, **Figure 2-20**. When using an electric eraser, exercise care not to press too hard or to remain in one spot too long. This could mar or distort the drawing surface or cause ghosting in the reproduction of prints.

Only soft rubber or vinyl erasers should be used in electric erasers. A very gentle pressure avoids overheating the drawing surface. Place a piece of thin gage copper, brass, or aluminum sheet under the area to be erased to dissipate the heat and reduce the possibility of damage to the drawing.

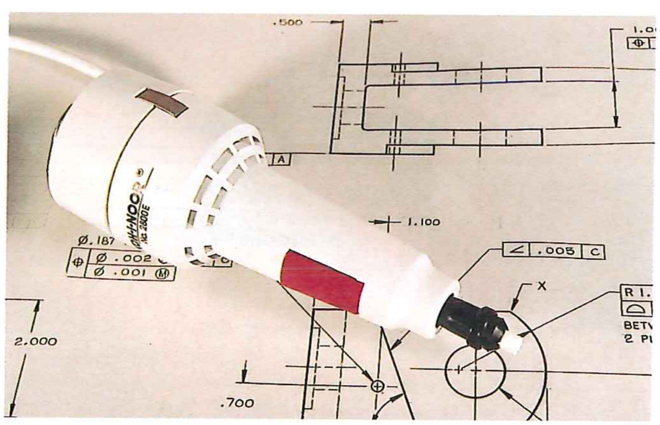


Figure 2-20. An electric eraser can save time for drafters.

Neatness in Drafting

The first impression is a lasting one. Remember that the appearance of your drawing is the first reflection of your ability as a drafter. People have a tendency, and rightly so, to associate neatness with ability in drafting.

Practice cleanliness from the start. Make it a habit to guard against anything that may make a drawing look dirty. The primary source of dirt on a drawing is pencil graphite (lead). Sliding a T-square, triangles, shirt sleeves, or hands across the drawing will smear graphite.

Another thing that detracts from the neatness of a drawing is ghosting. This occurs when dark, heavy lines are erased. Dark, heavy lines actually create a "groove" in the paper. If the line is erased, this groove will remain and a "ghost image" of the line will be visible.

The following suggestions will help you keep a drawing clean:

1. Wash your hands before starting to draw. Occasionally wash them again while drawing. Since you are continually working over the drawing, clean hands will help to keep the drawing clean.
2. Always wipe the dust and dirt from your instruments with a soft cloth before starting to draw and frequently during use. A thorough cleaning with a soft eraser or erasing solvent keeps instruments in good condition.
3. Lay out all views with light lines using a hard pencil. "Heavy-in" lines only when you are sure all parts are correct.
4. Remove dust as soon as it collects. After each line is drawn, use a soft cloth or dusting brush to remove particles of loose graphite from the sheet. Remove erasure dust immediately with a soft cloth or dusting brush.
5. Do not slide instruments across the drawing. Tilt the T-square by pressing down on the head before sliding. Lift the straightedge and triangles to prevent the smear of graphite dust from lines already drawn.
6. Sharpen your pencil away from the drawing. Also, enclose the sandpaper pad or file in an envelope before storing in a drawer with drawings or instruments.

Figure 2-21. An orderly work area will contribute to cleaner drawings and better reproductions.

7. Keep an orderly drawing area. Have only the tools and equipment needed on top of the desk. This will prevent crowding and avoid the possibility of instruments falling on the floor, **Figure 2-21**.
8. Use a paper overlay to cover completed parts of the drawing when lettering or working on other areas of the drawing.
9. Cover the drawing at night or store it in a drawer to prevent dust from gathering.
10. Store completed drawings in a portfolio to prevent damage.

Scales

The ***scale*** is one of the most frequently used drawing instruments. In addition to laying off measurements, it is used to reduce or enlarge the measurements of an object to a suitable size.

A standard scale is made in one of two basic shapes, flat or triangular, **Figure 2-22**. A *flat scale* is available in three bevel shapes: regular two-bevel, opposite two-bevel, and four-bevel. The *triangular scale* is available in two styles, regular and concave. The triangular scale has six faces. This allows for multiple scales, typically up to 11, on one instrument. Many drafters prefer a flat scale because it is easier to manipulate.

Scales are made of boxwood, boxwood with plastic faces, all plastic, and aluminum. They may have engine-divided (machine-divided), precision-molded, or die-engraved graduations. The better scales are engine-divided. Most are made of boxwood with white plastic on the faces to make the divisions easy to read.

A scale is classified as open-divided or full-divided, depending on the way the divisions are read. An ***open-divided scale*** has the main units numbered along the entire length of each scale. Also, only the first main unit is subdivided into fractional or decimal segments of the major unit. Some open-divided scales have two compatible scales on the same face reading from opposite ends. The larger of the two scales is typically twice the size of the smaller scale.

A ***full-divided scale*** has all units along the entire scale subdivided. This presents the advantage of allowing the drafter to lay off several values from the same origin without moving the instrument.

Many types of scales are required to draw objects ranging from small machine parts to large area maps. Therefore, scales are classified according to their use. The following are the most common types of scales.

Architect's Scale

An ***architect's scale*** is most commonly used in making drawings for the building and structural industry. Architect's scales are available in all five shapes. They are also used by many mechanical drafters since the major units are divided into feet and inches.

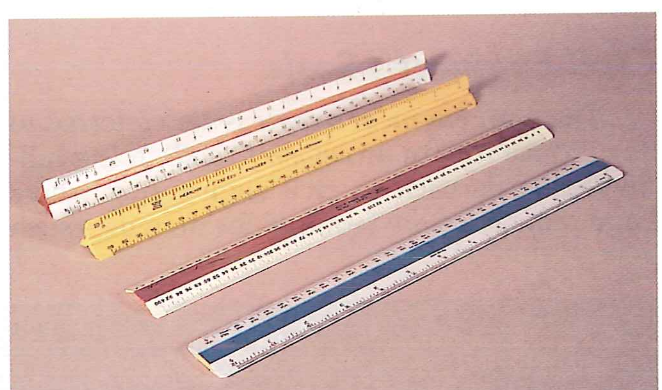


Figure 2-22. There are several basic shapes of standard drafting scales.

Architect's Scales	
Scale	**Size**
1″ = 1″	Full size
3″ = 1′–0″	1/4 size
1-1/2″ = 1′–0″	1/8 size
1″ = 1′–0″	1/12 size
3/4″ = 1′–0″	1/16 size
1/2″ = 1′–0″	1/24 size
3/8″ = 1′–0″	1/32 size
1/4″ = 1′–0″	1/48 size
3/16″ = 1′–0″	1/64 size
1/8″ = 1′–0″	1/96 size
3/32″ = 1′–0″	1/128 size

Figure 2-23. There are typically 11 different scales on an architect's scale.

The various scales usually represented on an architect's triangular scale are shown in **Figure 2-23**. These scales are arranged in pairs on five faces, and a full-size scale is given on the sixth face. The full-size scale is marked "16" to indicate that the inch is subdivided into sixteenths. This gives a total of 11 different scales on one instrument.

The individual scales on an architect's scale are open-divided (except the full-size scale). The end unit beyond the zero is subdivided into parts representing inches or fractional parts of an inch. On the 3/32″ and 1/8″ scales, the smallest division represents 2 inches. On the 3/16″, 1/4″, and 3/8″ scales, the smallest division represents 1 inch. On the larger scales, the smallest divisions represent fractional parts of an inch.

Civil Engineer's Scale

The ***civil engineer's scale*** is also referred to as a *decimal scale* or an *engineer's scale.* It is a full-divided scale used in civil engineering where large reductions are required for drawings such as maps and charts. It is also widely used in manufacturing.

Scales on a civil engineer's scale are divided into units representing decimal parts of an inch. Each 1″ unit on the 10 scale is subdivided into 10 parts, each 1/10″ (.10″) in size. The 50 scale has 50 parts to the inch, each 1/50″ (.02″), **Figure 2-24**.

In addition to inches, the divisions may represent feet, pounds, bushels, time, or any other quantity. The units may also be expanded to represent any proportional number. For example, the 50 scale could represent 50 feet, 500 feet, or 5000 feet. The subdivisions of the major units would have corresponding values.

Mechanical Engineer's Scales	
Scale	**Size**
1″ = 1″	Full size
1/2″ = 1″	Half size
1/4″ = 1″	1/4 size
1/8″ = 1″	1/8 size

Figure 2-25. There are four common mechanical engineer's scales.

Mechanical Engineer's Scale

The ***mechanical engineer's scale*** is useful in drawing machine parts where the dimensions are in inches or fractional parts of an inch. Common graduations for mechanical engineer's scales represent one inch. Typical mechanical engineer's scales are shown in **Figure 2-25**.

Mechanical engineer's scales are open-divided scales. They are often called *size* scales. For example, a "1/8" scale is used for drawings that are one-eighth the size of the object. The "1" scale is used for full-size scale drawings.

Combination Scales

A ***combination scale*** is a triangular scale combining selected scales from the architect's

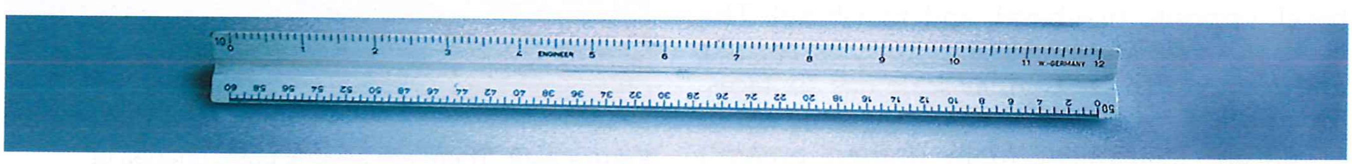


Figure 2-24. The divisions on a civil engineer's scale represent decimal parts of an inch.

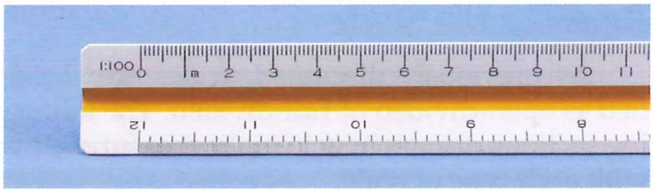


Figure 2-26. Metric scales are used for metric drawings and dual-dimensioned drawings.

scale (1/8″, 1/4″, 1/2″, and 1″ to the foot), civil engineer's scale (50 parts to the inch), and mechanical engineer's scale (1/4, 1/2, 3/8, 3/4, and full size). Special scales are also available for uses such as mapping, aerial photography, and statistical work.

Metric Scales

A ***metric scale*** is used for work on metric drawings or dual-dimensioned drawings, **Figure 2-26**. Metric scales are *size* scales. For example, a drawing made to a 1:20 scale means the drawing is 1/20th the size of the actual object.

A scale of 1:20 may be referenced on the drawing as 1:20 or 5 cm = 1 m, **Figure 2-27A**. A scale of 1:100 means the drawing is 1/100th the size of the actual object. It may be referenced as 1:100 or as 1 cm = 1 m, **Figure 2-27B**. (Refer to **Figure 2-26** for an example of a 1:100 scale.) When this scale is used as a reduction scale with a ratio of 1:100, the numerals 1, 2, and 3 represent 1 meter each (1 cm = 100 cm or 1 meter). The 1:100 scale may also be used as a full-size scale since the smallest division is actually 1 millimeter (mm). The numerals 1, 2, and 3 actually represent full-size centimeters (10 millimeters).

Since metric scales are decimal scales based on the number 10, the ratio of a metric scale may be changed by multiplying (or dividing) by a multiple of 10. For example, the 1:100 scale may be changed to 1:1000 by multiplying by 10. By multiplying each of the numerals on the scale (1, 2, and 3) by 10, they now represent different values (10 m, 20 m, and 30 m).

SCALE 1:20 (5 cm = 1 m)
A
SCALE 1:100 (1 cm = 1 m)
B
SCALE 1:100,000 (1 cm = 1 km)
C

Figure 2-27. A metric scale may be referenced on a drawing as a ratio with equivalents to indicate the relationship of units.

Metric units used on drawings

The basic unit of length in the metric system is the meter. However, different metric units are used in various fields as the standard unit of measure on metric drawings, **Figure 2-28**.

On metric drawings in the topographical field, where distances are great, the kilometer is used as the standard unit and a sizable scale reduction results. The meter serves as the standard unit of measure in the building and construction fields. The centimeter (1/100 m) is the standard unit in the lumber and cabinet industries. In the precision manufacturing industries (for which drawings are made of aerospace, automotive, computer, and machine parts), where close tolerances must be maintained, the standard unit is the millimeter (1/1000 m).

Industry	Standard Metric Drawing Unit	Symbol
Topographical	kilometer	km
Building, Construction	meter	m
Lumber, Cabinet	centimeter	cm
Mechanical Design, Manufacturing	millimeter	mm

Figure 2-28. Metric units of measure used on drawings vary by industry.

Drawing to Scale

All drawings should be drawn to scale, except schematics and tables. *Drawing to scale* often refers to making a drawing that is reduced proportionally from actual size so that it can be placed on the drawing sheet. There are also cases when a drawing has to be enlarged proportionally over the actual object size for clarity and detail, **Figure 2-29**. This is also referred to as "drawing to scale." "Drawing to scale" also refers to making drawings of objects full size. In this case, the scale would be 1″ = 1″.

The scale selected for a particular drawing depends on the size of the object to be drawn.

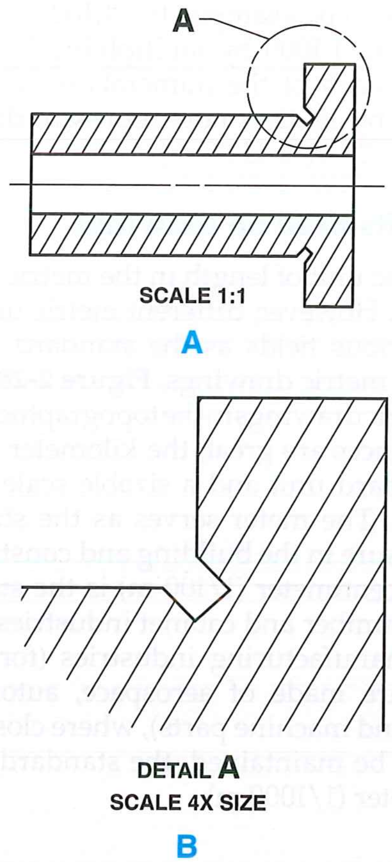


Figure 2-29. Drawing an object to scale. A—Shown is a drawing made to scale at full size. B—A feature of the part is enlarged to show detail. The detail is drawn at 4:1 (4X) scale.

In general, the drawing of the object should be as large as possible while still fitting a standard sheet size.

As discussed in previous sections, there are numerous scale sizes used in drafting. The first reduction on the architect's scale is to quarter size. The first reduction on the mechanical engineer's scale is to half size. If these reductions are insufficient, then a smaller scale must be selected.

Reading the Scale

As previously discussed, scales are classified as open-divided or full-divided. The following sections discuss how to make measurements with each type of scale.

Architect's scale

An architect's scale is an open-divided scale. Open-divided scales are read by first reading the main units in the open-divided section and then reading the subdivided units in the full-divided section. To read 2 feet and 3-1/2 inches on the 1/8th size architect's scale (1-1/2″ = 1′-0″), start with the numeral 2 in the open-divided section. Then move to the full-divided end unit to locate the 3-1/2″ measurement, **Figure 2-30**.

Mechanical engineer's scale

A mechanical engineer's scale is an open-divided scale (similar to an architect's scale). A measurement of 3-5/8″ on a half-size mechanical engineer's scale is read as shown in **Figure 2-31**. Remember that the units on this scale represent inches. Start with the numeral 3 in the open-divided section and move to the 5/8″ reading in the full-divided end unit.

Civil engineer's scale

A civil engineer's scale is a full-divided scale. To read the scale, first determine the number of whole units (major divisions). Then read the subdivided units. To read a decimal inch dimension of 2.125″ on the civil engineer's 10 scale, start from the 0 and move past the 2, **Figure 2-32A**. Continue past the first tenth (.10) to one-fourth of the next tenth (.025) (as judged by eye). This represents the decimal .125.

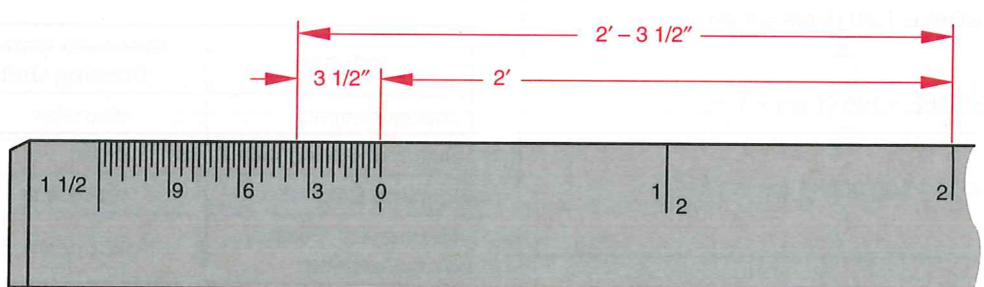


Figure 2-30. Measuring with the architect's scale.

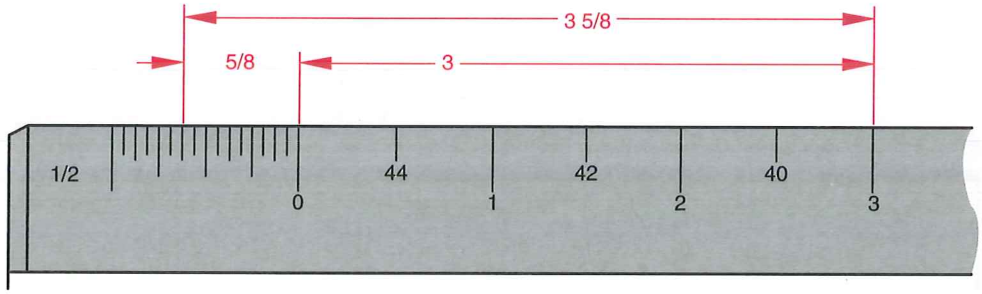


Figure 2-31. Measuring with the mechanical engineer's scale.

The same reading can be made with greater accuracy on the 50 scale, where each subdivision equals 1/50 of an inch or .02″, **Figure 2-32B**. Move from 0 to 10 (5 major divisions to the inch, 10 = 2 inches) and on to 6 subdivisions (6 × .02 = .12). Continue to one-fourth of the next subdivision (1/4 of .02 = .005) for a measurement of 2.125″.

The 50 scale is the most commonly used scale in the machine-parts manufacturing industries. Decimal inch dimensioning is standard practice in these industries.

Metric scale

A metric scale is a full-divided scale. Measuring with the metric scale is shown in **Figure 2-33**, using the .01 scale as a full-size scale. The measurement reads 43.5 mm. To use the same scale as a reducing scale of 1:100, let each numbered unit (actually one centimeter) represent a meter—a reduction of 1:100. That is, one unit on the drawing represents 100 on the object. The measurement in **Figure 2-33** would then represent 4.35 meters (or 4350 mm).

Usage of "Scale" and "Drawing Size"

It is important to understand the difference in the meaning of the words *scale* and *size* as used in scale drawings. The 1/4″ = 1′-0″ scale is a common scale for drawing house plans (often referred to as "quarter scale"). However, referring to **Figure 2-23**, note that this scale is actually 1/48 size since one-quarter inch on the drawing represents 1 foot on the house plan.

The word *scale* refers to the name of a particular scale and not to the size of the drawing.

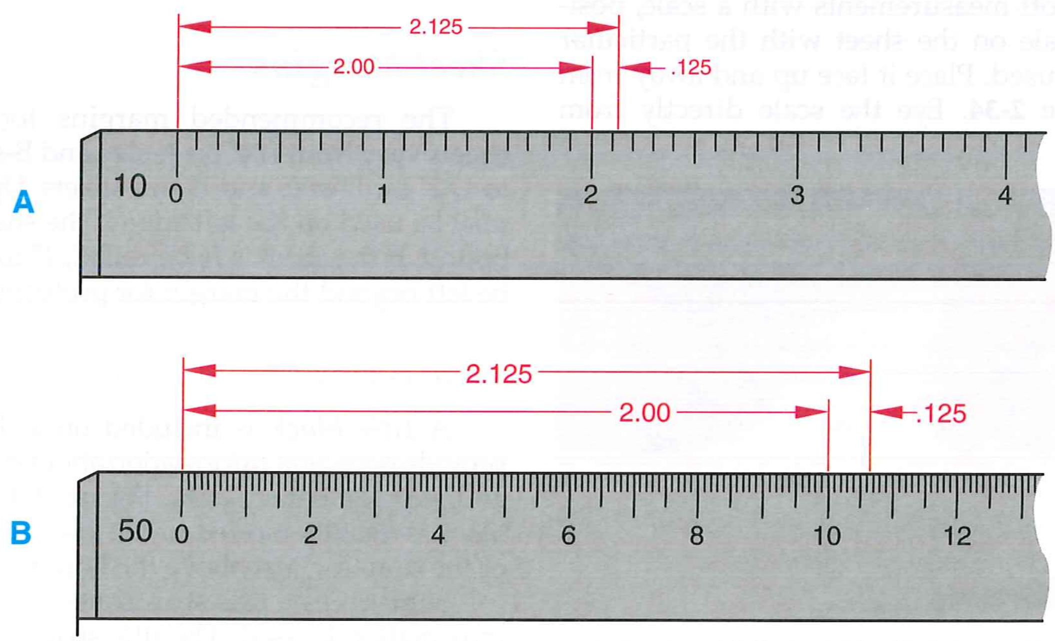


Figure 2-32. Measuring with the civil engineer's scale.

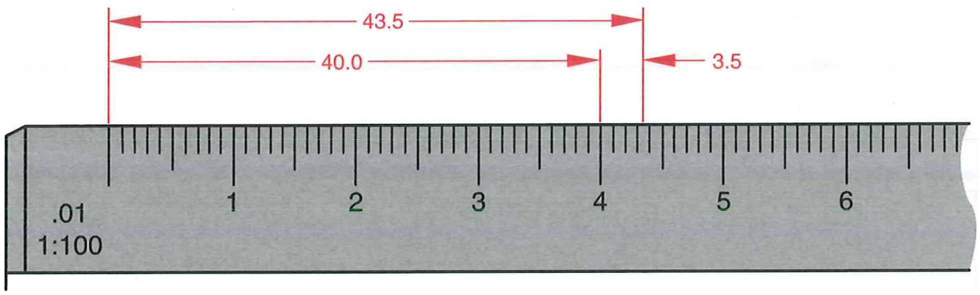


Figure 2-33. Measuring with the metric scale.

The word *size* does refer to the size of the drawing in relation to the size of the object. Hence, the "quarter size" scale on the mechanical engineer's scale, where 1/4" = 1", will produce a drawing that is one-quarter the size of the object.

The scale of a drawing is usually indicated in the title block of the drawing in a manner similar to that shown below:

Full size	1/1, FULL SIZE
Enlarged	2/1, 4/1, 10/1, 10X, TWICE SIZE
Reduced	1/4" = 1'-0", 1/2, 1/4, 1/10, 1/50, HALF SIZE, QUARTER SIZE

Views that have been drawn to a scale other than that indicated in the title block should have the scale noted below the view. Refer to **Figure 2-29B**.

Laying Off Measurements

To lay off measurements with a scale, position the scale on the sheet with the particular scale to be used. Place it face up and away from you, **Figure 2-34**. Eye the scale directly from above. Then, with a sharp conical pencil, mark the desired distance lightly with short dashes at right angles to the scale. Successive distances on the same line should be laid off without shifting the scale.

The dividers or compass should never be used to take distances directly from the scale. This procedure is harmful to the scale. Mark distances on the sheet, then set the dividers or compass to these marks.

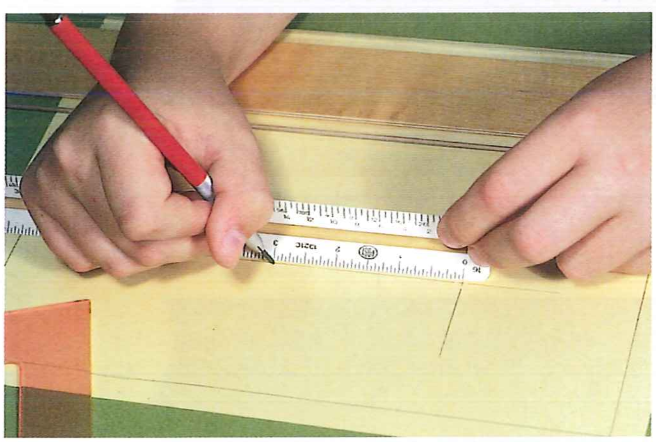


Figure 2-34. Draw at right angles to the scale when laying off measurements.

Sheet Format

Recommendations are made by the American Society of Mechanical Engineers for drawing sheet borders and basic title block data. However, these vary somewhat by the needs of particular applications. The following are the most common.

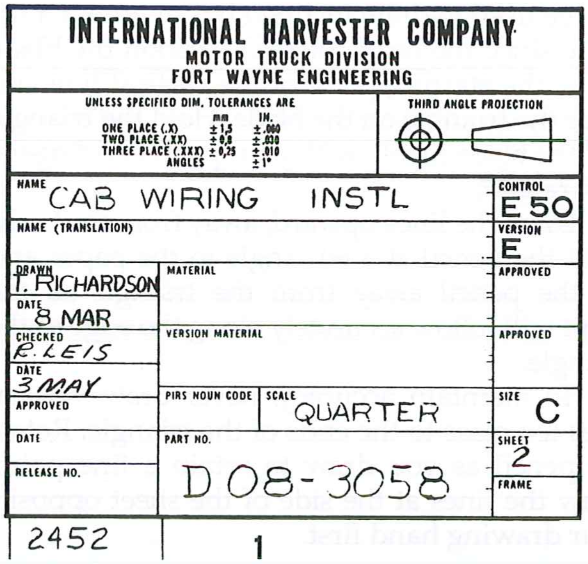
Sheet Margins

The recommended margins for drawing sheets vary from 1/4" on A-size and B-size sheets to 1/2" for D-size and E-size sheets. Up to 1-1/2" may be used on the left edge if the sheet is to be bound. If the sheet is to be rolled, 4" to 8" should be left beyond the margin for protection.

Title Block

A ***title block*** is included on a drawing to provide pertinent information about the drawing and supplementary data, **Figure 2-35**. The title block is usually located in the lower-right corner of the drawing just above the border line.

Sometimes a title strip containing the same information is used. The title strip extends partially or completely across the lower portion of


INTERNATIONAL HARVESTER COMPANY
MOTOR TRUCK DIVISION
FORT WAYNE ENGINEERING

UNLESS SPECIFIED DIM. TOLERANCES ARE mm / IN. ONE PLACE (.X) ±1.5 ±.000; TWO PLACE (.XX) ±0.8 ±.030; THREE PLACE (.XXX) ±0.25 ±.010; ANGLES ±1°		THIRD ANGLE PROJECTION
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Figure 2-35. A title block typically appears in the lower-right corner of the drawing.

the sheet. Suggested title block layouts are given in the Reference Section of this text.

Drafting Instrument Procedures

Basic drafting procedures in instrument usage are presented in this section to assist you in forming good habits. Study the material carefully and refer to it as needed in actual use of the various instruments.

Drawing Horizontal Lines

Horizontal lines are drawn along the upper edge of the drafting machine straightedge or T-square, **Figure 2-36A**. A T-square should be tight against the working edge of the drawing board. The working edge of the drawing board will be the edge opposite your drawing hand. Lift the drafting machine head to prevent the blade from sliding over the drawing (rubbing graphite across the drawing from existing pencil lines), while bringing it into approximate position for the line to be drawn, **Figure 2-36B**.

Let your non-drawing hand slide from the head to the blade with the fingers resting on the blade and the thumb on the drawing board. Your fingers are now in position to bring the blade in

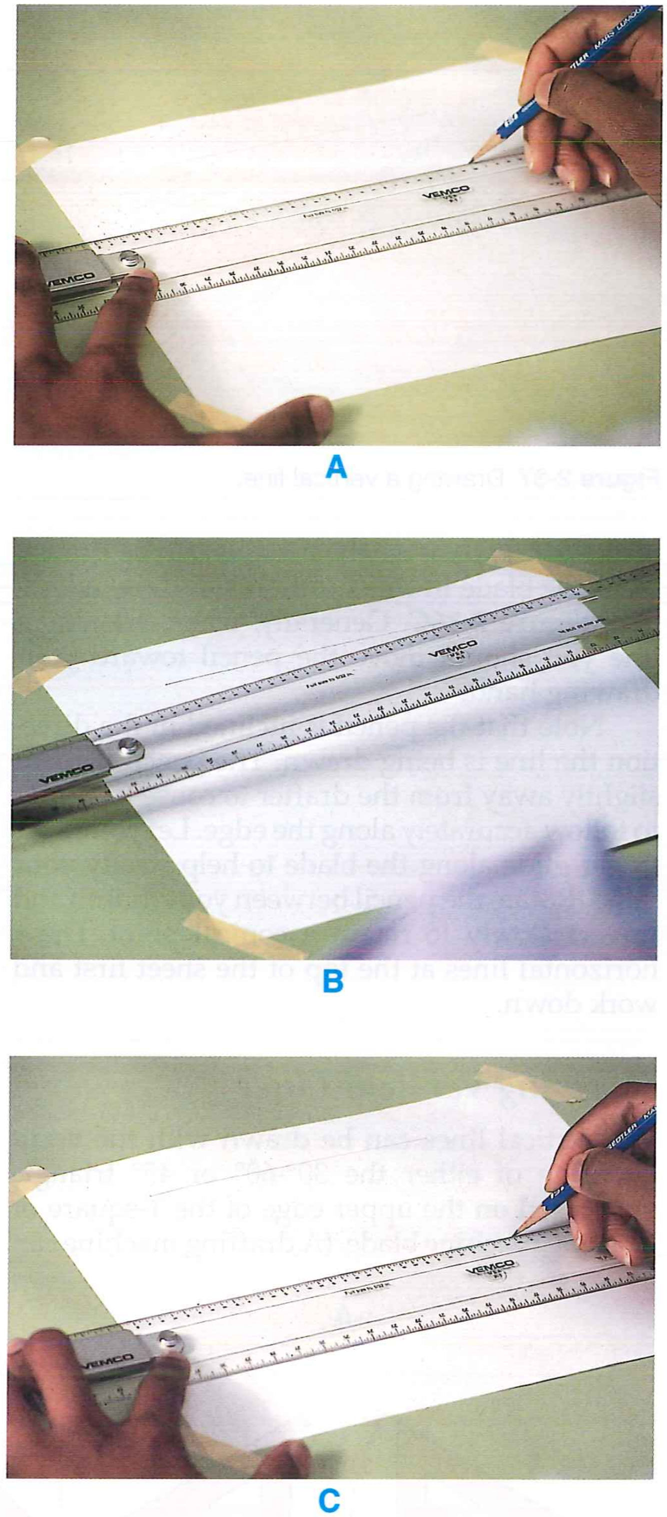


Figure 2-36. Drawing horizontal lines. A—Hold the straightedge tight against the drawing board and move the pencil toward your drawing hand. B—Lift the straightedge off the drawing board when repositioning to avoid making contact with lines on the drawing. C—Incline the pencil in the direction the line is being drawn and rotate it slowly.

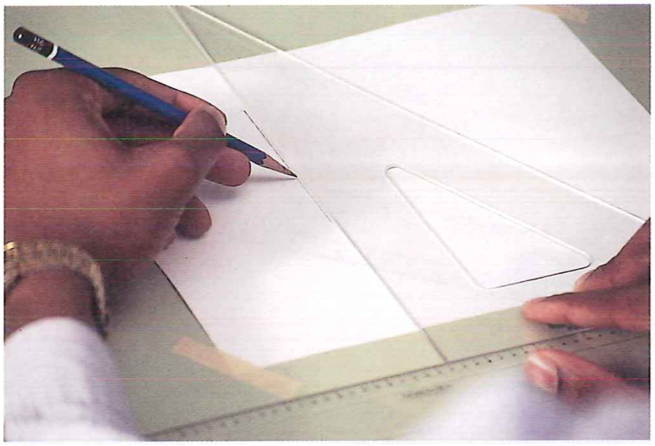


Figure 2-37. Drawing a vertical line.

perfect alignment where the line is to be drawn. Hold the blade in this position and draw a light line, **Figure 2-36C**. Generally, when drawing a line you should move the pencil toward your drawing hand.

Note that the pencil is inclined in the direction the line is being drawn. The pencil is tilted slightly away from the drafter to cause the point to follow accurately along the edge. Let your little finger glide along the blade to help steady your hand. Rotate the pencil between your thumb and fingers slowly to retain a conical point. Draw horizontal lines at the top of the sheet first and work down.

Drawing Vertical Lines

Vertical lines can be drawn with the vertical edge of either the 30°-60° or 45° triangle supported on the upper edge of the T-square or drafting machine blade. (A drafting machine can also be used to draw inclined lines without a triangle since the head rotates.) Position the blade below the starting point of the vertical line and place the triangle on the blade. Hold the triangle and the blade firmly with your palm and fingers, **Figure 2-37**.

Draw the lines upward, away from the body. Hold the pencil at a 60° angle to the paper and tilt the pencil away from the triangle so the point will follow accurately along the edge of the triangle.

To maintain accuracy, never draw vertical lines too close to the ends of the triangle. Rotate the pencil as you draw to retain a fine point. Draw the lines at the side of the sheet opposite your drawing hand first.

Drawing Inclined Lines

Inclined lines at 30°, 45°, and 60° may be drawn by using the appropriate triangle with the T-square, **Figure 2-38**. By using a 45° triangle and a 30°-60° triangle in combination, lines at 15° and 75° can be drawn, **Figure 2-39**. By using these two triangles individually or in combination, a complete circle may be divided into 24 sectors of 15° each, **Figure 2-40**. Inclined lines at other angles can be drawn with a protractor or a drafting machine.

Drawing Parallel Inclined Lines

Lines parallel to inclined lines can be drawn using a T-square and one triangle, **Figure 2-41A**. Adjust the T-square to align the triangle with the given line AB. Hold the T-square firm, place the

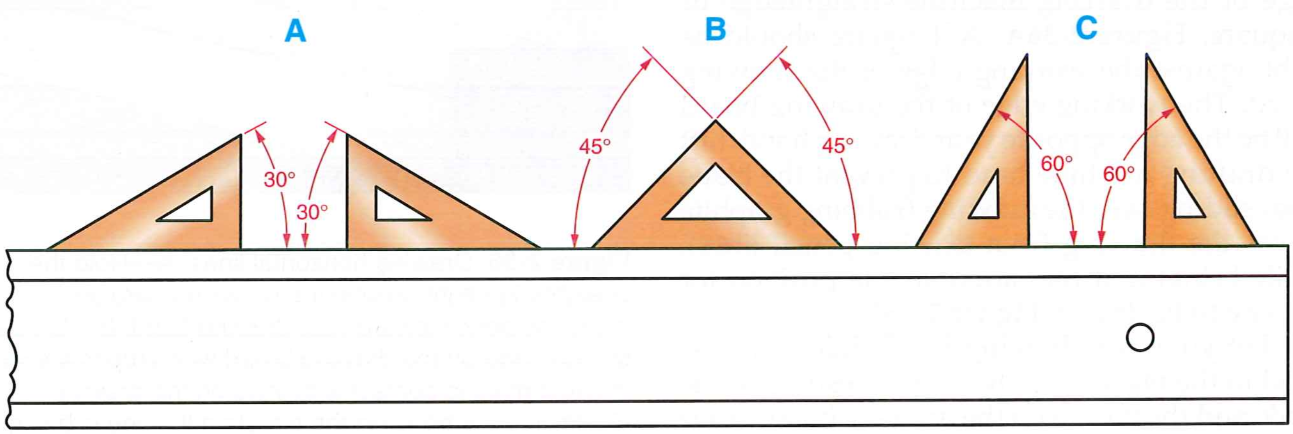


Figure 2-38. Drawing lines inclined at 30°, 45°, and 60°.

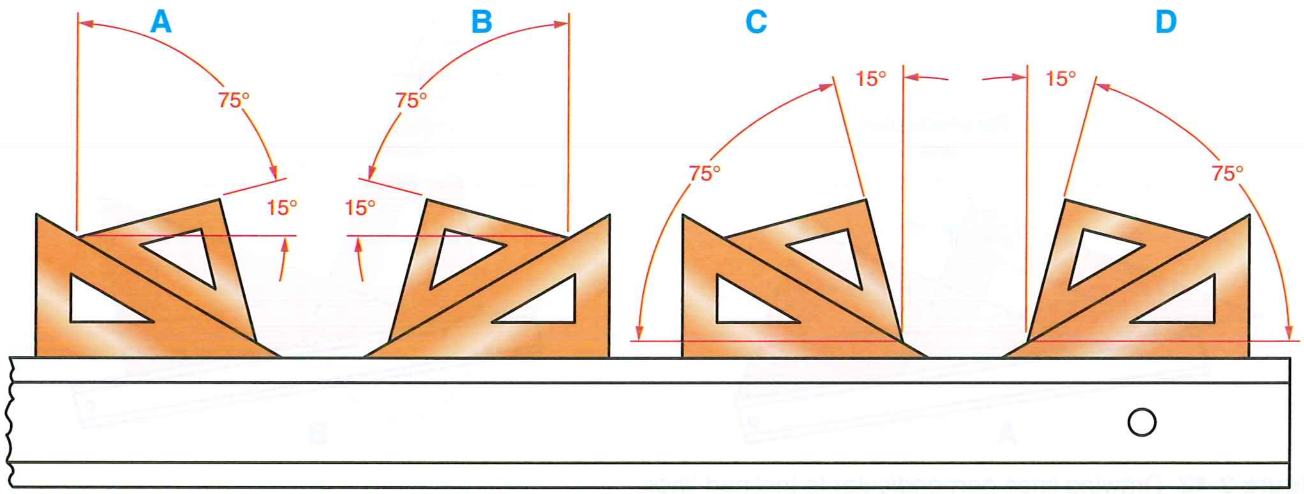


Figure 2-39. Combining triangles to draw lines at angles of 15° and 75°.

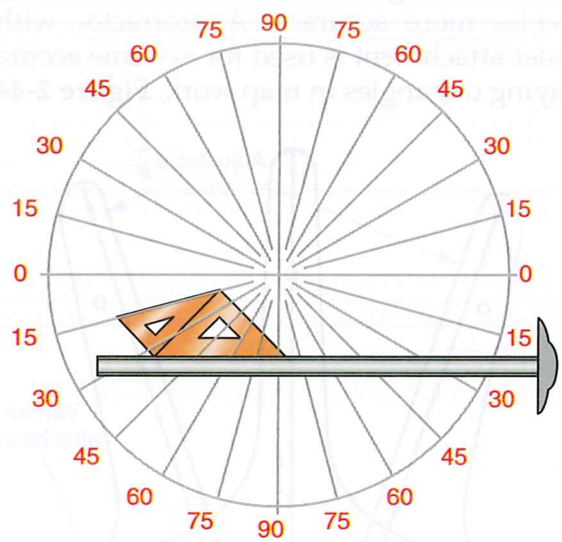


Figure 2-40. Dividing a circle into 15° sectors with triangles.

triangle in the desired location, and draw the parallel line. Lines parallel to inclined lines can be drawn by using two triangles (eliminating the T-square) if the lines are not widely separated, **Figure 2-41B**.

Drawing a Perpendicular to an Inclined Line

To draw a perpendicular line to an inclined line, place the hypotenuse of a triangle (the line opposite the 90° angle) along the edge of the T-square and adjust until one side of the triangle is aligned with the given line. See **Figure 2-42A**. Hold the T-square firmly and move the triangle until the second side is in the desired location. Draw the perpendicular line.

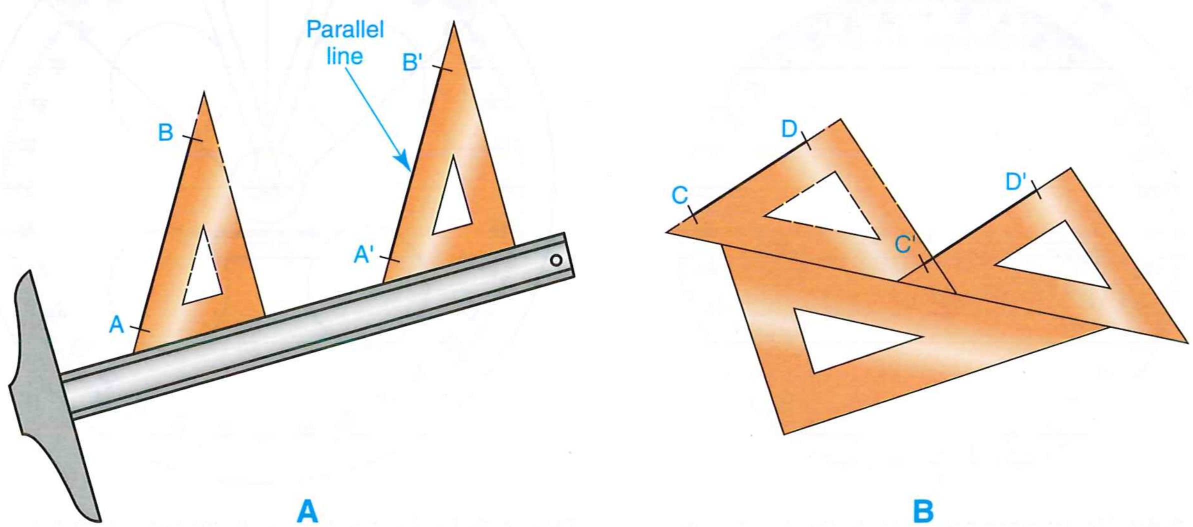


Figure 2-41. Drawing parallel inclined lines. A—Using the T-square and a triangle. B—Using two triangles.

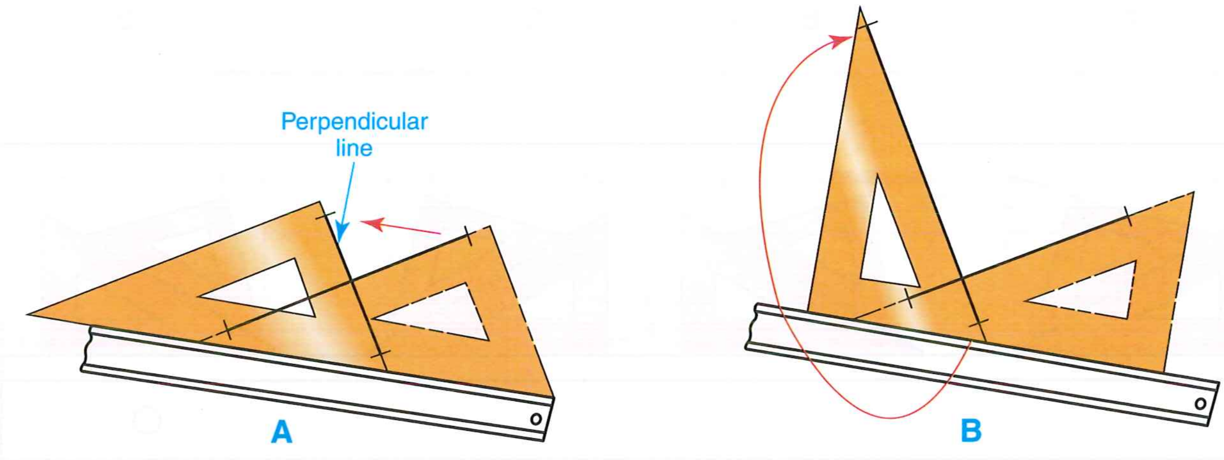


Figure 2-42. Drawing lines perpendicular to inclined lines.

When a longer perpendicular line is required, place the triangle against the T-square and adjust until the hypotenuse is aligned with the given line. Hold the T-square firmly and revolve the triangle until the hypotenuse is perpendicular to the line. Then move the triangle to the desired location and draw the line, **Figure 2-42B**. This process can be performed with the T-square and either triangle or with the two triangles in combination.

Using a Protractor

A ***protractor*** is used to measure and to mark off angles that cannot be measured with a T-square and triangles. Protractors are available in several designs, including semicircular and circular, **Figure 2-43**. An adjustable triangle provides more accuracy. A protractor with a vernier attachment is used for extreme accuracy in laying out angles in map work, **Figure 2-44**.

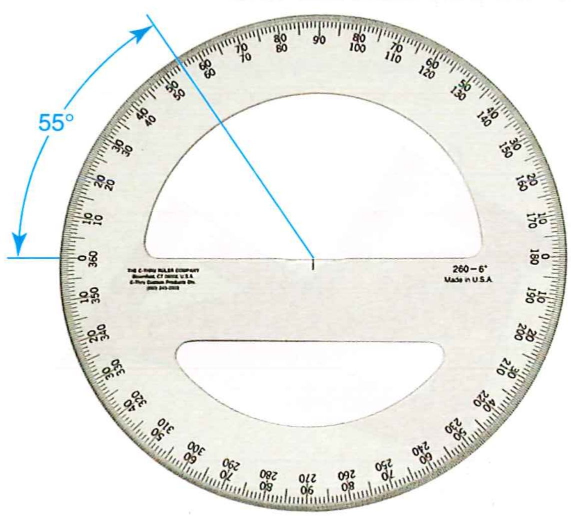


Figure 2-43. Protractors are used to lay out angles. (Alvin & Co.)

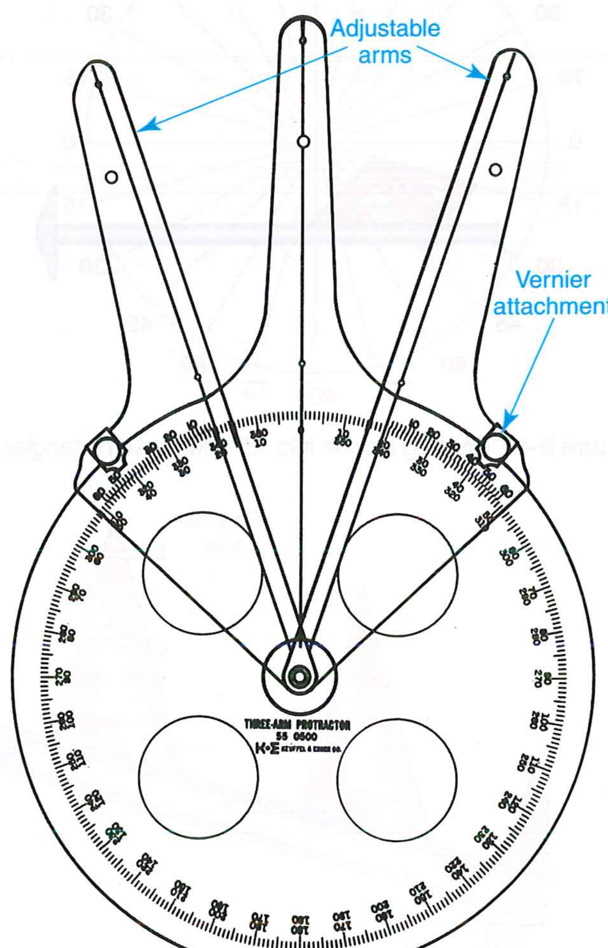


Figure 2-44. Protractors with vernier attachments are more accurate in laying out angles. (Keuffel & Esser Co.)

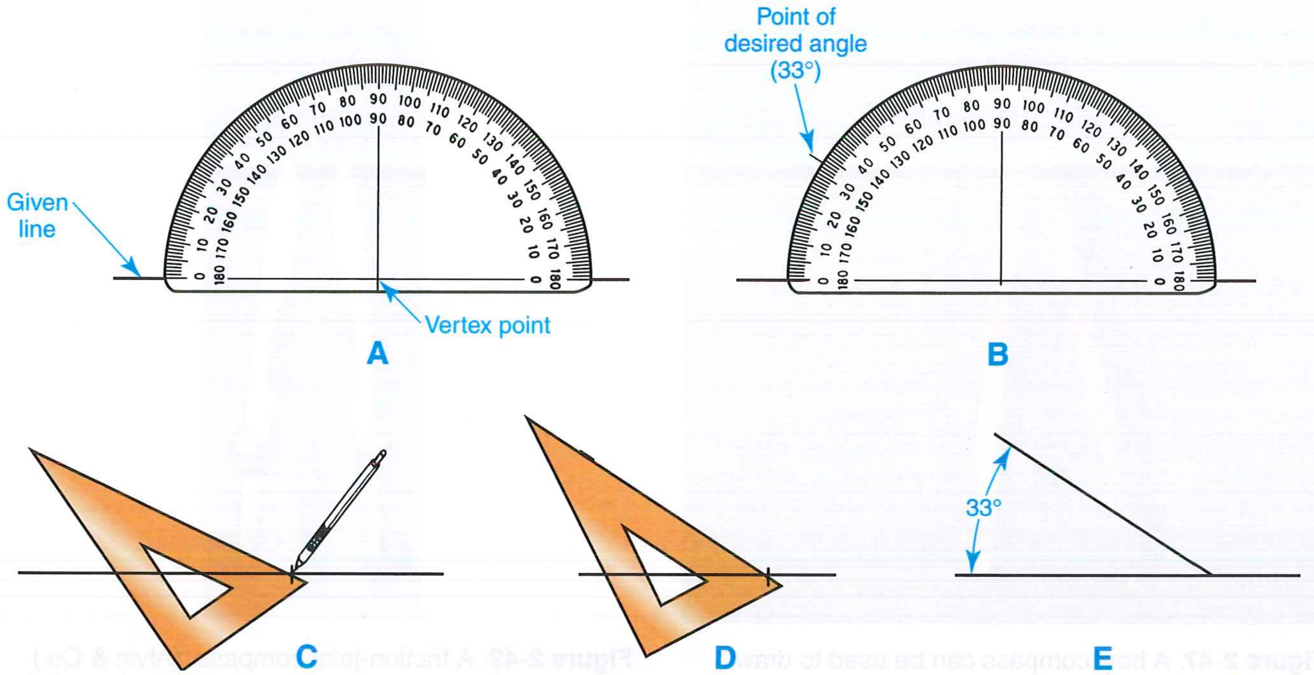


Figure 2-45. Laying out an angle with a protractor.

To lay out an angle with a protractor, set the vertex indicator at the vertex of the angle to be drawn, **Figure 2-45A**. Mark the desired angle with two fine points, **Figure 2-45B**. Make sure you use light marks, otherwise they may not erase. Align the triangle with one of the two points by placing your pencil on one point and revolving the triangle in line with the vertex, **Figure 2-45C**. Draw a line between the vertex and the other point, **Figure 2-45D**. When laying out angles, be sure to draw light lines first. If you draw lines too dark to start with, they may "ghost" if you try to erase them.

Protractors are also available in graduations other than degrees. A percentage protractor is useful in laying out circle graphs, **Figure 2-46**.

Using a Compass

A ***compass*** is used to draw circles and arcs. There are several types of compasses used in drafting, including large and small bow compasses. A ***bow compass*** has a steel ring head and an adjusting screw, **Figure 2-47**. The small bow instrument is used for drawing smaller circles with radii of approximately 1″ or less. A large bow compass is used for circles with radii up to 5″ or 6″. A drop bow compass has removable tips that make it a very versatile tool, **Figure 2-48**.

A ***friction-joint compass*** provides easy adjustment for drawing larger arcs or circles, **Figure 2-49**. A lengthening bar may also be used for drawing larger circles, **Figure 2-50**.

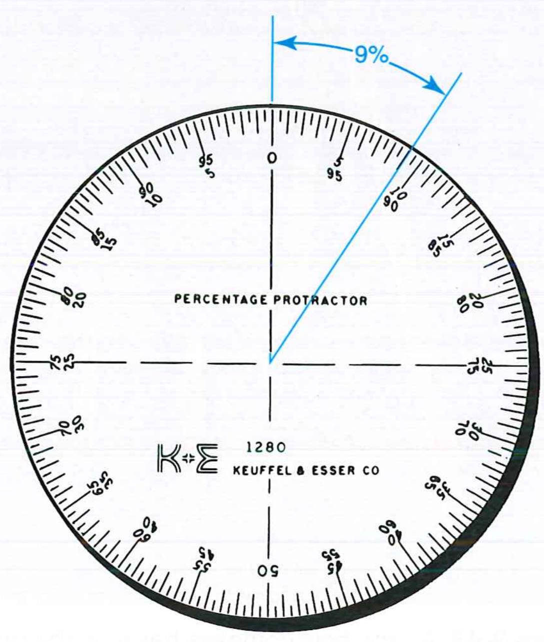


Figure 2-46. A percentage protractor.

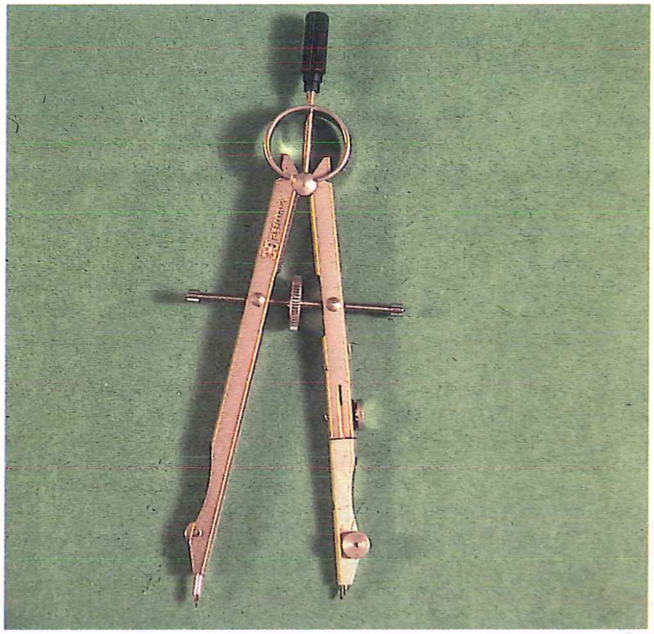


Figure 2-47. A bow compass can be used to draw arcs and circles.

Beam Compass

The ***beam compass*** is used for drawing very large arcs and circles. This compass consists of two holders, one for a needle pivot point and the other for a pen or pencil point, and a beam that the points clamp onto, **Figure 2-51**. To draw arcs and circles with the beam compass, hold the pivot point steady with one hand and swing the pen or pencil point with the other.

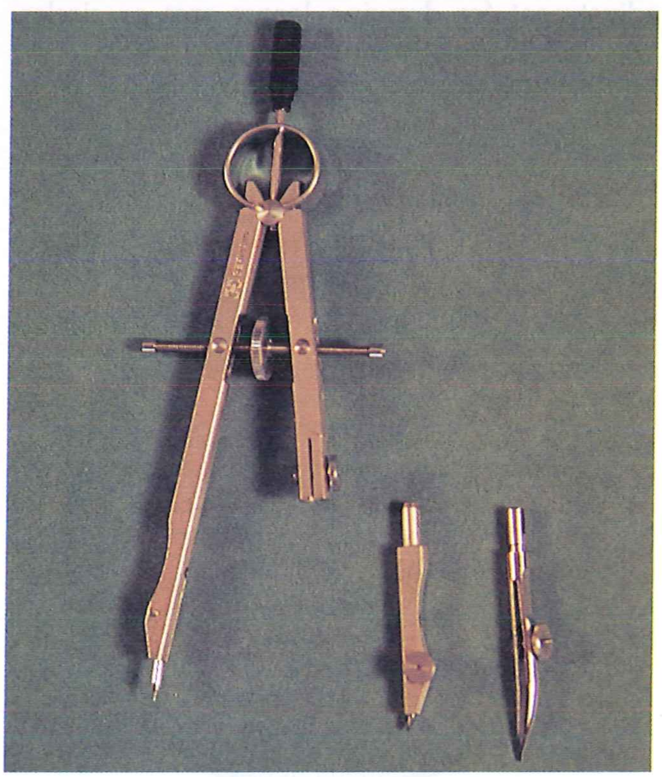


Figure 2-48. A drop bow compass has interchangeable parts to allow for different applications.

Figure 2-49. A friction-joint compass. (Alvin & Co.)

Sharpening the Compass Lead

The compass is used with both pencil and pen attachments. Lead used in the compass should be about one grade softer than that used in your pencil. This will allow you to exert less pressure on the compass. The lead should extend

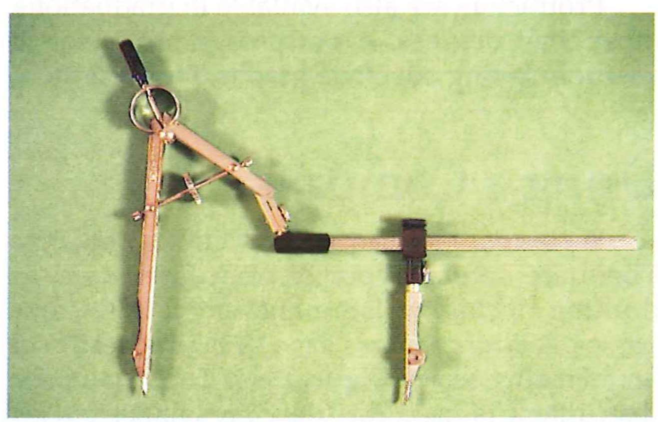


Figure 2-50. Using a bow compass with a lengthening bar allows large circles to be drawn.

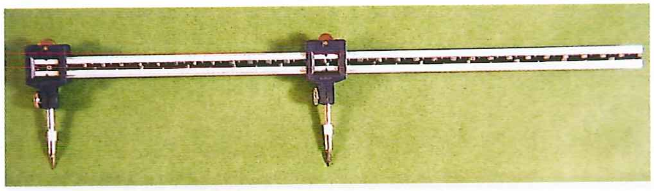


Figure 2-51. A beam compass.

approximately 3/8". Sharpen the lead to a chisel point as shown in **Figure 2-52**. After sharpening, adjust the lead to a length of 1/32" shorter than the needle point.

Drawing Arcs and Circles

The bow compass is adjusted to a radius by twisting the adjusting screw between the thumb and forefinger. Measure off the radius on a scrap of paper (or lightly on your drawing) and adjust the compass accordingly, **Figure 2-53**. Test the setting by drawing the circle lightly on the drawing or scrap paper, and then measure the diameter.

To draw a circle, hold the compass in your drawing hand. Lean the compass slightly forward, and revolve the handle between the thumb and forefinger, **Figure 2-54**. Draw the circle or arc lightly at first. When you are ready to "heavy-in," make repeated turns to darken the line.

Arcs and circles to be joined by straight lines should be drawn first. When a number of concentric circles are to be drawn with the compass, draw the smaller circles first since there is a tendency for the needle point to make a hole

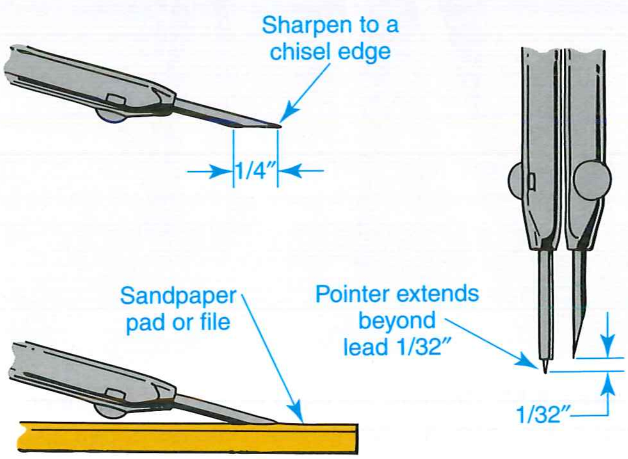


Figure 2-52. Sharpen the compass lead and adjust so that the pointer extends just beyond the lead.

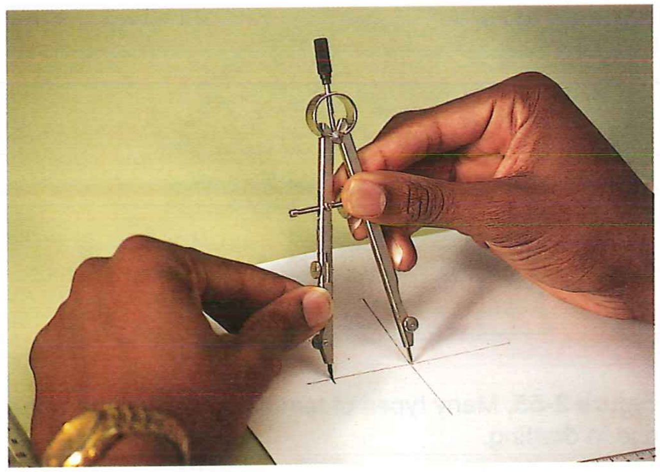


Figure 2-53. Set the bow compass with the adjusting screw.

in the sheet. Some tools have a compass center point with a cup shape or shoulder to prevent this from occurring.

Drafting Templates

Drafting templates are useful for drawing commonly used characters and symbols, **Figure 2-55**. They provide economy and consistency. Templates are available for nearly all standard size circles in fractional, decimal, and metric units. Templates for ellipses and bolt heads, as well as symbols for nearly every field of drafting, are available to speed the drafter's work.

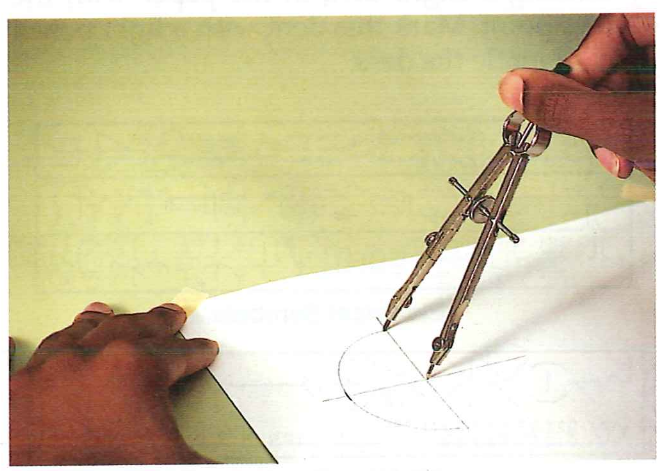


Figure 2-54. When drawing a circle with a compass, tilt the compass slightly so that the lead "follows" the compass.

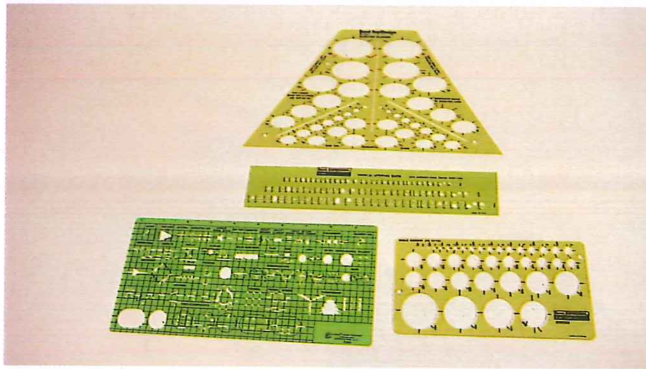


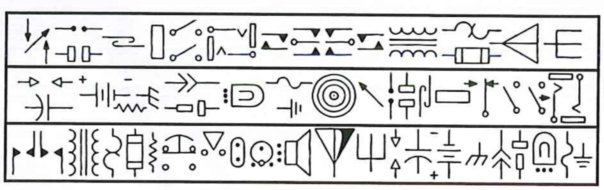
Figure 2-55. Many types of templates are available for use in drafting.

Templates are also available for use with lettering equipment for drawing many types of symbols, **Figure 2-56**. To draw circles, arcs, or ellipses with the aid of a template, first lay out the centerlines on the drawing, **Figure 2-57**. Then align the centerlines of the template and draw the figure.

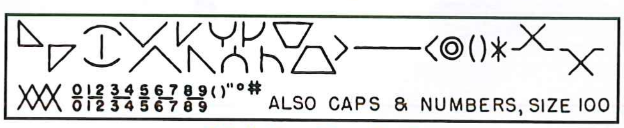
Dividers

Dividers are used to transfer distances and to divide straight and circular lines into equal parts. Two types of dividers are used extensively by drafters: *bow dividers* and *friction-joint dividers*, **Figure 2-58**.

Dividers are adjusted in the same manner as the compass. To transfer or "step off" distances, hold the knurled handle and place the dividers in position, **Figure 2-59**. Mark the distances by making a slight dent in the paper with the divider point. Mark this dent with a light pencil mark or circle the dent.



Electrical Symbols



Welding Symbols

Figure 2-56. Some symbol templates are made for use with lettering equipment. (Keuffel & Esser Co.)

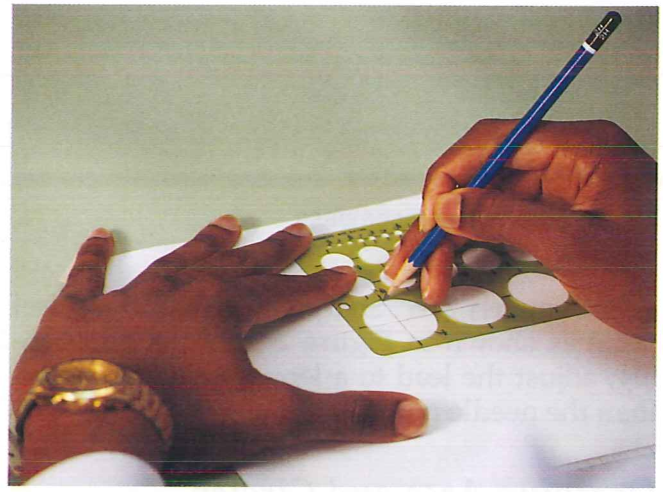


Figure 2-57. When drawing circles with a template, draw the centerlines first. The centerlines on the template should then be aligned with those on the drawing.

Dividers are also used to divide lines. To divide a line into three equal spaces, for example, set the dividers for an estimated 1/3 of the distance and step off, **Figure 2-60**. Correct any error in estimation by decreasing or increasing the divider setting by 1/3 of the error and making

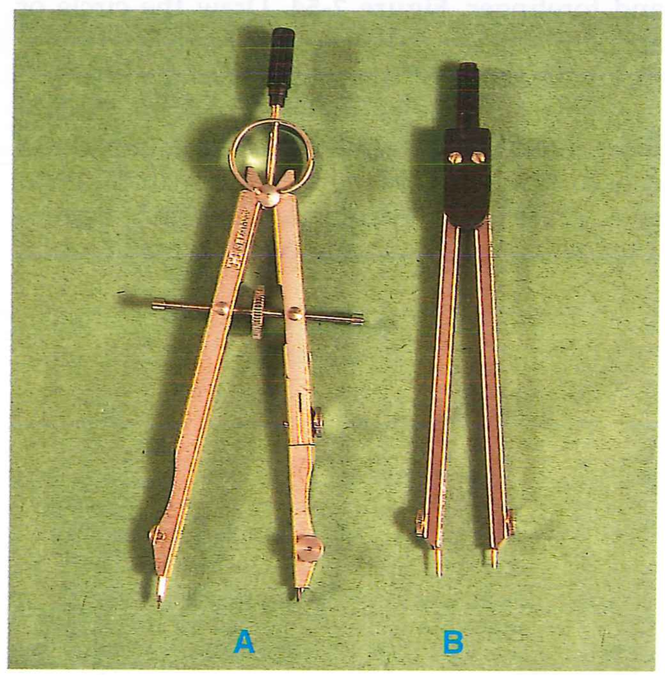


Figure 2-58. Dividers are used to transfer distances and divide lines. A— Many bow compasses can also be used as dividers by placing an additional point where the lead is normally held. B—Friction-joint dividers.

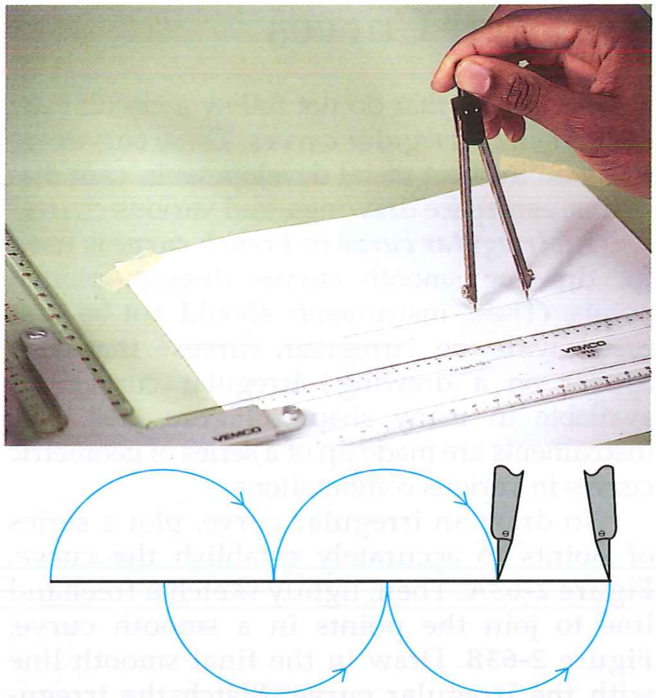


Figure 2-59. Dividers can be used to step off several lines of the same length.

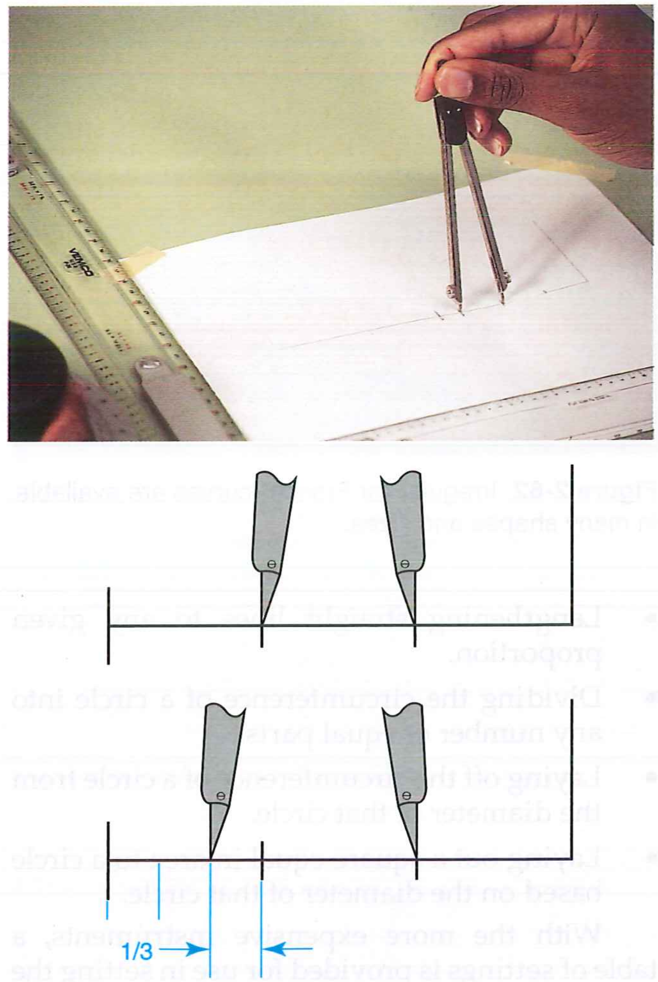


Figure 2-60. Dividing a line into three equal parts.

another trial. Careful estimation of the distance and adjustment after the first trial should enable you to complete the division in two or three trials. Avoid puncturing the paper with the divider points.

Proportional Dividers

Proportional dividers are used for dividing linear and circular measurements into equal parts. They are also used to lay off measurements in a given proportion.

The instrument consists of two legs held together by a sliding pivot. It can be adjusted to obtain various ratios between the two sets of points on the ends of the legs, **Figure 2-61**.

Graduations on the dividers vary by type. They vary from ratios for the division of lines on less expensive dividers to vernier graduations on more expensive dividers. Settings for any desired ratio between 1:1 and 1:10 and ratios for circles, squares, and area may be made.

Examples of uses of proportional dividers include:

- Dividing straight lines into any number of equal parts.

Figure 2-61. Proportional dividers. (Alvin & Co.)

Figure 2-62. Irregular (or French) curves are available in many shapes and sizes.

- Lengthening straight lines to any given proportion.
- Dividing the circumference of a circle into any number of equal parts.
- Laying off the circumference of a circle from the diameter of that circle.
- Laying out a square equal in area to a circle based on the diameter of that circle.

With the more expensive instruments, a table of settings is provided for use in setting the dividers for various proportions.

Irregular Curves

All curves that do not follow a circular arc are known as ***irregular curves***. These curves are common in sheet metal developments, cam diagrams, aerospace drawings, and various charts.

An ***irregular curve*** or ***French curve*** is used for drawing smooth curves through plotted points. (These instruments should not be confused with the "irregular curves" that may appear on a drawing.) Irregular curves are available in many shapes, **Figure 2-62**. The instruments are made up of a series of geometric curves in various combinations.

To draw an irregular curve, plot a series of points to accurately establish the curve, **Figure 2-63A**. Then, lightly sketch a freehand line to join the points in a smooth curve, **Figure 2-63B**. Draw in the final smooth line with the irregular curve. Match the irregular curve with three or more points on the sketched curve. Draw a segment at a time until the line is complete, **Figure 2-63C**.

Check to see that the general curvature of the irregular curve is placed in the same direction as the curve of the line to be drawn. Do not draw the full distance matched by the irregular curve. Stop short and make the next setting of the irregular curve flow out of the previous one, **Figure 2-63D**.

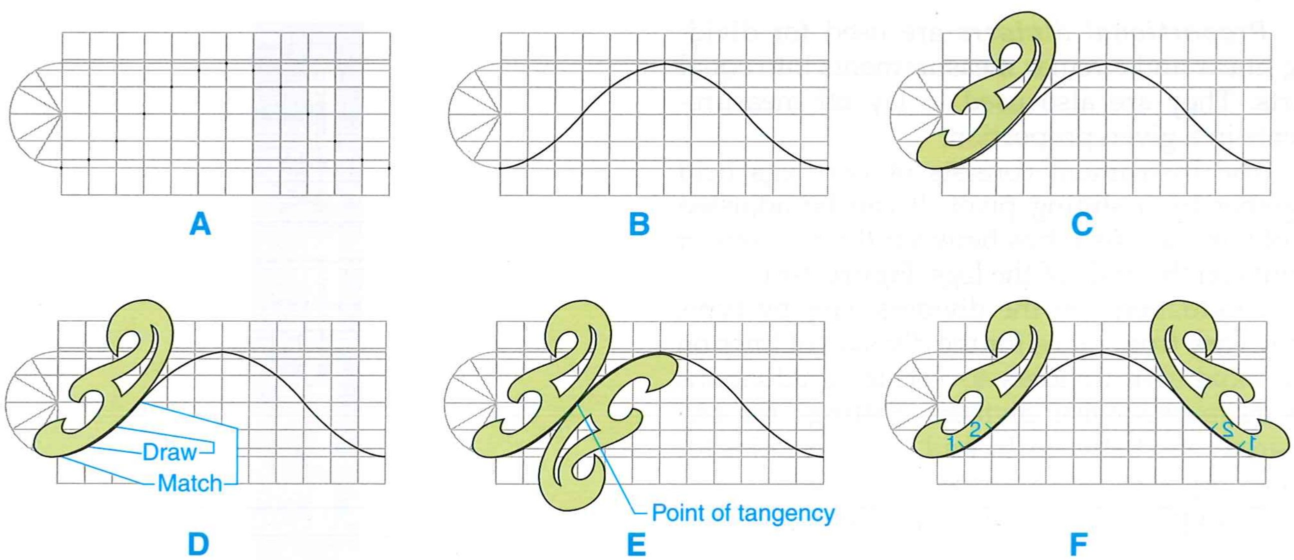


Figure 2-63. Smooth irregular curves can be drawn with the aid of an irregular (French) curve instrument.

When the plotted points of the curve reverse direction, watch for the point of tangency where the irregular curve (instrument) should be reversed and overlap the previous setting with a smooth flow, free of "humps," **Figure 2-63E**.

If the curve is symmetrical in repeated phases (such as in the development of a cam diagram), the same segment of the irregular curve should be used, **Figure 2-63F**. Marking the curve with a pencil when the first symmetrical segment is drawn will aid in locating that segment for successive phases of the curve.

Flexible curve rules and splines with lead weights are useful in ruling a smooth curve through a number of points, **Figure 2-64**.

Pencil Techniques with Instruments

To produce accurate and clean drawings, it is important that you develop proper pencil techniques when using instruments. Carefully observe, practice, and follow these suggestions as they will aid in developing proper techniques.

1. All layout work on drawings should be done with light construction lines. Use a 4H pencil and rotate it slowly when drawing to help retain the conical point.
2. Before the drawing is "heavied-in," erase all unnecessary lines.
3. "Heavy-in" all lines to their proper line weight. Use the proper grade pencil to give the best results with the paper being used. Refer to the line weights listed in **Figure 2-13**.
4. For accuracy, and to minimize working over finished lines, pencil in lines in the following order:
   1. Arcs and circles.
   2. Horizontal lines starting at the top of the drawing and working down.
   3. Vertical lines from your non-drawing hand to your drawing hand.
   4. Inclined lines from the top down and from your non-drawing hand to your drawing hand.
5. To prevent smearing of lines, dust loose graphite from the drawing after each line is drawn. Avoid sliding the T-square, triangles, and other instruments across the drawing.

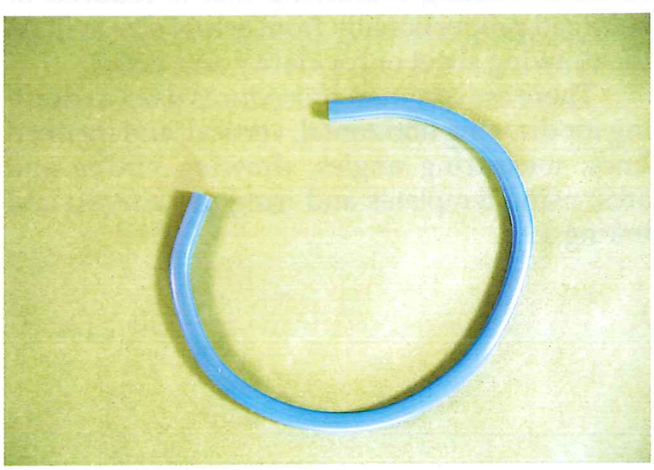


Figure 2-64. Flexible curves can be used to draw many different irregular curves.

Inking

Manual inking of working drawings in industry is practiced very little today, but inking drawings for technical publications is quite common. The difficulty of inking has been greatly reduced with the introduction of improved instruments and drafting media (including higher-grade paper and polyester film).

Inked drawings provide a sharper line definition and make cleaning of the finished drawing much easier. It is possible to erase right over inked lines with a soft eraser and remove penciled construction lines.

Instruments for Inking

The ***technical pen*** has largely replaced the use of ruling pens in industrial and technical illustration, **Figure 2-65**. Pens are available in a series of point sizes, assuring uniformity of line weight throughout a single drawing or several drawings.

The technical pen has a supply reservoir of ink and does not require filling for each use. Today's technical pens offer instant start-up in inking, even after weeks of storage. They are very versatile and can be used with straightedges,

Figure 2-65. Technical pens are versatile instruments for inking drawings. (Staedtler Mars GmbH & Co.)

irregular curves, compasses, templates of all sorts, and in lettering devices. There is very little additional skill required to use a technical pen over a pencil or lead holder.

Procedure for Inking

The following procedure tends to produce neat inked drawings:

1. Lay out the drawing. Use light construction lines with a 2H or harder pencil.
2. Ink arcs from tangent point to tangent point (the points where an arc is joined by a straight line). These points are located by drawing a light circle and drawing the tangent line lightly so that it just touches the circle. This point is the point of tangency.
3. Ink full circles and ellipses.
4. Ink irregular curves.
5. Ink all straight lines of one line weight. Move the pen in one direction. Continue inking remaining straight lines of different weight.
6. Ink notes, dimensions, arrowheads, and the title block.

Chapter Summary

The process of making technical drawings using instruments, templates, scales, and other mechanical equipment is called instrument drafting. Computer-based drafting is accomplished using a computer-aided drafting (CAD) system.

Several types of drafting equipment are used by the mechanical drafter. The following are some of the most basic:

- Lead holder or drafting pencil and pointing devices
- Technical pen
- Drawing board or drafting table
- T-square or drafting machine
- Plastic triangles (30°-60°, 45°, or adjustable)
- Scales (architect's and engineer's scales)
- Lettering device
- Protractor
- Irregular or French curve
- Templates for circles and ellipses
- Eraser and erasing shield
- Drawing paper and drafting tape

The Alphabet of Lines is a drafting standard that gives universal meaning to the lines of a drawing. Each drawing produced should conform to the standard.

All drawings should be drawn to scale, except schematics and tables. Drawing to scale refers to making a drawing that is reduced or enlarged proportionally from actual size to fit on the drawing sheet or for clarity and detail.

There are common procedures used in drafting for drawing horizontal, vertical, and inclined lines; measuring angles; drawing circles and arcs; using templates and irregular curves; and inking.

Additional Resources

Product Suppliers

Alvin & Co., Inc.
www.alvinco.com

Chartpak, Inc.
www.chartpak.com

Staedtler, Inc.
www.staedtler-usa.com

Vemco Corporation
www.vemcocorp.com

Resource Providers

American National Standards Institute (ANSI)
www.ansi.org

American Society of Mechanical Engineers (ASME)
www.asme.org

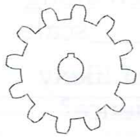
Review Questions

1. The process of making technical drawings using instruments, templates, scales, and other mechanical equipment is called _____ drafting.
2. _____ are used to draw vertical and inclined lines.
3. A _____ combines the functions of the T-square, straightedge, triangles, protractor, and scales into one tool.
4. Materials used in the preparation of drawings or tracings are called drafting _____.
5. _____ is referred to as transparentized or prepared tracing paper.
6. Name three types of drawing pencils.
7. What is the range of drawing leads based on hardness?
8. Name the two types of points used on drafting pencils.
9. The American Society of Mechanical Engineers (ASME) standard for drawing lines accepted throughout industry is known as the _____.
10. Object lines are also known as _____ lines.
11. Hidden lines start and end with a _____.
12. What is another name for section lines?
13. What do centerlines represent?
14. Lines used to indicate the extent and direction of dimensions are known as _____ lines.
15. _____ lines are used to limit a partial view of a broken section.
16. What is *ghosting*?
17. What are the two basic shapes that scales are made in?
18. A scale that has all units subdivided along the entire scale is said to be a(n)_____ scale.
19. What type of scale would you most likely use to draw a floor plan for a residence?
20. The _____ engineer's scale is an open-divided scale useful in drawing machine parts where the dimensions are in inches or fractional parts of an inch.
21. The basic unit of length in the metric system is the _____.
22. A scale of 1/4″ = 1′-0″ is commonly referred to as _____ scale.
23. The _____ is usually located in the lower-right corner of the drawing just above the border line.
24. When drawing a line, the pencil should be _____ in the direction the line is being drawn.
25. A _____ is used to measure and mark off angles that cannot be measured with a T-square and triangles.
26. What instrument is used to draw circles and arcs?
27. Commonly used characters and symbols may be drawn using drafting _____.
28. _____ are used to transfer distances and to divide straight and circular lines into equal parts.
29. What device is used to draw smooth curves through plotted points?

Drawing Problems

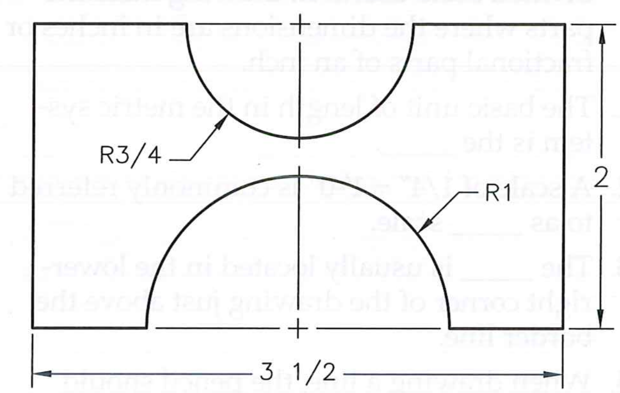
The following drawing problems are one-view drawing problems designed to provide you an opportunity to become familiar with the use of basic drafting instruments. They are classified as introductory, intermediate, and advanced. A drawing icon identifies the classification. The problems include customary inch drawings and metric drawings.

Use A-size drawing sheets and draw the objects. Select a scale size to make good use of available drawing space without crowding. Do not dimension these drawings.

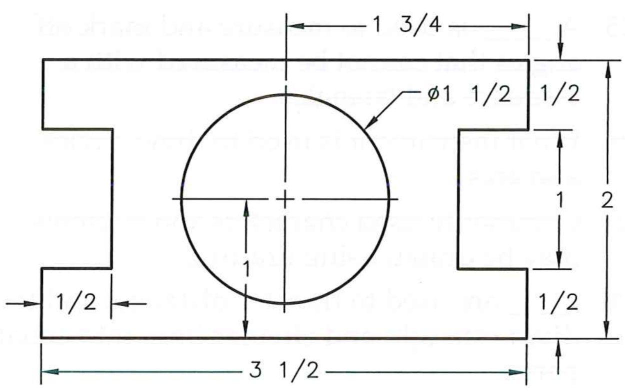


Introductory

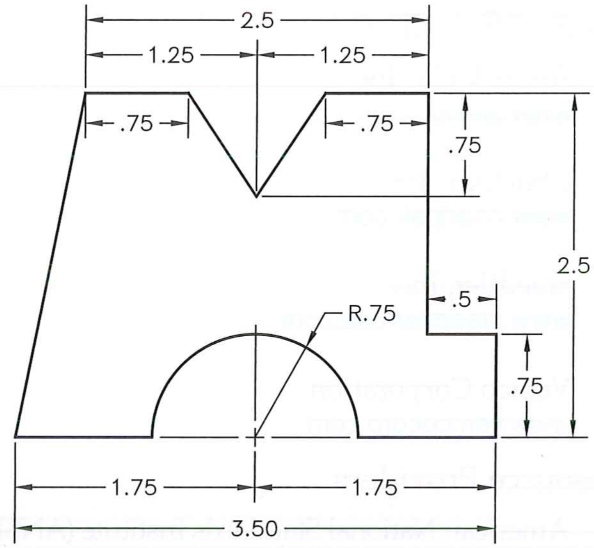
1. Template



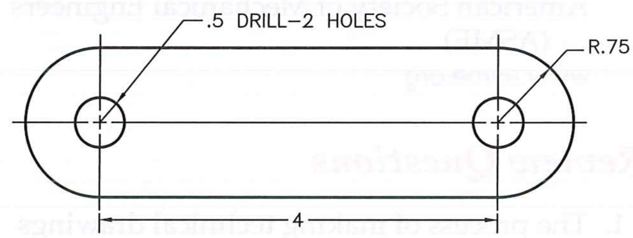
2. Hole Guide



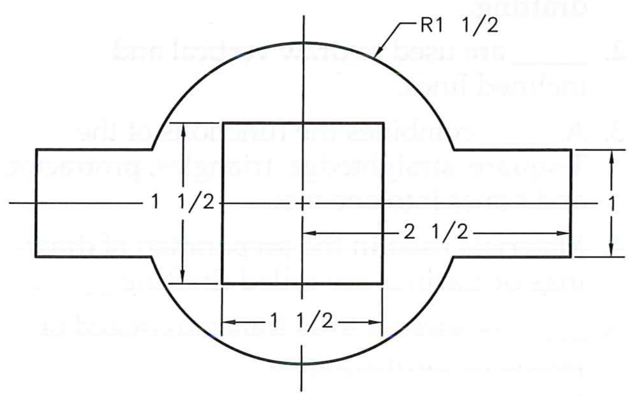
3. Cutting Guide



4. Clamp

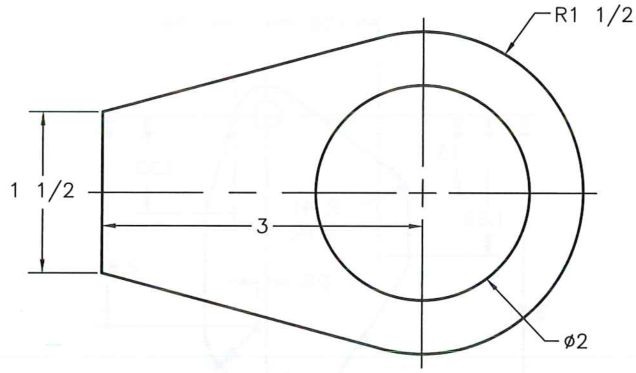


5. Tab Lock

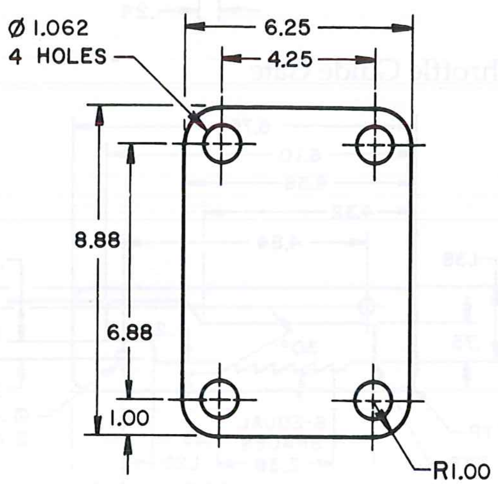


Introductory

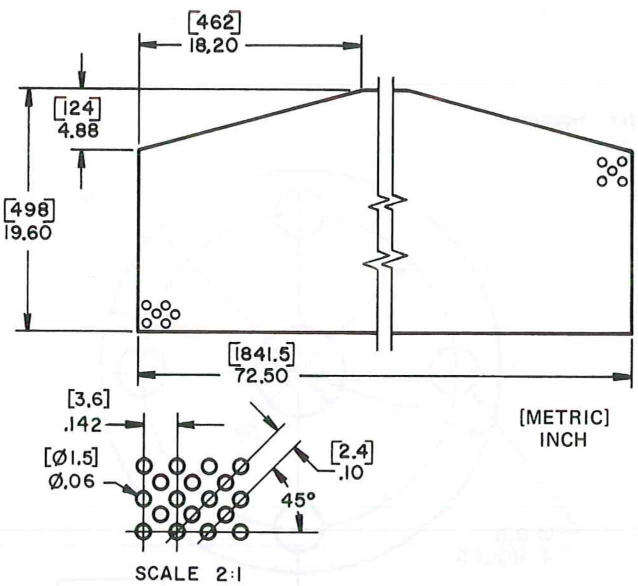
6. Spacer



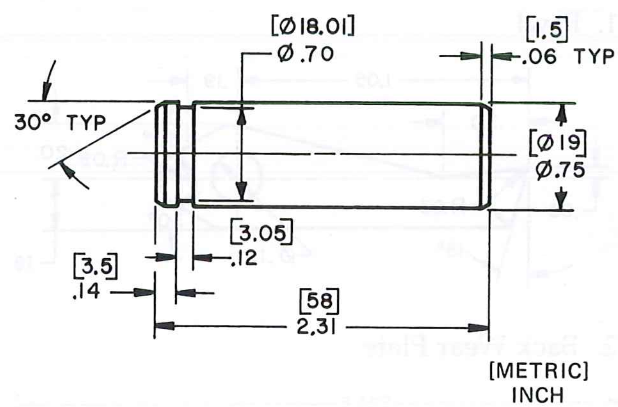
7. Plate



8. Screen

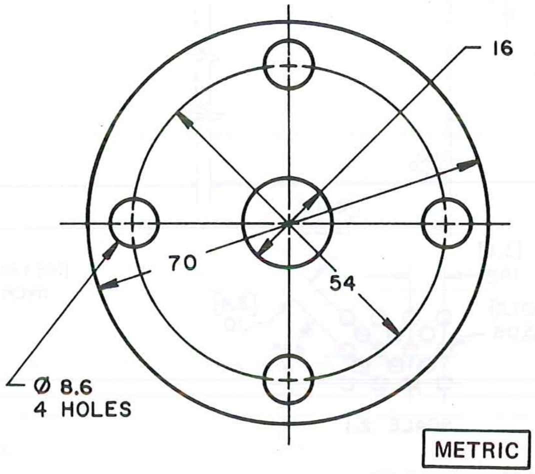


9. Idler Arm Pin

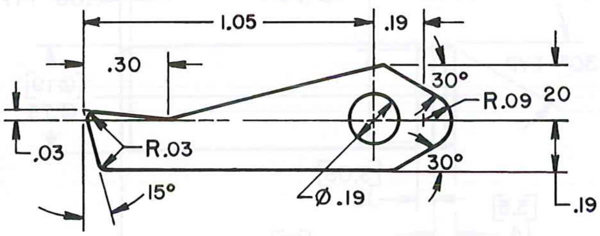


Introductory

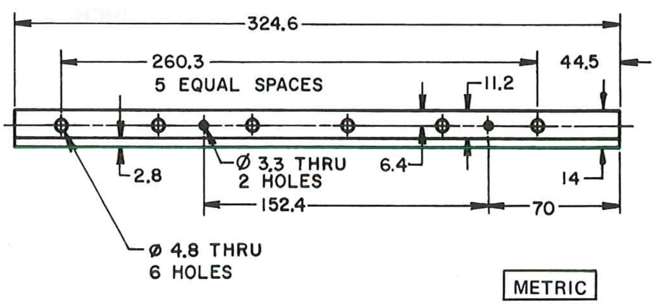
10. Spacer



11. Pawl

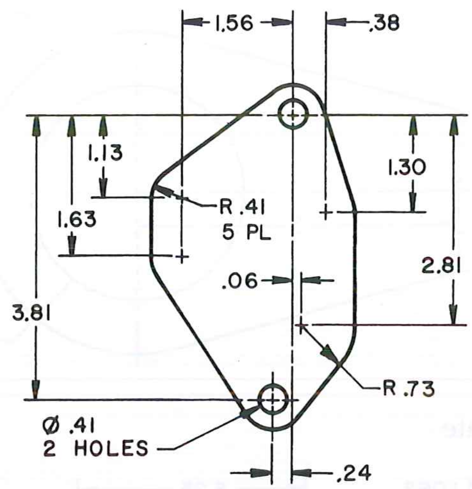


12. Back Wear Plate

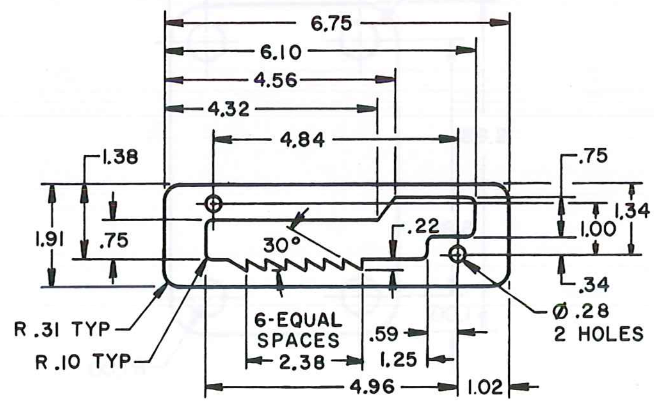


Intermediate

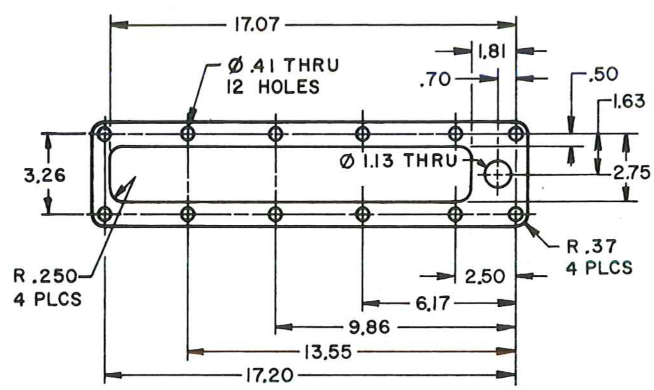
13. Cover Plate



14. Throttle Guide Gate

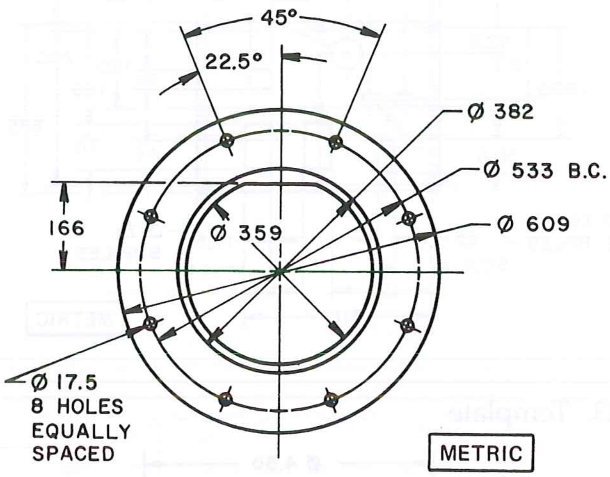


15. Water Inlet Connect Gasket

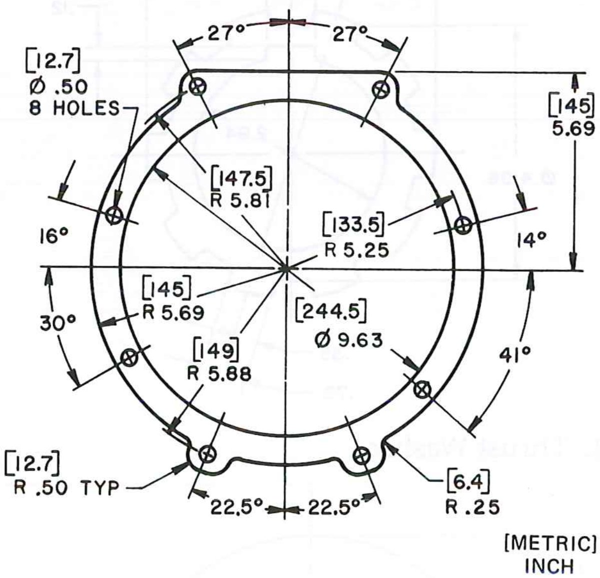


Intermediate

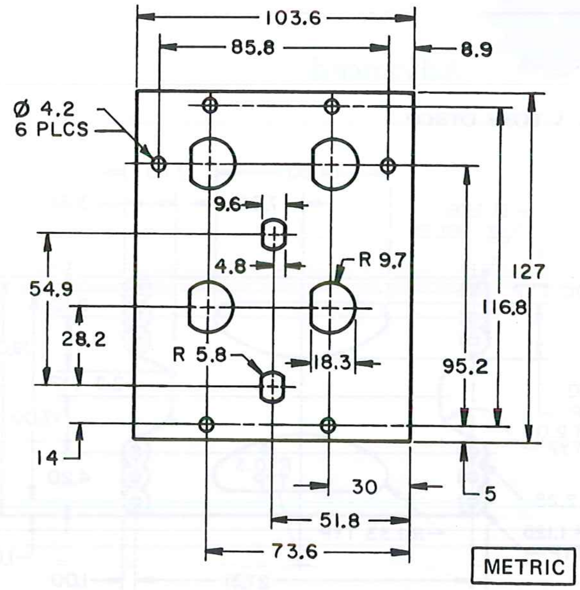
16. Retainer



17. Vacuum Pump Gasket

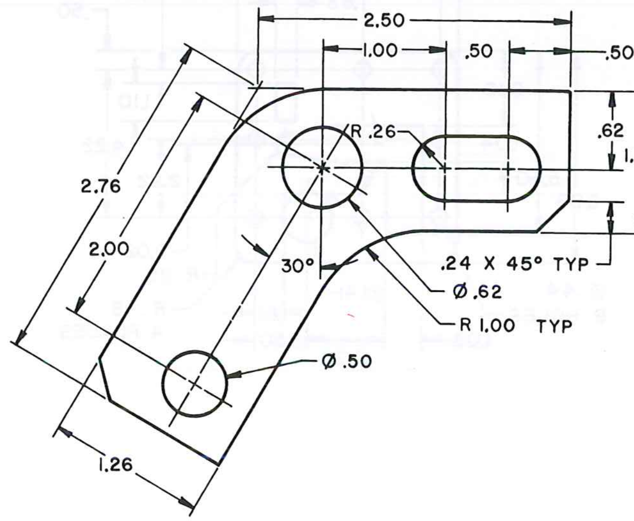


18. Frontal Plate



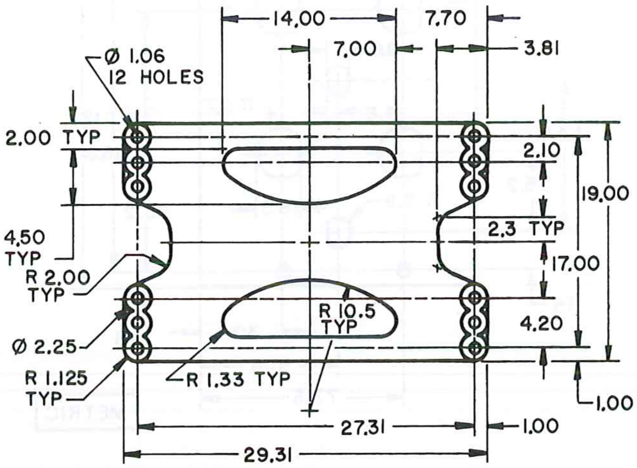
Advanced

19. Entry Clamp

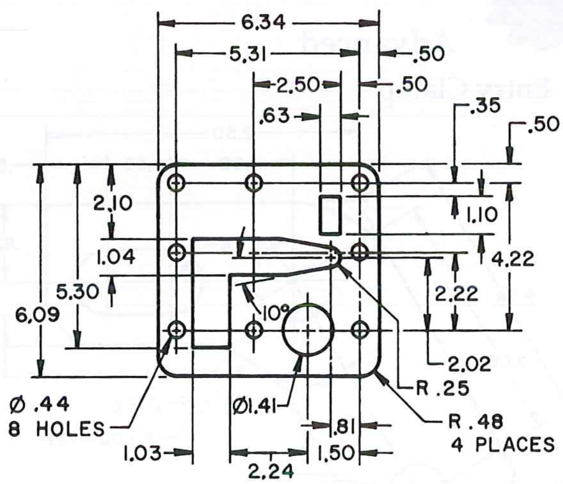


Advanced

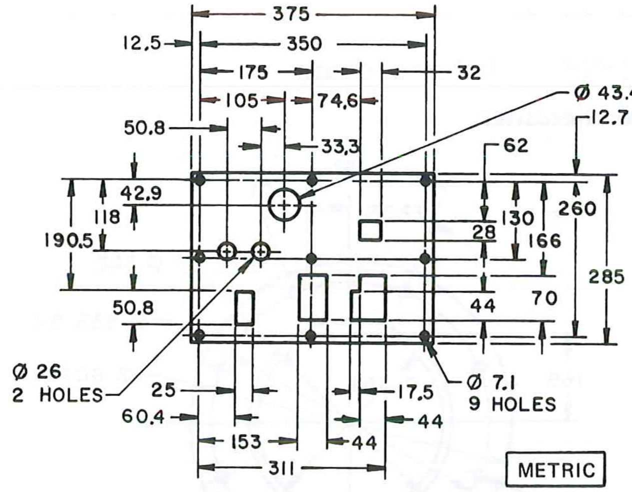
20. Cross Brace



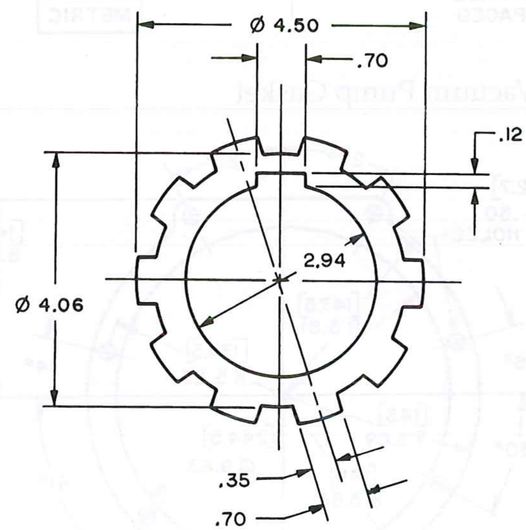
21. Ditch Plate Gasket



22. Base Plate



23. Template



24. Thrust Washer