DOCUMENT RESUME

ED 175 733 SE 028 913

AUTHOR	McKaughan, Stephen V.; And Others
TITLE	Basic Shop Skills in Wood, Metal, Circuits, Glass.
INSTITUTION	Boston Univ., Mass. Physical Science Group.
SPONS AGENCY	National Science Foundation, Washington, D.C.
PUB DATE	75
GRANT	NSF-GZ-2892
NOTE	216p.; Photogra : may not reproduce well
EDRS PRICE	MF01/PC09 Plus Postage.
DESCRIPTORS	Class Activities; Electronics; Glass; Higher Education; *Industrial Arts; Interdisciplinary Approach; *Laboratories; *Laboratory Equipment; *Laboratory Technology; Science Education; *Science Laboratories; Secondary Education; Sheet Metal Work; Woodworking
IDENTIFIERS	National Science Foundation

ABSTRACT

The text seeks to help students reach, through about 90 hours of class instruction, to acquire a level of competency necessary to repair a piece of laboratory equipment or construct a simple piece of equipment. Tools are introduced as needed in each of three sections of the text: (1) woodwork and metalworking; (2) electrical circuits; and (3) glassblowing. The course is intended for undergraduate, preservice science education majors and graduate students in science education. (Author/RE)

BASIC SHOP SKILLS

IN WOOD, METAL, CIRCUITS, GLASS

PHYSICAL SCIENCE GROUP
BOSTON UNIVERSITY

BASIC SHOP SKILLS

in

Wood, Metal, Circuits, Glass

PHYSICAL SCIENCE GROUP

Boston University

Printed in the United States of America

PREFACE

Whether the setting is a science classroom at a high school or a research laboratory at a university, there are times when it is advantageous to know how to repair a piece of equipment or to construct a simple piece of apparatus. The job may require only the mastery of a simple skill such as making a solder joint, bending a piece of glass, or tapping a hole for a screw. Nevertheless, even the mastery of such rudimentary skills requires careful instruction and a good deal of practice. It is the primary aim of this text to help students reach this essential level of competency.

The text naturally divides into three sections: woodworking and metalworking, electronic circuits, and glassblowing. Rather than instructing the students to perform lengthy and often tedious practice operations, the text is designed around the construction of a carefully planned series of projects. Within each section different tools and operations are introduced as they are needed, the procedures becoming more complex for each successive project. By actually building useful pieces of equipment the students gain confidence in knowing that they can use the skills they are learning.

The recommended time allotment for the entire course is approximately ninety hours with each work session being at least two hours long. Approximately half the course consists of the wood and metal section, with the remainder being divided between circuits and glass.

Because the three sections of the text are independent, each can be used separately.

Orig. ıally developed as part of an undergraduate course for the preparation of physics-chemistry teachers, the text has been revised and expanded to meet the needs of a wider group of students, including undergraduate science majors and graduate students in science education. During its piloting, the course was taught to a variety of students, both men and women, some of whom had previous experience and others none. The course best accomplished its goals when each student completed the projects at a pace that matched his or her ability. By learning a few skills well, the students gained the confidence to use them again.

● ● ●

The early planning of the shop course was done by Stephen V. McKaughan, Judson B. Cross, James A. Walter, and Uri Haber-Schaim, Director of the Undergraduate Program for Physics-Chemistry Teachers. The drawings were done by George V. Friguliettl and Myrna Goldblat, and R. Paul Larkin took most of the photographs. The text was edited and produced by Susan J. McMahon. The camera copy was typed by Caroline E. Russell.

The development of the Undergraduate Program is supported by a grant from the National Science Foundation.

Stephen V. McKaughan
Richard J. Duffy
July 1975

A WORD ON SAFETY

In this course you will learn to use a variety of tools, ranging from hammers to an oxygen-gas torch, to perform many different operations. If used improperly, many of these tools can cause physical harm. For this reason safety in the shop is extremely important. Safety methods, as they apply to each tool, will be taught along with the use of the tool, but there are a few general rules to remember.

In the shop the most dangerous clothes to wear are those with long sleeves, which can get caught in machines, and ties, scarves, or any loose apparel around the neck. Always wear shoes that give good traction, because a slip at the wrong time could result in injury. If you have long hair, be sure to tie it back securely.

The basic safety rule in all shop work is to think ahead, plan each operation, and anticipate all the possible results of what you are about to do.

CONTENTS

WOOD AND METAL

The materials most commonly available for making equipment are wood and metal. From visits to the local lumberyard and the hardware store and with a little ingenuity, you will have the material that you need for the construction of simple laboratory equipment.

The first section of this text is designed to teach you the skills needed to work with these materials. Although the tools used for working wood are different from those used to work metal, the operations and the coordination needed to perform the operations are very similar. When you make a piece of apparatus different parts will be made of different materials. To work with other materials, which have some of the properties of wood and some of the properties of metal, you will have to combine woodworking and metalworking techniques. For these reasons, this section combines woodworking and metalworking, teaching the skills as they are needed to build a project.

The projects in this section are simple if they are done consecutively because each project teaches techniques that are used over and over. The instructional material contained here will appear difficult or easy depending mostly on your experience with the tools involved. Even if you think you know all about certain operations and tools, read the sections through because they may contain information you have forgotten. Most power tools are introduced later in the section because they are more dangerous to use than hand tools and should be operated only after you have gained some understanding of the work involved.

Above all else, think before you act. Your thoughtfulness can prevent errors and minimize the chance of injury.

Project 1: A LABORATORY STAND

Your first project is the wooden stand shown in Fig. 1.1(a). For a number of experiments where equipment must be supported about two feet above a table top, the stand is clamped as shown. The stand is sturdy enough so that it will not bend, vibrate, or otherwise interfere with the operation of the apparatus it supports. Clamped to the stand, in Fig. 1.1(b), is a weighted bicycle wheel used for a study of kinetic energy.

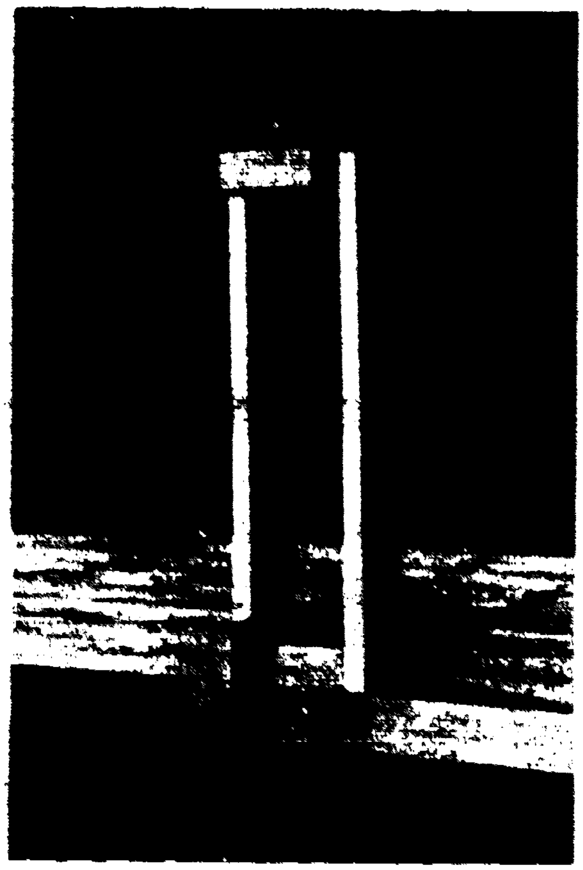


Fig. 1.1(a)

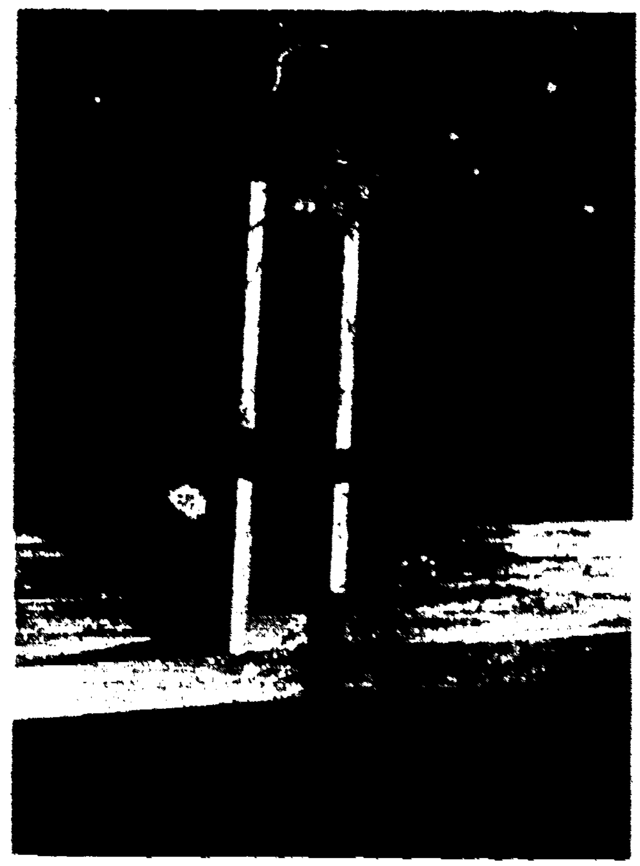


Fig. 1.1(b)

1.1 The Handsaw

Generally, the first operation in any shop project is to bring a piece of wood or metal (called stock) to the proper length, width, and thickness. In most cases, this operation is done with a saw of some kind.

o o o o o o o o

Using a handsaw, cut a few short pieces off one end of a board.

Was it easy to get the saw started? In which direction did the saw remove more material, when moving toward you or away from you?

What happened when you neared the end of the cut?

Were the sawcuts straight and square (at right angles) to the adjoining surfaces?

What did you find was the easiest position in which to stand while you were sawing?

o o o o o o o o

Handsaws are used only to cut wood and other soft materials. They are purchased by length of cutting edge (usually 24 or 26 inches) and by the number of points (teeth) per inch. There are two kinds of handsaws: crosscut saws and ripsaws.

Crosscut saws are used to cut across the grain of the wood. Figure 1.2(a) shows the teeth of a crosscut saw. Observe that the teeth do not lie in a straight line but are bent alternately a little to one side and then to the other. This is called set. Because of the set, the width of the sawcut is greater than the thickness of the steel of which the saw is made. The set provides clearance so that the saw blade does not stick and bind in the wood while cutting. Notice also that the teeth are sharpened at an angle and are close together (8 to 12 points per inch) to make it easier to cut across the grain of the wood.

Fig. 1.2(a)

Ripsaws are used to cut with the grain of the wood. Although you will not use a ripsaw in this course, you should be able to recognize one. Like the set of a crosscut saw, a ripsaw's set also prevents the blade from sticking in the wood. The difference between a ripsaw and a crosscut saw is that the teeth of a ripsaw are sharpened straight across, as shown in Fig. 1.2(b), and are spaced much farther apart (5-1/2 points per inch).

Fig. 1.2(b)

If it is necessary to rip a board and a ripsaw is not available, a crosscut saw can be used, although it will take more time. However, the opposite is not true: If a ripsaw is used to cut across the grain of the wood, it will splinter the wood.

The proper way to use a handsaw is demonstrated in Fig. 1.3. Note that the knuckle of the left thumb rests against the blade above the teeth to guide the saw. The initial motion of the saw should be toward you. Note that the cutting edge of the saw makes approximately a 45 degree angle with the board. Always find a comfortable position while cutting a board. Usually the board is placed low and is cut with smooth strokes using most of the saw blade. When you approach the end of the cut, use very short, easy strokes, applying less pressure so that the last bit of wood will not chip away.

Fig. 1.3

1.2 The Square

In Section 1.1 you were told to try to cut a piece of stock so that the cut surface was at an angle of 90 degrees to all the other surfaces. You probably judged the angle by eye, which was perfectly adequate for the practice operation. However, if greater accuracy is required, a tool called a square is generally used.

Of the two common types of squares shown in Fig. 1.4, the combination square is the most versatile. Its blade slides in the head to vary the

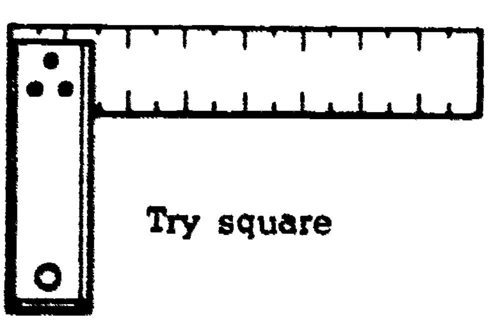
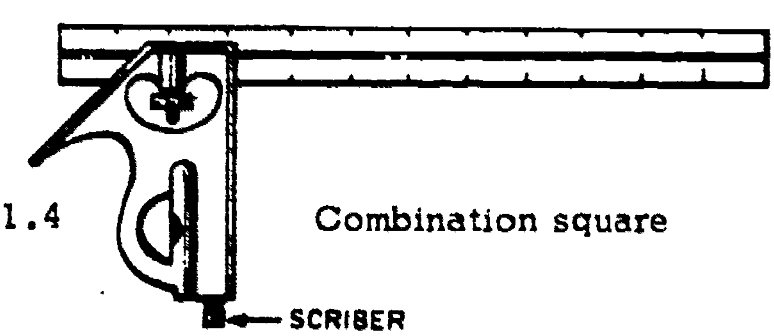


Fig. 1.4



length, and there is a face for drawing or measuring a 45 degree angle.

Perhaps the biggest problem that occurs when using a square is in deciding to which surface another should be square. No problem arises when all the surfaces of a board are already square to each other. However, what happens when two edges of a board are not parallel? The ends may be square with one edge of the board but not with the other. Therefore, you must choose one surface as a reference from which other surfaces can be compared for squareness or for size. The reference surface should be smooth and flat and be square with as many adjoining surfaces as possible. A reference surface must be chosen in each plane to measure the length, the width, and the height of a board. Since three references may not be available, you will have to make them. To begin with, you must choose one surface for cutting the end of a board square, and this surface will become the reference for all future operations.

When using a square to draw a line for a sawcut, place the flat surface of the head against the surface that is used as a reference, as shown in Fig. 1.5. Then mark the line. When using it to check the end of a piece of stock, place the square as in Fig. 1.6 and move it until the blade touches at one point. By holding the stock and the square up to the light, you will be able to see if the blade is in contact with the entire edge being measured.

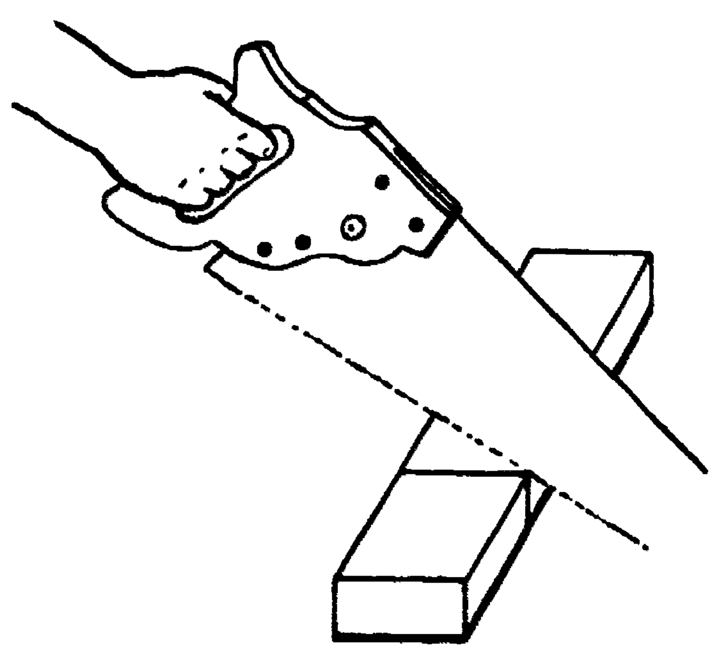
Fig. 1.5

Fig. 1.6

o o o o o o o o

Draw a line across a board at right angles to its edge, as shown in Fig. 1.5. An additional line can be drawn on the front edge of the board (Fig. 1.7) to act as a guide for the vertical alignment of the saw-cut. Cut the end off and practice until you can follow the lines and cut the end square — that is, with the resulting surface perpendicular to the adjoining surfaces of the board.

Fig. 1.7



Take a close look at the saw you used. How many points per inch does it have? What do you think would be the advantages or the disadvantages of using a saw with more points per inch?

o o o o o o o o

1.3 Shop Sketches

Figure 1.8 is called an assembly drawing and illustrates how parts of a piece of apparatus are aligned and fastened together. This particular drawing shows a pair of clamped blocks used to hold different pieces of equipment on the apparatus stand. As a pictorial representation it provides an idea of the shape of the device but gives little information concerning its size or construction.

Figure 1.9 is a shop drawing and contains all the information needed to construct the same clamping blocks. It shows the overall size of the blocks and the position and the size of each hole. To someone not familiar with shop drawings, the objects that these two figures represent may not resemble one another. Therefore, it is necessary to understand the procedures and symbols used in making shop drawings.

By looking at Fig. 1.9, you can see that a shop drawing consists of three separate illustrations. Each represents the clamping blocks from a different viewpoint: top, front, and right-hand view. The top view depicts the clamping blocks as viewed along the arrow from point 1 (Fig. 1.8). The front view is observed

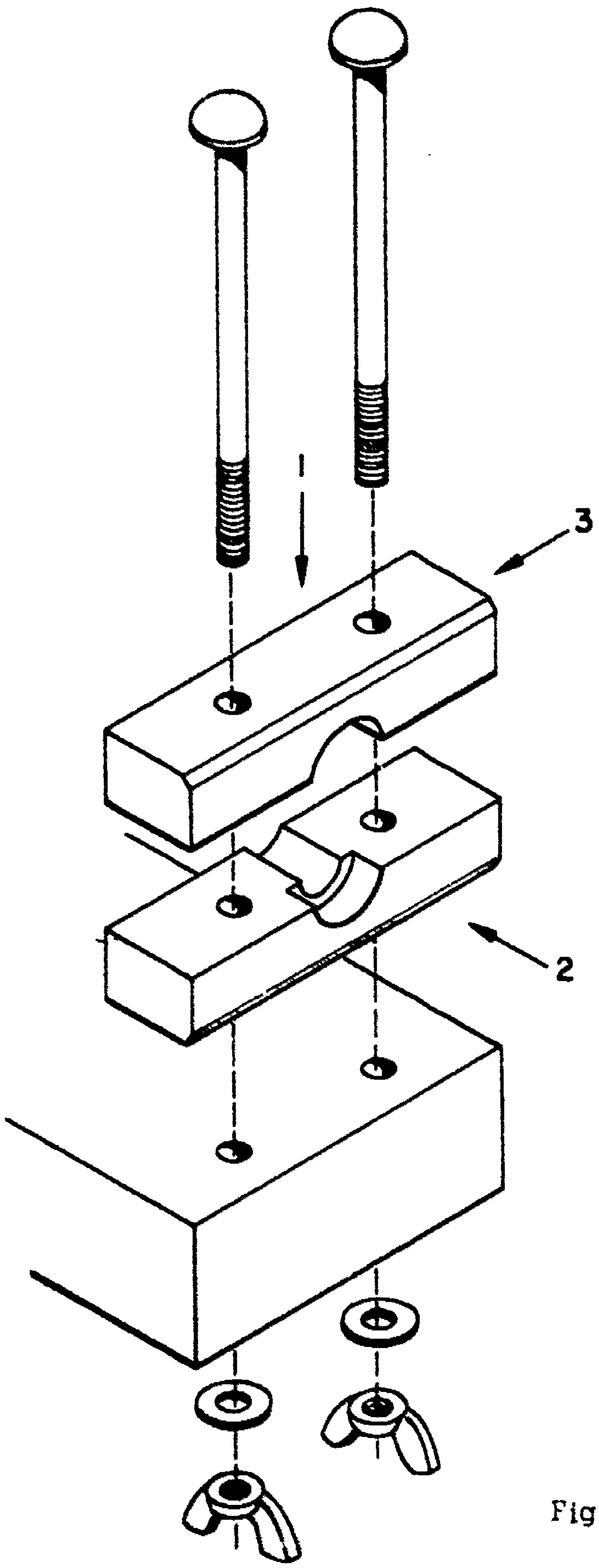


Fig. 1.8

from point 2 and the end view from point 3.* Note that in the top view, holes A and B appear as circles, whereas in the front view they are shown as dashed lines with an alternately long and short dashed line down the middle.

In some cases, such as simple, cylindrically shaped objects, only two views are required to give all the necessary information. However, in the majority of cases (Fig. 1.9 included), if any view were not supplied, you could only guess about some of the dimensions and shapes.

Some of the line symbols used in shop drawings are shown in Fig. 1.10. The object line is used to outline the piece to be made. Hidden

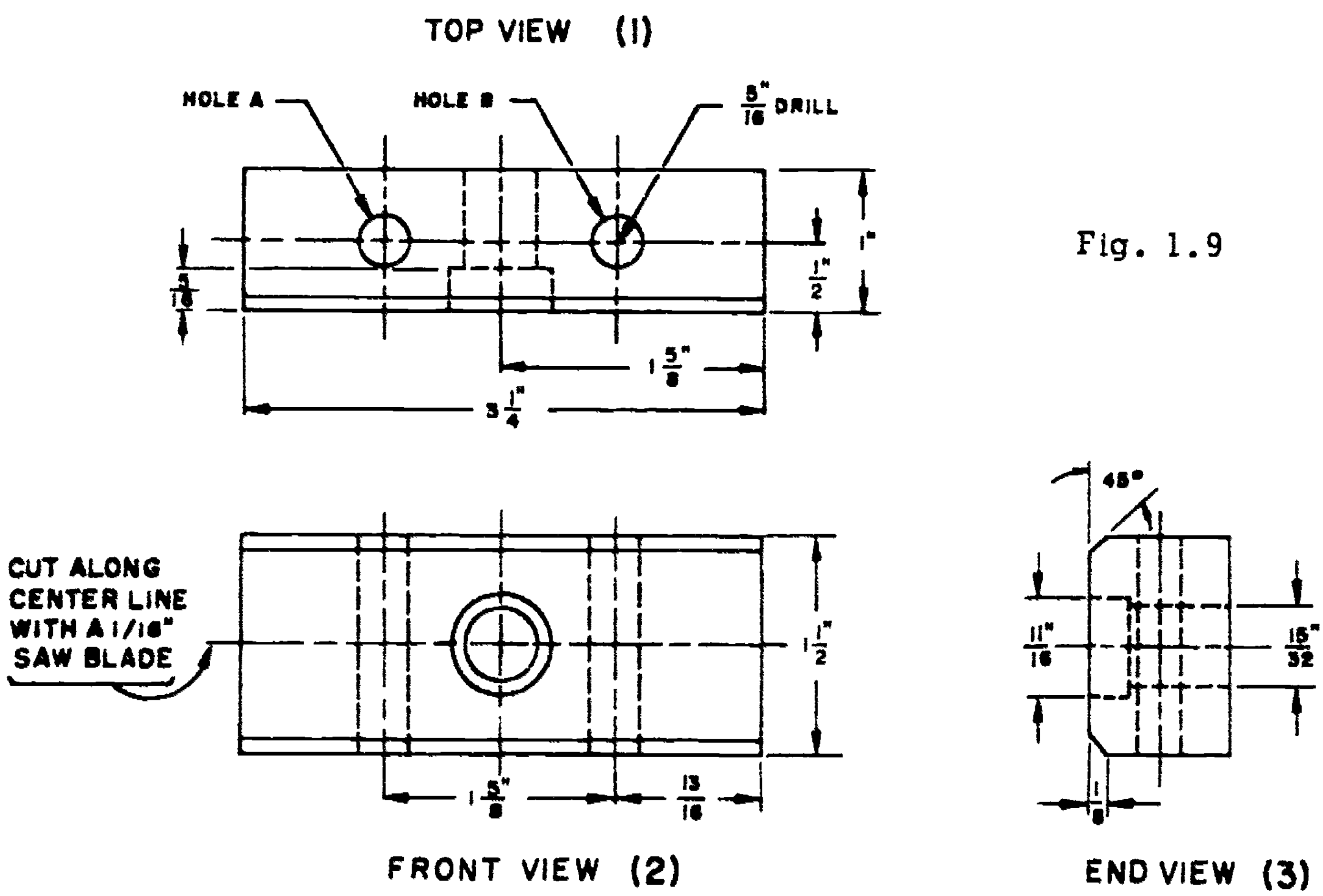


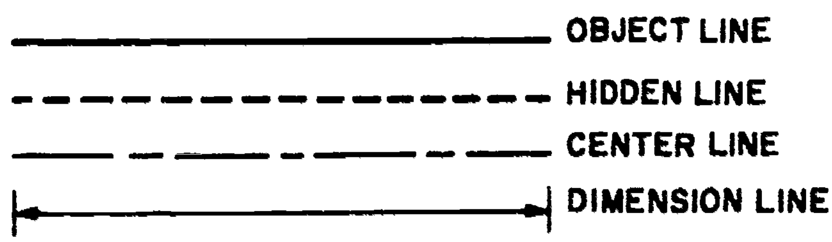
Fig. 1.9

*Note that two blocks are shown in Fig. 1.8 whereas they are indicated as one piece in Fig. 1.9. The two pieces are produced by cutting the block in half after all other operations are completed. This sawcut is noted on the drawing.

lines are edges that cannot be seen from the point of view of the drawing. These lines can indicate holes, slots in the other side of the piece, hidden edges of all kinds. Center lines are used to show the center of any piece or hole and to show the axis of the piece. All circular holes or circles are drawn with center lines through their centers, and dimensions are measured from these center lines. Any center line in the middle of a piece is considered to be its axis if marked with the symbol ℄.

A dimension line represents a measurement between the arrow points on its ends. Often the dimension you want is not shown on a drawing, and you have to do some addition or subtraction to find it.

Fig. 1.10



In many drawings some lines are made heavier than others for emphasis, making the drawing easier to understand. (Dimension lines, for example, are usually lighter than object lines.) In general, a good drawing contains only enough detail to make it understandable. Any additional detail may just clutter it.

o o o o o o o o o

In Fig. 1.9, how far in from each side is hole A? How far apart are holes A and B? How deep is hole A? How deep is the 11/16-inch-diameter hole? How far in from the left-hand end is the 15/32-inch-diameter hole?

The pieces needed to assemble the apparatus stand are depicted in Fig. 1.11. Get the necessary boards and cut them approximately 1/16 inch longer than given in the drawing to allow for finishing. Use a square as shown in Fig. 1.5 to draw the lines on the boards to mark the sawcuts.

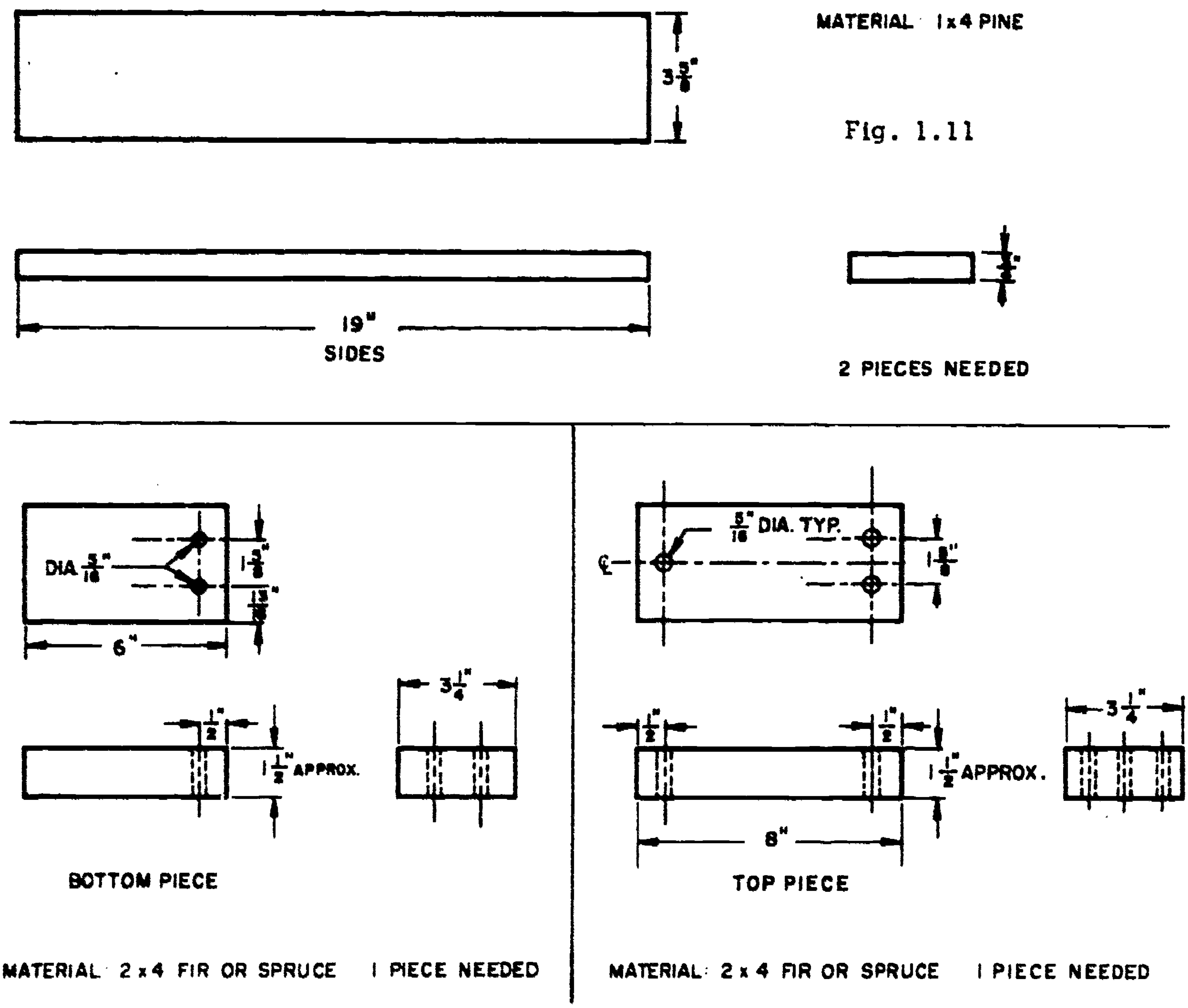


Fig. 1.11

If you wish a board to come out a precise length, where should you make the sawcuts, along the center of the lines or to one side?

o o o o o o o o

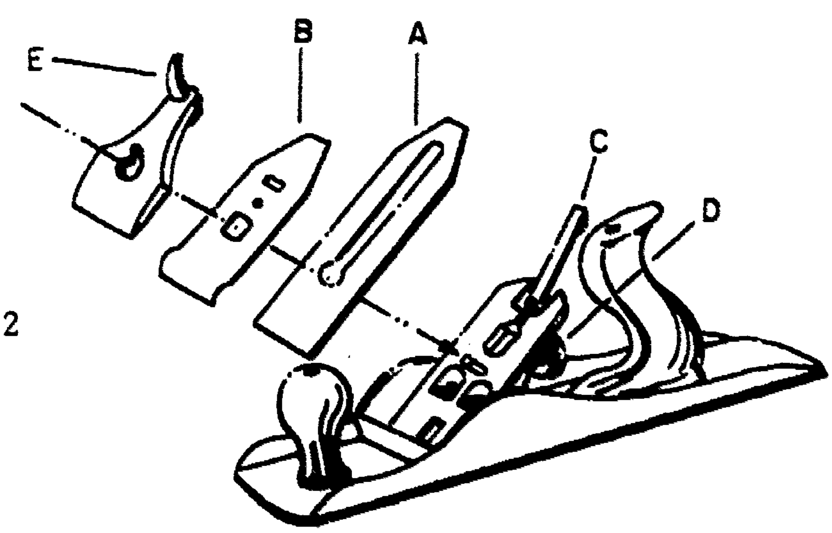
1.4 The Plane

When a sawcut is not square, or when only a small amount of wood needs to be removed to make the piece the desired dimension, a plane can be used. There are several different kinds of planes. They all look like the one shown in Fig. 1.12, although they vary in length from about six inches to approximately 30 inches.

Each plane holds a sharp blade that protrudes through the bottom surface of the plane to slice off material. A jointer plane is about 22 to 30 inches long and is used for planing the edges of long boards. A smoothing plane is about eight inches long and is used for doing precise work. A block plane, about six inches long, looks slightly different from the others but is adjusted the same way. Because of its compactness, a block plane is used for small jobs and is ideal for planing the ends of boards. The jack plane is the most common of all. It is between a smoothing plane and a jointer plane in size, and therefore it can do most of the jobs of all the other planes.

The parts of a plane are shown in Fig. 1.12. Part A is the blade that does the actual cutting. Part B keeps the blade rigid and also breaks off the thin slices of wood so that they will not jam the plane. Its front edge should be about 1/16 inch back from the cutting edge of the blade. Part C is used to adjust the blade so that its cutting edge is parallel to the surface of the board. Part D is used to control the depth that is cut.

Fig. 1.12



Because the blade is very sharp, you should never touch the cutting edge with your fingers. Keep your fingers away from the bottom of the plane when using it. Because the cutting edge can be easily chipped or dulled, always lay the plane on its side when not in use.

o o o o o o o o

Disassemble the plane by first lifting the release lever (part E). Note how the parts fit together and check to see how the adjustments work. When reassembling the plane, be sure that part B (see Fig. 1.12) is adjusted so that its front edge is about 1/16 inch back from the cutting edge of the blade.

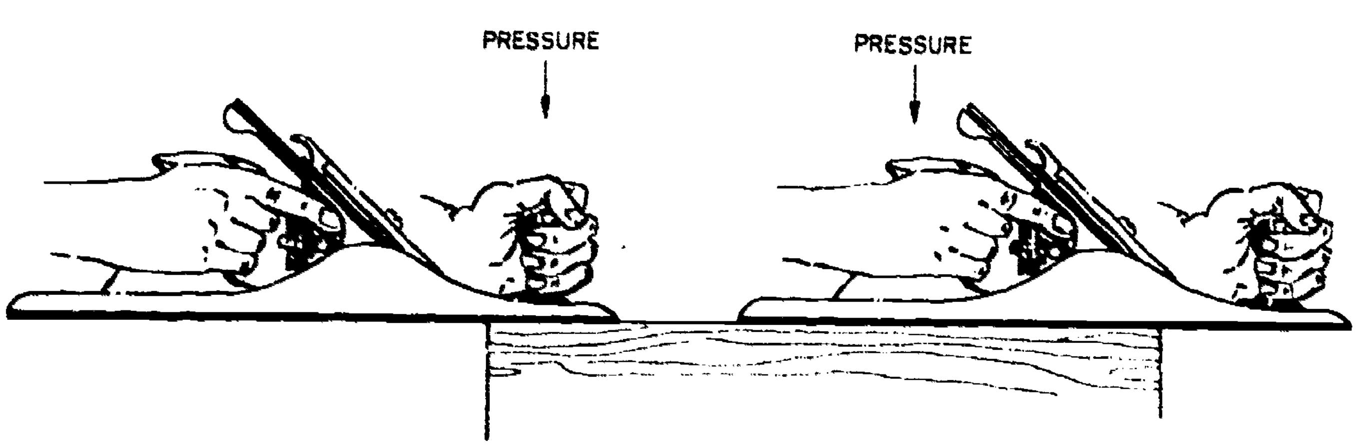
o o o o o o o o

When both edges are square and flat, planing down a board to a specified dimension is a simple matter. First choose one edge as a reference. Parallel to the reference edge, draw a line corresponding to the final dimension. Then clamp the board in a carpenter's vise with the edge to be planed facing up. Hold the plane as shown in Fig. 1.13 and push it along

Fig. 1.13

the edge of the board with one smooth stroke. The beginning and the end of a stroke are shown in Fig. 1.14. Note that the stroke begins with the blade to the left of the end of the board and that downward pressure is exerted on

Fig. 1.14



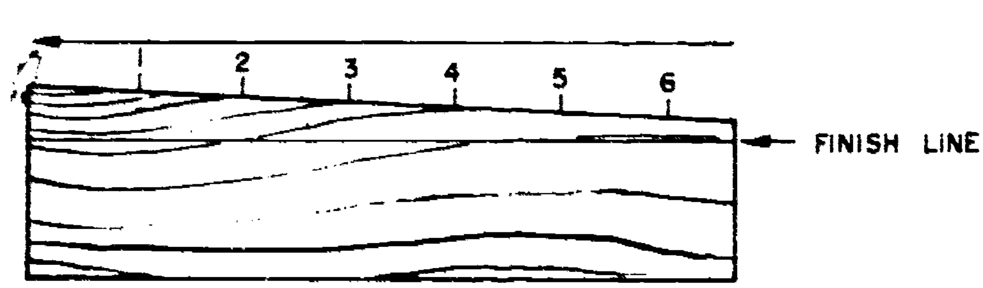
the front of the plane. The stroke ends with the blade beyond the other end of the board and with the pressure on the rear of the plane. This is the only way to make sure that the surface remains flat. After every few strokes, check the edge at different points to see if it remains square. If it does, continue the operation until the board is planed to the line you drew earlier.

With the blade adjusted properly (with its cutting edge parallel to the bottom surface of the plane), nothing can alter the angle of the edge being planed. Therefore, if the edge is square it will remain square as the board becomes narrower. Likewise, if the edge is not square it will remain untrue.

Planing an edge of a board that is not square to begin with, therefore, becomes a matter of trial and error. First, check to see which side of the edge is highest. Then take a few strokes with the plane, removing material from the high side. By watching the chips that are formed by the blade, you can see where material is being removed. Looking down on the edge of the board, if the right side is the higher, the chip should appear on the right side of the blade. If it does not, tip the plane clockwise and try again. After a few strokes, removing material from the same place, check to see if the surface you have generated is square. If it is, proceed with the operation by using the newly squared edge as a reference. If it is not, find the high spot and try again.

Another problem you may encounter when planing a board to its final dimension is that the edge to be planed is not parallel to the reference edge. Therefore, it is necessary to remove more material from the wider end than the narrower one. Figure 1.15 will assist in the explanation of this operation. Begin planing in the direction indicated by the arrow, removing mate-

Fig. 1.15



rial beginning at point (1). (Two or three strokes should be sufficient.) Then begin the stroke at point (2); then (3); and so on. After the edge is flat, measure the distance from the finish line to the planed edge to see if the two edges are parallel. Make corrections if needed and proceed to plane the board to its final width.

o o o o o o o o

Take a piece of stock, adjust the plane for a thin cut, and practice planing the edge of a board. Use one smooth, continuous stroke from one end of the board to the other. Take several strokes and check to see that the surface is square and flat.

After practicing for a while, use the plane to square one edge of each piece of wood you cut for the apparatus stand. This edge can then be used as a reference for planing the opposite edge to its final dimension (3-1/4 inch, as shown in Fig. 1.11).

o o o o o o o o

1.5 Finishing End Grain

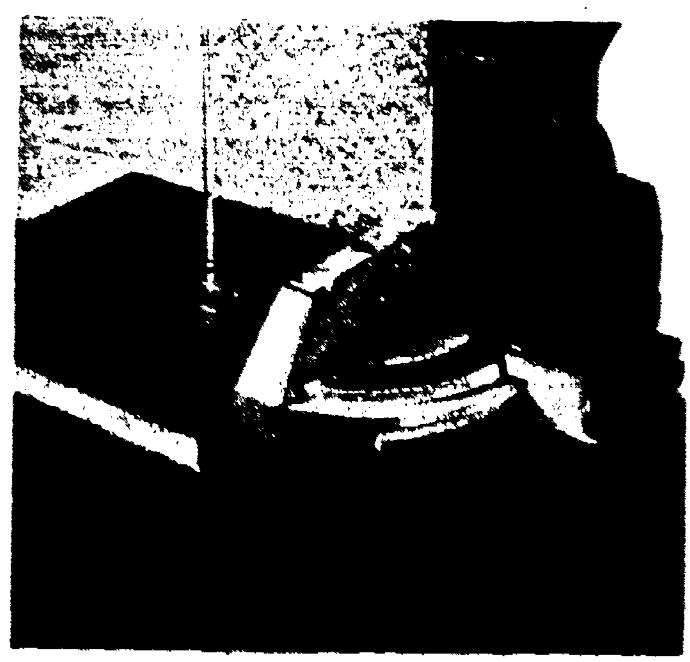
In Section 1.3 you were instructed to cut the boards for the laboratory stand about 1/16 inch longer than specified to allow for finishing. As you may have observed, after the boards were cut with the saw, the resulting surface was not as smooth as the sides or edges of the board. They may not have been perfectly flat and square either. In building a house, the end of a board has to be reasonably square and flat to fit properly, but because the end will not been seen, it doesn't have to be perfectly smooth. However, when building furniture or apparatus, not only must the ends be flat and square but they must also look good.

Figure 1.16 depicts a power tool called a belt sander. It has a motor connected by V belts and pulleys to a drum located at about the middle of the machine. At the top of the machine there is another drum, which can be adjusted in height and made parallel to the lower drum. A flat cloth belt on which abrasive material is cemented is placed around the two drums and tightened by adjusting the height of the upper drum. When the motor is switched on, the belt moves downward and slides over a piece of steel that keeps the belt flat when wood is pressed against it. Because the belt is flat, it generates a flat surface on the piece of wood.

Fig. 1.16

On the front of the belt sander is a table with a groove in it. The angle of the table can be adjusted to sand pieces at different angles. The groove in the top of the table is used to index an attachment called a mitre gauge (Fig. 1.17). The surface against which the wood is held can be adjusted so that you can sand at different angles to the side of the board. The mitre gauge is calibrated in degrees for easy adjustment. On some gauges a 90 degree setting produces a surface at 90 degrees to the side, whereas on others, it is done with a setting of zero degrees.

Fig. 1.17



To finish the ends of a board, first sand one end square, removing as little material as possible. To do this, adjust both the belt sander table and mitre gauge so that they are at right angles to the sanding belt. To check the settings, take a piece of scrap wood and hold it firmly against the table and mitre gauge but with some clearance between the end of the board and the sanding belt. Switch on the machine and slide the board toward the sanding belt, keeping it in contact with the gauge and table. Press it against the sanding belt until the end is completely sanded. Remove the board from the table and turn off the motor. Check the end of the board with a square, and readjust the table or gauge if needed. Once you determine that the settings are correct, proceed by sanding the one end of your workpiece. Using the sanded surface as a reference, draw a line at the proper length and sand the marked end to the line, completing both ends.

A word of caution: Keep your hands as far away from the moving belt as possible. It is very abrasive and will remove skin more rapidly than it will remove wood.

o o o o o o o o o

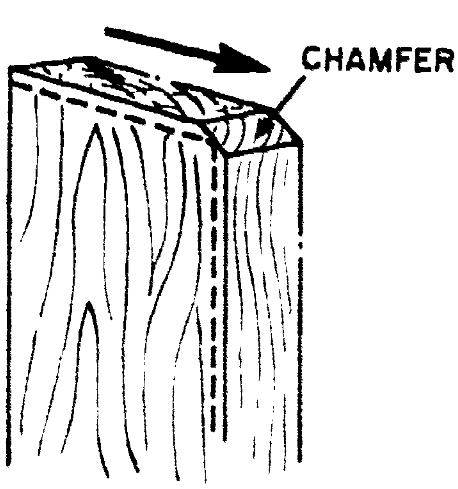
Take a piece of scrap wood and saw one end square.

o o o o o o o o o

When a belt sander is not available to finish end grain, a plane can be used to perform the same operation, although the process is much more rigorous. If a plane is used, the ends must be finished before the board is planed to its specified width. Remember, one edge must be planed square to be used as a reference for the ends.

The first step in planing end grain is to chamfer (bevel) one corner, as shown in Fig. 1.18, to reduce the possibility of chipping the wood. This is done by clamping the workpiece in a vise at a 45 degree angle and by using the plane as shown in Fig. 1.19. The size of the chamfer is determined

Fig. 1.18



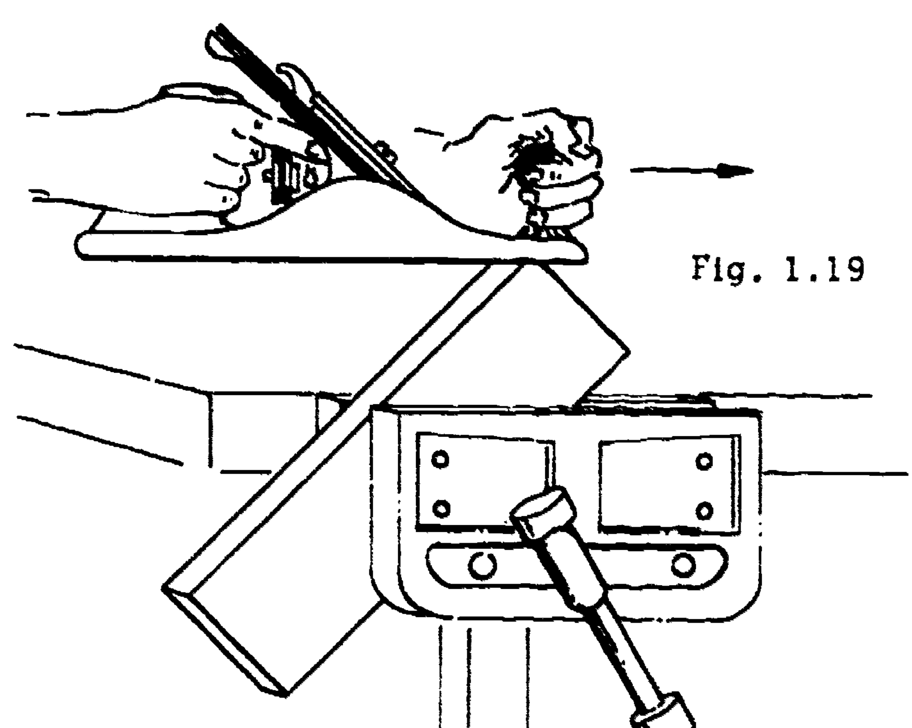


Fig. 1.19

by the amount of material to be removed both in the length and the width of the board. Therefore, it is necessary to draw lines that correspond to the final dimensions of the piece. The surface that forms the chamfer is planed until it meets the intersection of the dimension lines (see Fig. 1.18).

After the chamfer is made, adjust the plane to as fine a cut as possible. Proceed to remove material using the plane in the direction indicated by the arrow in Fig. 1.18.

When both ends are completed, plane the second edge to the line drawn on the side of the board. After you have finished this operation, there should be no indication that any corner was chamfered.

o o o o o o o o

Take a piece of scrap wood and plane the end.

Now finish both ends of the pieces for the laboratory stand (by either method) and then plane the boards to their specified widths.

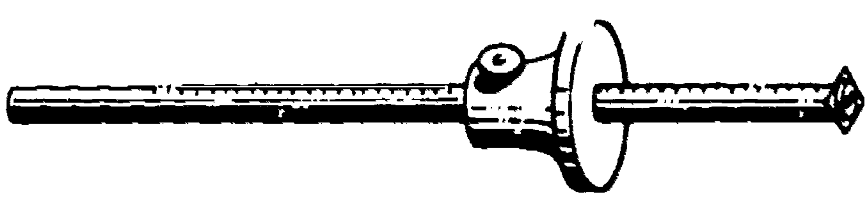
o o o o o o o o

1.6 Layout of Holes

Now that you have cut and squared all the pieces for the apparatus stand, it is time to drill the 5/16-inch-diameter holes in the top and bottom pieces (see Fig. 1.11).

Before drilling holes, you must draw intersecting lines to locate their centers. A square and a marking gauge can be used for this purpose. The square is used to make the line perpendicular to the edge of the board, and the marking gauge (Fig. 1.20) is used to make the line that is parallel to the edge of the board. The dimension that is requ. ed is set between the point

Fig. 1.20



and the adjustable collar. When you guide the collar along the edge of a board, the point makes a fine line at the desired distance from the edge of the board. (Figure 1.21 shows how a square and a pencil can be used in place of the marking gauge.)

Fig. 1.21

In using a scale (ruler) to lay out dimensions, be careful of parallax. Always recheck the dimensions of your lines after you have drawn them. A little extra care will save a lot of time and material!

o o o o o o o o

Lay out all the lines necessary to prepare for drilling the holes in the top and in the bottom of the apparatus stand. Check all of the lines to make sure you have made no mistakes. Now that the positions are marked, you are ready to drill the holes.

o o o o o o o o

1.7 Drilling Holes with a Brace and a Bit

In this course you will use various types of drill bits. They will have different applications and look different, but all of them remove material only when rotated in a clockwise direction. Because leverage is needed to do the work, all drill bits require the use of an additional tool to drive them.

The tool that is most commonly used to hold drills for drilling wood is called a brace (as illustrated in Fig. 1.22). Figure 1.23 shows an auger bit, the type of drill that is used with a brace. Auger bits come in sizes from 1/4 inch to 1 inch in diameter. They are made in 1/16-inch steps and are marked accordingly. Thus, a bit with a diameter of 9/16 inch would have a "9" on the tang (square end of the shaft), and a 3/4-inch bit is a No. 12.

Fig. 1.22

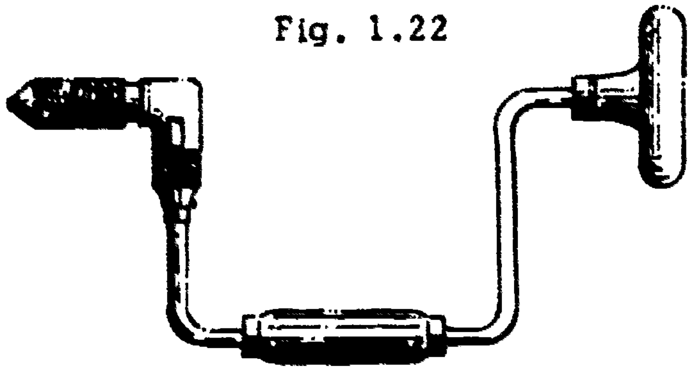


Fig. 1.23

Fig. 1.24(a)

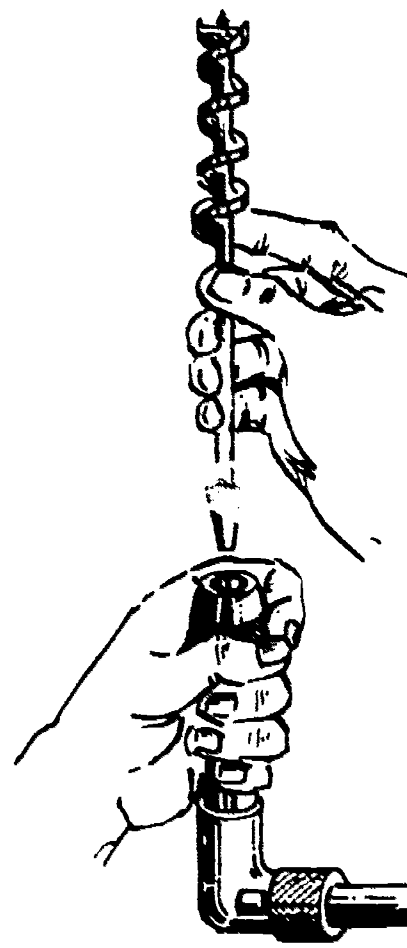
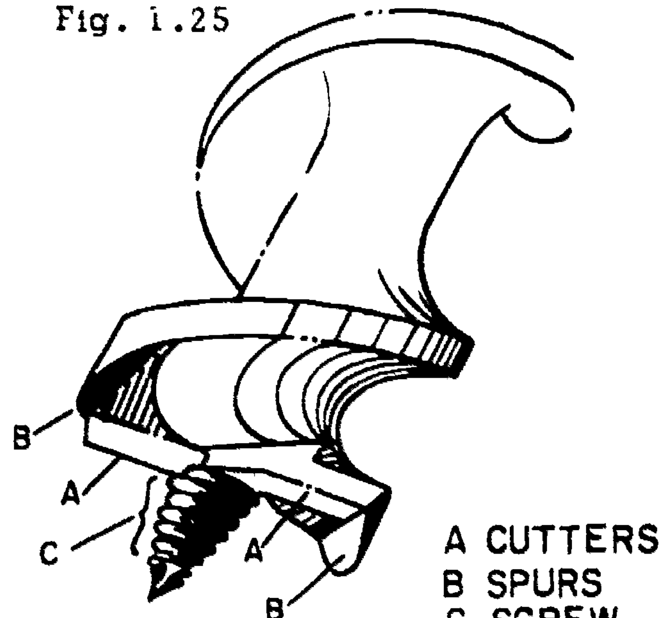


Fig. 1.24(b)

Figure 1.24(a) demonstrates how to insert and tighten the auger in the chuck of the brace. The jaws of the chuck are closed when the chuck is rotated in a clockwise direction. Only drills that have a tang on the end can be used with a brace. Be sure that the tang is properly aligned with the triangular grooves of the jaws, as shown in Fig. 1.24(b), so that it fits into the braces snugly and will not slip.

Because of the design of the auger bit (Fig. 1.25) it is not necessary to exert a large downward force on the brace. Part C screws into the wood and pulls the bit along with it. Part B slices the wood vertically to provide a neat outline for the hole, and part A removes the material in the same way as the blade of a plane. The drill is helical, and the material that is cut away travels up the helix and is cleared from the hole.

Fig. 1.25



To start the drill, place the point (part C) at the intersection of the layout lines you have drawn. Visually align the drill perpendicular to the board and turn the handle in a clockwise direction, keeping a steady downward pressure on the brace with your left hand.

Fig. 1.26

Figure 1.26 shows one way the bit and the brace are used. A second way is to clamp the board vertically in a vise and use the brace and bit horizontally. By holding the end of the brace against your hip, you may find it easier to hold the drill straight and to apply the required force.

Figure 1.27(a) shows how not to bore a hole with a brace and bit. In this illustration drilling too deep has made the back of the board break and chip away. Figure 1.27(b) indicates one of the correct ways. Another way is to place a piece of scrap wood under the board you are drilling, to keep the back from breaking and chipping.

Fig. 1.27(a)

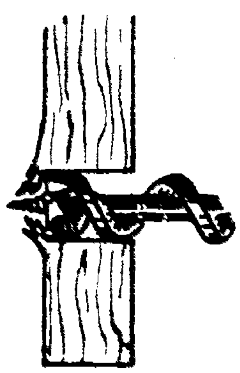
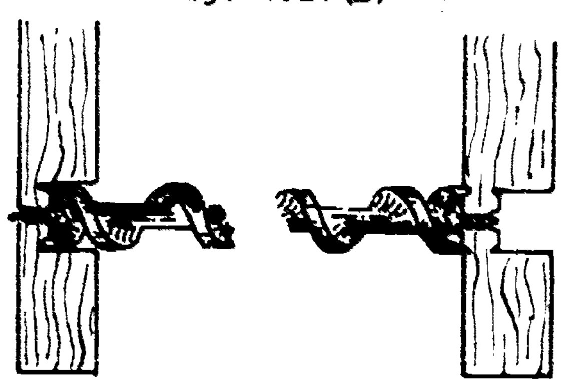


Fig. 1.27(b)



o o o o o o o o

Practice drilling holes in a piece of scrap wood with a bit and brace. Make sure the holes are perpendicular to the board. How can you check this? When you are sure you are ready, drill the holes you have marked in the top and in the bottom blocks of the apparatus stand.

o o o o o o o o

1.8 Sanding

Before you assemble the apparatus stand, the pieces should be smoothed with an abrasive to erase dirt and pencil marks and to remove burrs from the edges of the pieces. For this purpose there are three kinds of abrasives: sandpaper, garnet paper, and emery cloth. The least durable kind is sandpaper, which is also the cheapest. Garnet paper is more durable, while emery cloth is very tough and is often used for smoothing metal.

Abrasive papers are sometimes classified according to texture — coarse, medium, fine, or extra-fine. Another classification is by grit numbers such as 50, 80, 220. These represent the number of grits per unit area, so that the larger the number the finer the abrasive. For example, coarse garnet paper is about 50 grit, fine paper about 120 grit, and extra-fine paper about 220.

When smoothing a surface that is very rough, start with a coarse-grit paper. After all the rough spots are smoothed, switch to a finer paper for finish sanding. The easiest way to hold a piece of abrasive paper is to wrap it around a small block of wood. By the application of even pressure, the block will help to produce a flat surface. Always sand with the grain rather than across it. Instead of concentrating on small spots, use a smooth back-and-forth stroke that covers the entire surface. This also will help to keep the surface flat.

To remove burrs from the corners, sand them lightly (one or two strokes should be sufficient). This too will help prevent the pieces from chipping and splitting.

o o o o o o o o

Sand all the parts for the apparatus stand. Sanding is hard work, and doing a good job takes a long time. While sanding, make certain that you do not round surfaces you have planed flat. They must remain flat to fit together properly and look neat.

o o o o o o o o

1.9 Joining Pieces of Wood

There are many different methods of joining two pieces of wood together. Nails, glue, wood screws, dowels, and metal fasteners are commonly used. The strongest is a combination of wood screws and glue, which is stronger than nails and glue because nails can pull out of wood more easily than screws. Boards can be joined much faster with nails than with wood screws. If two parts may need to be disassembled later, wood screws should be used, but no glue.

Using dowels requires precision drilling. Dowels are use' mostly in furniture so that the means of fastening will not show.

Metal fasteners are employed mostly in situations in which a narrow board makes screws or nails impractical. They are a poor substitute, however, and should be used only when nothing else will work.

For this project, the use of glue and nails is suggested. If either one were used by itself, the joint would not be satisfactory. However, the combination of the two makes a solid and durable joint. The choice of nails rather than wood screws is determined by cost (nails are much cheaper) and by time (nails are faster to install).

1.10 Nails

The kinds of nails that are most often used are common nails, finishing nails, and wire nails. Common nails are used for general construction. Finishing nails, which have small heads, are used where it is desirable to hide the nail. With a nail set, a finishing nail can be driven so that its head is just below the surface (Fig. 1.28) and can then be covered with plastic wood.

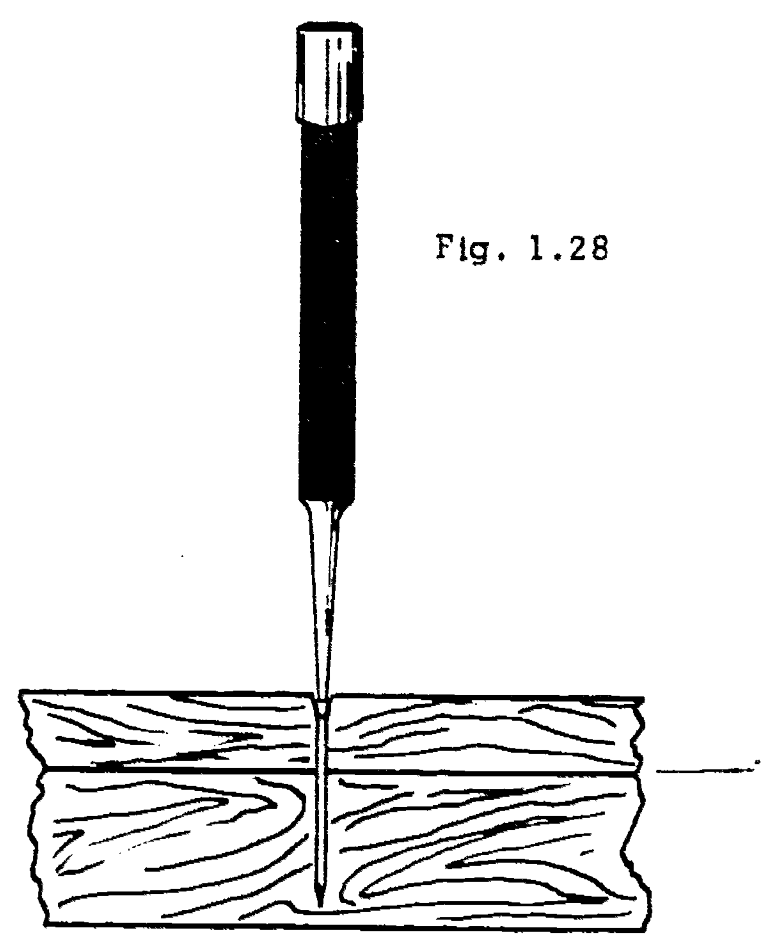


Fig. 1.28

Common nails and finishing nails are rated for size by the term "penny," which has the abbreviation "d." This describes not only the length but also the diameter. Table 1.1 shows the relationship of the penny size to the length of the nail. Note that from 2 to 10 penny, for every increase of one penny in size the length increases by 1/4 inch.

TABLE 1.1

Size	Length (in.)
2d	1
3d	1-1/4
4d	1-1/2
5d	1-3/4
6d	2
7d	2-1/4
8d	2-1/2
9d	2-3/4
10d	3
12d	3-1/4
16d	3-1/2

Wire nails are of two types, brads and flat-head nails. Wire nails can be purchased by both length and diameter. The diameter is given in terms of the wire size used to make the nails. As the number of the nail increases, the diameter decreases. For example, a 1-1/4-inch No. 20 brad has a smaller diameter than does a 1-1/4-inch No. 18 brad. Wire nails range in lengths from about 1/4 inch to 1-1/2 inch. There are some sizes that are longer, but they come in one diameter only. A brad is a small version of a finishing nail. A flat-head wire nail looks like a common nail. Figure 1.29 illustrates the various kinds of nails we have been discussing.

Most nails can be purchased so that they have a thin coating of glue that heats and melts when the nail is hammered into the wood. The glue then hardens and holds the nail tightly in the wood, thus strengthening the construction.

When choosing the nail for a job, there are two things to consider: (1) The length should be at least twice the thickness of the board through which you are nailing, but the nail should not protrude through the far side of the second board. (2) The diameter of the nail should not be so large as to split the wood. Sometimes a small pilot hole (a hole about 1/2 the diameter of the nail) may have to be drilled in both pieces to prevent splitting.

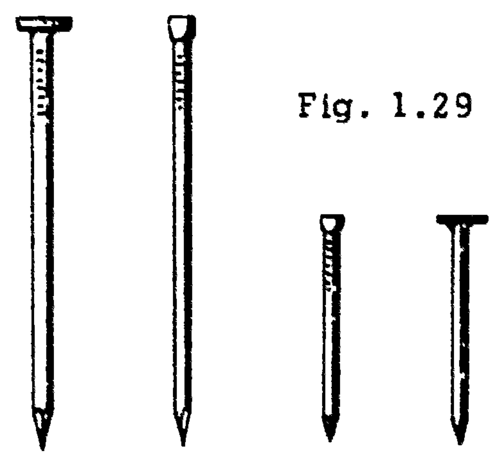


Fig. 1.29

1.11 <u>The Nail Hammer</u>

Figure 1.30 shows the type of hammer used to drive nails into wood and to remove them. Nail hammers come in various sizes and are rated by the weight of the head of the hammer, ranging from 7 ounces to 1-3/4 pounds.

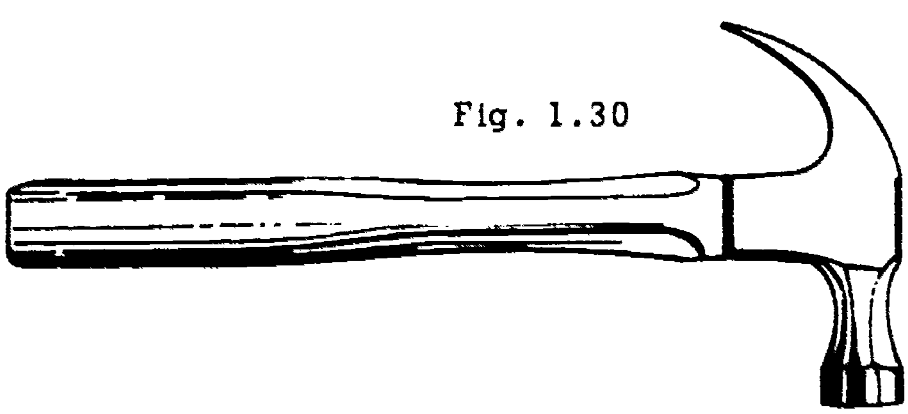


Fig. 1.30

The heavier hammers have longer handles for better balance and leverage. The most commonly used hammer is 16 ounces, which is suitable for driving most nail sizes. A 7-ounce hammer is often used for driving smaller nails.

In using a nail hammer, always hold it near the end of the handle for better leverage. To start a nail, hold it firmly in position with the fingers of your left hand and lightly tap the head once or twice. Then take away your fingers and drive the nail into the wood with firm, smooth strokes (Fig. 1.31).

Fig. 1.31

Do not watch the hammer; keep your eye on the nail. When the nail is nearly all the way in, use light blows of the hammer to finish. Just drive the nail until the top of the head is flush with the surface of the wood. Do not dent the wood with the face of the hammer. If you are using finishing nails, you can then use a nail set to drive the top of the nail just below the surface.

In driving a nail, you may bend it so that it cannot be driven into the wood. Remove the nail and use another. To remove a nail, turn the hammer around and place the head of the nail between the two claws. Then use the hammer as a lever, as shown in Fig. 1.32. To increase the leverage for pulling out long nails, you can place a small block of wood under the head of the hammer.

The first step in fastening two boards together with nails is to decide where the nails should go and how many to use. If a nail is placed too near the edge of a board the nail may split it. Not only will a split make the piece look bad, but the nail will have little holding power. Whenever possible, position the nail between 1/2 inch and 3/4 inch in from an edge. This is close enough to hold the corner securely but not so close that the wood will split. You should drill a pilot hole if you think the wood might split.

The distance between nails is determined by the amount of strength required of the device. To ensure that the piece is sturdy, always use at least two nails. After that, you must decide how many nails to use. Experience is the only teacher because each item you build will have different requirements.

o o o o o o o o

Practice driving nails into a scrap piece of two-by-four.* Watch out for your fingers when you start each nail.

o o o o o o o o

Fig. 1.32

1.12 Gluing and Nailing

Once you have decided where the nails should be placed, drive them into the top board about three-quarters of the way through. Then apply glue to one of the surfaces to be joined. Use enough glue to cover the whole surface, but not so much that it oozes out over the edges when the surfaces

*A two-by-four (2 × 4) is the material you used to make the top and bottom pieces of the stand. It is called a two-by-four because the original size of the board before it is finish-milled is 2 inches by 4 inches. After milling, it is considerably smaller, however. The wood used for the sides of the stand is called a one-by-four because its premilled size was 1 inch by 4 inches. All board lumber is referred to in this manner, so remember, if you need a board that is 5 inches wide by 3/4 inch thick you must order a one-by-six and cut it to size.

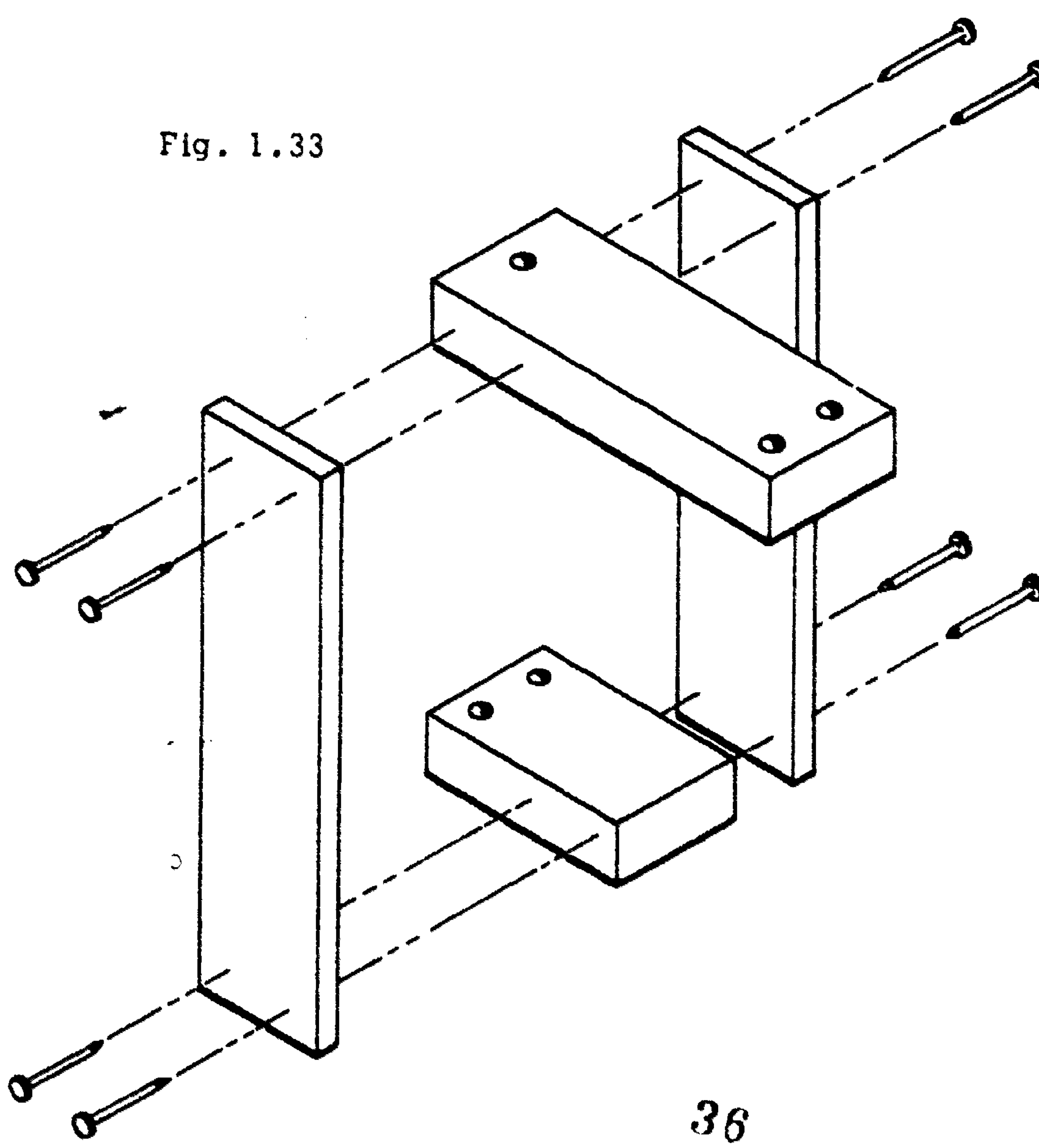
are squeezed together. Place the two surfaces together and move them around a little to make sure the glue is spread evenly over the whole surface. Hold the two surfaces together with your free hand, making certain the required edges are flush, and drive one nail part way into the bottom piece of wood. Check to see that the edges are flush and finish nailing. Then proceed by driving all the other nails into the wood.

o o o o o o o o

Figure 1.33 is an assembly drawing of the apparatus stand. First glue and nail the left side to the top and bottom pieces. The second side may be more difficult because you may have to apply pressure to the top or bottom piece to make the edges flush while hammering.

o o o o o o o o

Fig. 1.33



Project 2: A DENSITY KIT

The three rectangular objects shown in Fig. 2.1 are designed for use in an experiment on density. The purpose of the experiment is to determine by measurements of size and mass whether two of the objects are made of the same material. Because all three pieces are painted the same color the student's decision is based solely on the measurements taken.

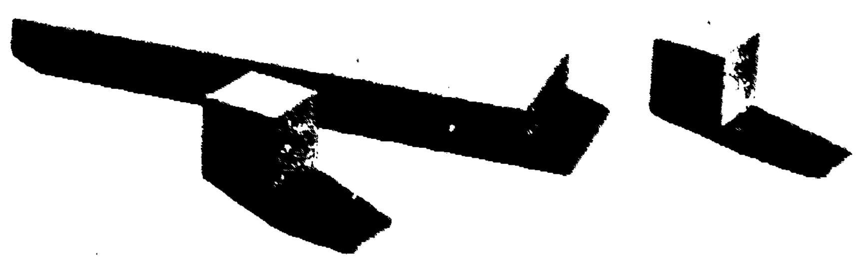


Fig. 2.1

In making this project, you will use steel for one of the cubes, aluminum for the other cube, and aluminum for the long rectangular piece. Figure 2.2 is a shop sketch of the pieces for this project. The material – aluminum and steel bar stock – has two of the dimensions set and must be cut to length and finished to dimension.

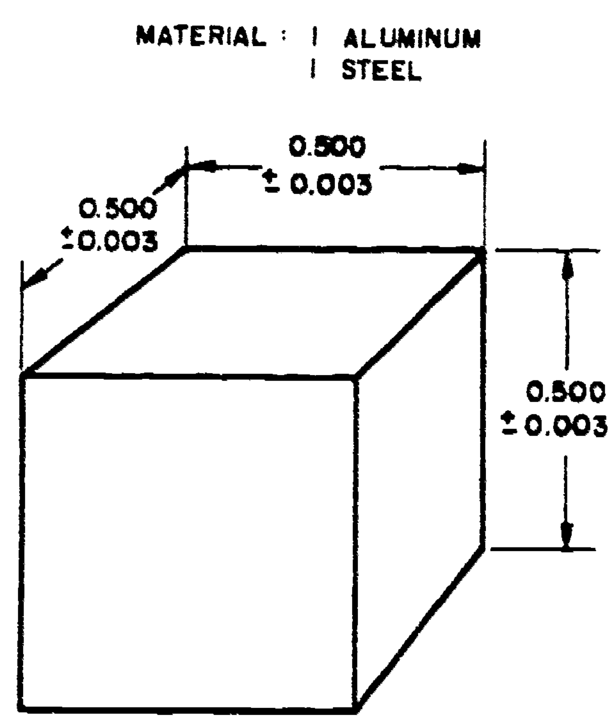
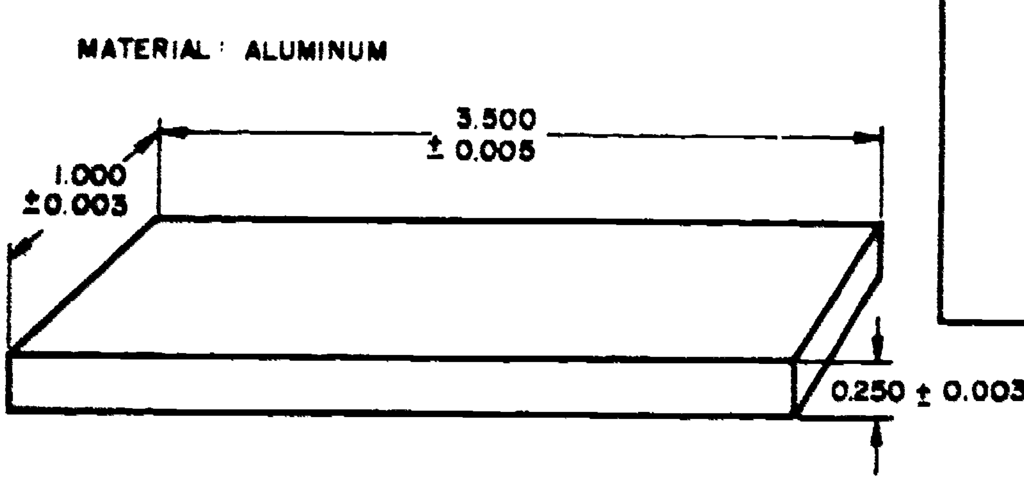


Fig. 2.2



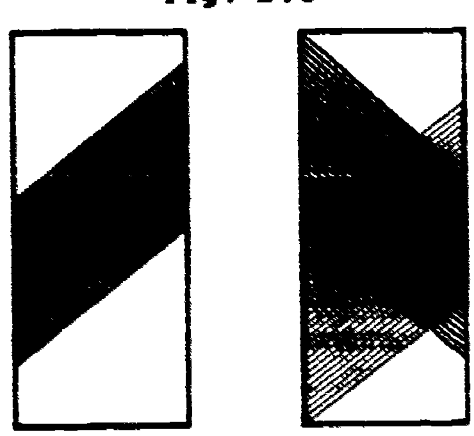
2.1 Files and Filing

As in Project 1, the first step in making the density kit is to square one end of the stock so that this surface can be used as a reference for the length of the piece. In making the laboratory stand you used a belt sander or a plane to square the end of the piece of wood stock and to bring the piece to the final dimension. Because metal is much harder than wood you will have to use different tools to perform the same operations that you did in Project 1. Instead of a belt sander or a plane, you will use a file.

Files can be purchased in nearly any shape, such as flat, square, round, triangular, and half-round, to name a few. The most common type of files range in size from about 4 inches to 16 inches in length. They are used in general work to produce flat surfaces on metal.

The rate at which material can be removed from a piece of stock is determined by the space between the teeth of a file. A coarse file, one with teeth spaced far apart, can remove metal faster than a smooth file. Of the three grades of coarseness, the bastard-cut file is the coarsest tooth file and is used to remove stock quickly, but leaves a very rough finish. A second-cut file has medium-spaced teeth and is used for general work. A smooth-cut file, used for doing finish work, has teeth that are close together. Each grade of file can be either a single-cut or a double-cut (see Fig. 2.3). A single-cut file has one set of teeth cut at an angle across the face of the file. A double-cut file, not to be confused with a second-cut file, has a set of teeth like the single-cut file and another set crossing the first to produce many sharp, pointed teeth. This makes it possible to remove material faster.

Fig. 2.3



The length of a file also determines the coarseness of the teeth. The longer the file, the greater the distance between the teeth. For example, a 12-inch second-cut file will remove material faster than an 8-inch second-cut file.

Figure 2.4 demonstrates the proper way to hold the stock and the file. Note that on the end of the file there is a wood handle, which prevents the end of the file from piercing the hand.

Fig. 2.4

The motion and coordination for filing is very similar to that of planing, the main difference is that much less force is required in filing than in planing. At the beginning of the stroke the pressure is placed on the leading end of the file, and during the stroke it is gradually transferred to the rear end. The tendency is to place too much pressure on the rear end of the file at the beginning and on the front end at the end of the stroke. If this mistake is made, a convex surface rather than a flat one results. You will be more likely to get a flat surface if you file diagonally from corner to corner and then change your position so you can file across the opposite corners. When you change the direction in which you are filing, the first stroke will tell you if the surface is flat. The marks made by the file should cover the entire surface of the metal. If the file marks appear only in the middle, the middle is too high. Only by observing these marks can you make corrections in your motion to produce a flat surface. Even though a surface is flat, it might not be square to the sides of the stock. As you did in the first project, be sure to check the squareness of the surface with a square.

The file is made to be used in only one direction; therefore, you should lift it off the stock during the backward stroke. If you do not, you dull the file without removing any material.

Be sure the file is clean before you use it, and clean it every few strokes. If it is not kept clean, small chips may stick in the teeth and gouge the surface of the stock. To clean the file use a file card, a short wire-bristled brush that cleans out the grooves when pushed along them. Figure 2.5 shows a file card being used to clean a file.

Fig. 2.5

Figure 2.6 depicts a method of filing called drawfiling, which is used to remove small amounts of material from the surface or when the surface needs to be smoothed. After using the regular method to remove most of the material, drawfiling is used to finish the workpiece.

Fig. 2.6

During drawfiling, a smooth-cut, single-cut file is held flat against the surface of the stock and moved back and forth with light pressure. Although the cutting motion is forward, the file is not removed from the stock during the backward stroke as before, but held against it. This will help you avoid rocking the file and thereby make it easier to generate a flat surface. The reason drawfiling is not used for the entire filing operation is that it requires more time than regular filing.

After a piece has been brought to dimension with a file, small burrs are usually found on the edges. To remove these, hold the file at about a 45 degree angle with the surface (Fig. 2.7). Beginning at the left corner, move the file forward and to the right in one smooth, continuous motion. It is usually easier to hold the stock in one hand, as shown, rather than in a vise.

Fig. 2.7

Another type of file, called a Swiss pattern file, is used to form delicate shapes and may be purchased in various sizes ranging from 3-1/2 inches to about 7 inches in length. Unlike the files previously described, the length of this file does not determine the coarseness of the file. Swiss pattern files are supplied in various "cuts" ranging from 00 to 8, with an 8 cut being the coarsest. Because they are small and delicate, these files should not be used for heavy filing.

2.2 Dimensions, Tolerance, and Layouts

In Fig. 2.2 you will note that the dimensions are given in decimals rather than in fractions of an inch. In general, fractional dimensions are used for woodworking, whereas decimal dimensions, in thousandths of an inch, are used for metalworking. Therefore, a piece of metal that is 1-3/4 inches long has this dimension written as 1.750 inches.

Decimal dimensions are commonly described in thousandths of an inch rather than in a combination of thousandths, hundredths, and tenths. Therefore, the dimension 1.250 would be referred to as "one inch, two hundred and fifty thousandths"; and the dimension 0.056 as "fifty-six thousandths."

Most dimensions in Fig. 2.2 are followed by "±0.003." This gives the the tolerance to which the piece must be made. That is, the final size must be no more than 0.003 inch larger and no more than 0.003 inch less than the dimension given. For a dimension given as 2.250 ±0.003 inch, the piece would be acceptable if it measured between 2.247 inches and 2.253 inches.

To lay out the cuts to be made on the boards for the apparatus stand you simply drew the lines on the wood with a pencil. Because pencil marks do not show very well on smooth metal surfaces, you must now use another method. The metal must be coated with a dye that dries quickly, leaving a dark or dull-coated soft substance. Scratching this surface with a sharp-pointed tool called a scriber leaves a shiny line on the metal underneath. The most common of these layout dyes is an inklike, alcohol-based liquid, which, when dry, produces a blue or purple surface that contrasts nicely with the shiny lines. Light pressure is sufficient in using the scriber. It is necessary only to scratch through the dye, not to leave a mark on the metal. After the piece is completed, the dye can be removed easily with alcohol.

o o o o o o o o

Take the stock you will use to make the density kit and square one end with a file.

How can you determine whether the end is square within the tolerances given in Fig. 2.2?

Figure 2.8 shows a cube of metal. The shop sketch from which it was made specified its size as 1.125 ±0.005 inches. When measured, dimension a = 1.127 inches, b 1.121 inches, c = 1.130 inches, and d = 1.125 inches. Is the cube within the specified tolerances?

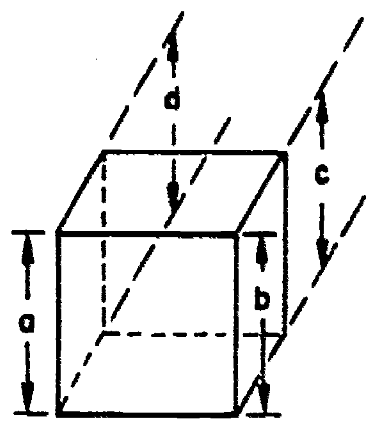


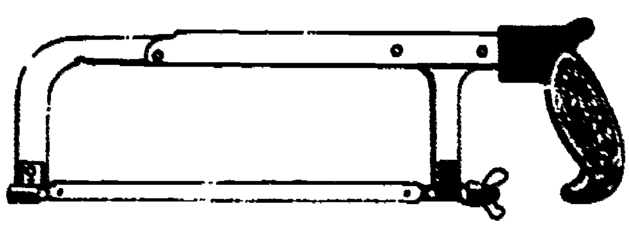
Fig. 2.8

o o o o o o o o

2.3 Hacksaws

The tool most commonly used to cut metal stock is a hacksaw. An adjustable hacksaw like the one in Fig. 2.9 can be set to accommodate blades of different lengths. The wing nut near the handle loosens and tightens the blade. The blade itself is made of a harder metal than that used in a saw blade for cutting wood. Because of this, hacksaw blades are brittle and can easily break when bent or twisted.

Fig. 2.9



Hacksaw blades are purchased according to the number of teeth per inch (14 to 32) and by the length (8, 10, or 12 inches). Teeth of a hacksaw blade also have set. Blades with many teeth per inch will have several consecutive teeth set to one side, followed by several set to the other side. When viewed from the top of the blade the set looks wavy.

A simple guideline for selecting the proper blade for a given operation is: The thinner the stock to be cut, the more teeth per inch on the blade. As a rule of thumb, about three teeth of the blade should be in contact with the material being cut.

2.4 Using a Hacksaw

Hacksaws are designed to operate only in one direction. The stock is held in a machinist's vise, as shown in Fig. 2.10. To reduce vibration place the stock so that the sawcut will be made close to the jaws of the

Fig. 2.10

vise. A short forward motion with the corner of the file on the surface to be cut produces a small nick at the appropriate spot. Place the blade in the nick and start with a downward motion. Apply pressure on the front hand during the forward stroke and release it on the back stroke. If pressure is maintained during the backward stroke, it will only dull the blade. When nearing the end of a cut, use short motions with light pressure. This prevents injury to your hands if the saw should suddenly finish the cut while you have pressure on it.

o o o o o o o o

Take the stock that has one end filed square and lay out the pieces to be cut. Cut the pieces, allowing an extra 0.015 or 0.020 inch in case of inaccurate cutting. If you allow too much, it will take too long to complete the pieces.

Don't try to rush. Cutting metal takes time and patience. More time will be spent if you have to make the pieces over than if you cut slowly.

o o o o o o o o

2.5 Precision Measurements

Because the tolerances in metalworking are usually small, the dimension of a piece must be checked often as filing continues. A scale whose smallest division is 1/64 inch is unsuitable for measuring to thousandths of an inch (see Fig. 2.11). For these precise measurements a micrometer is used.

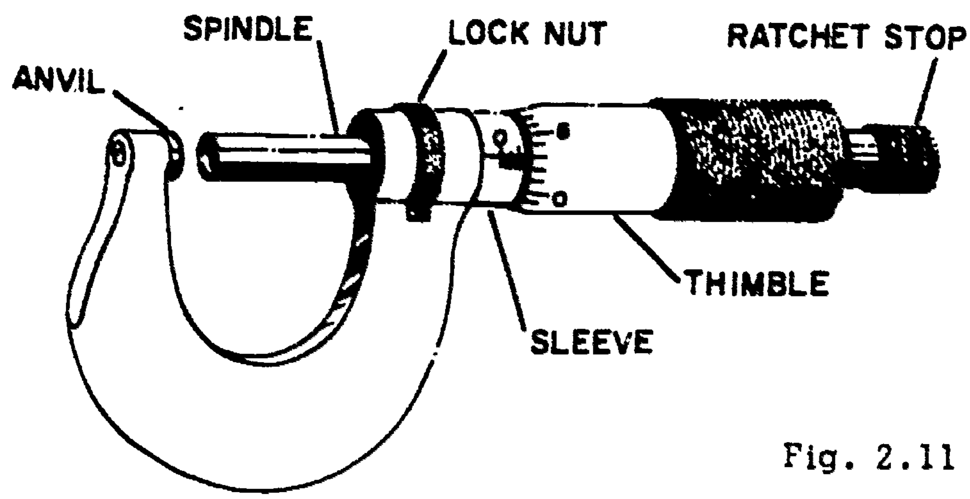


Fig. 2.11

As the thimble is turned clockwise (looking from the thimble toward the anvil), the distance between the spindle and the anvil decreases by 0.025 inch with each revolution. If you examine the thimble, you will notice that it is graduated into 25 divisions around its circumference. Therefore, each division is 1/25 of a revolution and represents 0.001 inch of movement of the spindle.

Each division marked along the sleeve (Fig. 2.12) is 0.025 inch (you can check this by rotating the thimble one revolution), and every fourth division is marked by a number, 1, 2, 3, 4, etc., which is the distance in tenths of an inch. To read the micrometer, each tenth of an inch and each small division exposed by the thimble are added together with the reading on

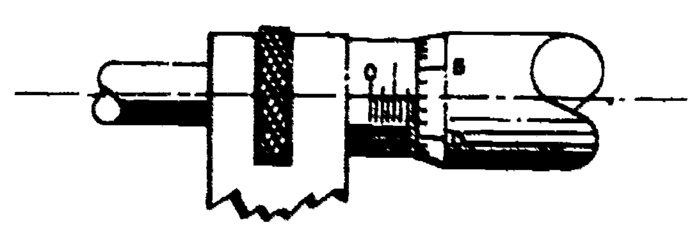
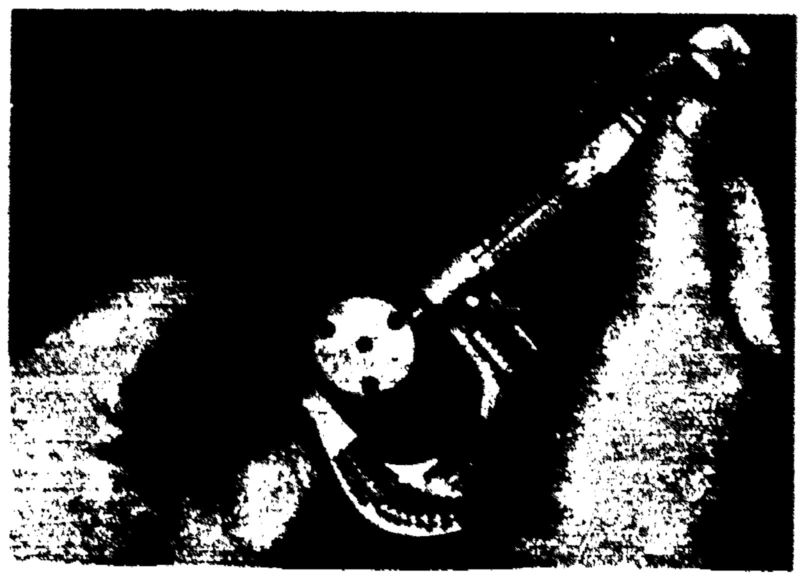


Fig. 2.12

the thimble to determine the distance between the anvil and the spindle. In Fig. 2.12, one-tenth is exposed plus three divisions (0.025 inch each). Add to that sum the reading (3) on the thimble, and the setting is 0.178 inch.

The stock to be measured is placed against the anvil, and the thimble is turned until the spindle just touches the other side of the stock. The scales on the thimble and sleeve are then read and added together to give the dimensions of the stock. Figure 2.13 demonstrates the correct way to hold the micrometer while measuring a piece of stock.

Fig. 2.13



A micrometer is a delicate instrument. When taking a measurement, the thimble should not be tightened down as if it were a clamp. Only a light pressure needs to be applied. Some micrometers come equipped with a rachet stop or a "friction thimble," which is turned instead of the regular thimble. If too much torque is applied, it "slips."

The micrometer is an excellent device for making precision measurements; however, it does have limitations. The standard micrometer is designed to measure only outside dimensions of stock. A different type must be used to measure inside dimensions, and still another to measure the depth of a hole. Although micrometers can be purchased in many different sizes, ranging from 1/2 to 24 inches, most are limited to a range of one inch. For example, a 2-inch micrometer can only be used to measure stock between one and two inches long. To cover the range from zero to six inches, a machinist would need six micrometers. To have micrometers available to do all these jobs and cover a reasonable range of sizes would be very expensive.

Figure 2.14 is an illustration of a vernier caliper. This instrument can be used to measure inside or outside dimensions, measure pieces up to six inches in length, and measure the depth of holes. It is not as precise as a micrometer because it is more difficult to read, but its versatility more than compensates for this limitation.

There are two parts to a caliper. The first is an L-shaped piece of steel, the short section of which forms one of the jaws of the caliper. The

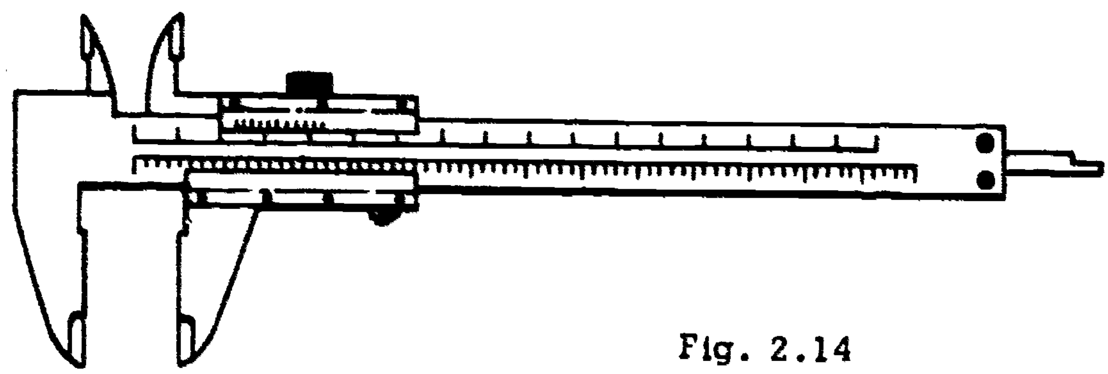


Fig. 2.14

second is the other jaw that slides on the long section of the L. The scale on the sliding jaw is used with the scale on the first part to determine the distance between the jaws.

Figure 2.15 is a close-up photograph of the scale of the caliper.

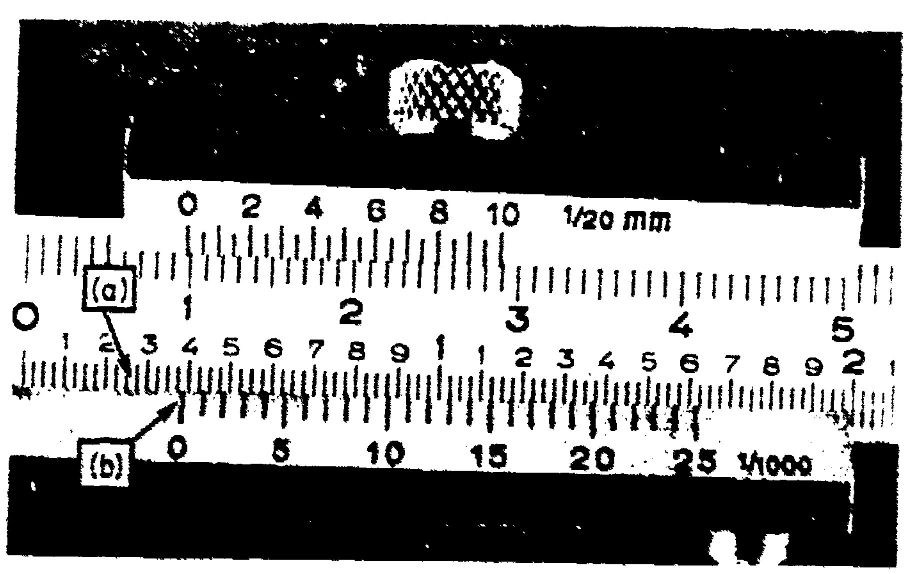


Fig. 2.15

The upper set of scales is for the metric measurements; the lower set for the English system. Our discussion pertains to the English system, though the principles of the vernier are the same for both. The large numbers, 1 and 2, on scale a represent inches. Each inch is divided into tenths of an inch represented by the smaller numbers 1 through 9. And each tenth of an inch is subdivided into four parts, which results in the smallest division on scale a being equal to 0.025 inch. Scale a is similar to the scale on the sleeve of the micrometer, and both can be considered to be a ruler whose smallest division is equal to twenty-five thousandths of an inch.

The line that corresponds to zero on scale b enables you to read scale a. For the moment, ignore all the other divisions and the numbers on scale b; we shall return to them later. If the zero line on scale b aligns with the zero on scale a, the distance between the jaws of the caliper is zero. If it lines up with the large 1 on scale a, the distance is one inch, and so on. Figure 2.15 shows that the zero on scale b is between the small 3 and the small 4. Consequently, the distance is between three-tenths and four-tenths of an inch. A closer look at the zero of scale b shows that it is between the third small division and four-tenths inch. Therefore, the distance between the jaws of the caliper is greater than 0.375 but less than 0.400. You can estimate that the reading is about halfway between the two, but estimating is not accurate enough when measuring to a thousandth of an inch.

Scale b is used to read to 0.001 inch. It is divided into twenty-five parts and is used in conjunction with scale a to divide each small division of scale a into twenty-five parts or one thousandth of an inch. We shall not discuss why scale b works, but how it works: When one of its divisions lines up with any division on scale a, the number on scale b represents the number of thousandths of an inch. For example, in Fig. 2.15 the number 13 on scale b lines up with a division on scale a. Therefore, the reading is 0.013 plus 0.075 (three small divisions) plus 0.300, or a total of 0.388 inch.

Unlike the micrometer, sometimes it is difficult to determine which of two lines is lined up with a division on the other scale. When looking at Fig. 2.15, it is difficult to decide whether the reading is 0.388 or 0.389. This is the limitation of the vernier caliper.

Figure 2.16 demonstrates how to hold the vernier caliper while measuring stock. Place the stock against one jaw. Then slide the movable jaw by pushing it with your thumb until both jaws are in contact with the stock.

Do not force the jaws of the caliper to make the vernier read what you wish. As with the micrometer, get a feel for how much force to use by closing the jaws with just enough force to make the vernier scale read zero.

Fig. 2.16

Some vernier calipers have a friction lock that must be released by the thumb while sliding the jaw. This helps prevent errors resulting from inadvertent movement of the jaw. Others, such as the one shown in Figs. 2.14 and 2.15, have a locking screw for the same purpose.

Most vernier calipers are equipped with a second set of jaws for measuring inside dimensions (Fig. 2.14). To measure the diameter of a hole, the vernier caliper and the stock are held as shown in Fig. 2.17. Close the jaws, and insert them into the hole. Then open them by pulling on the sliding jaw with your thumb until the jaws touch both sides of the hole at the diameter. Then read....

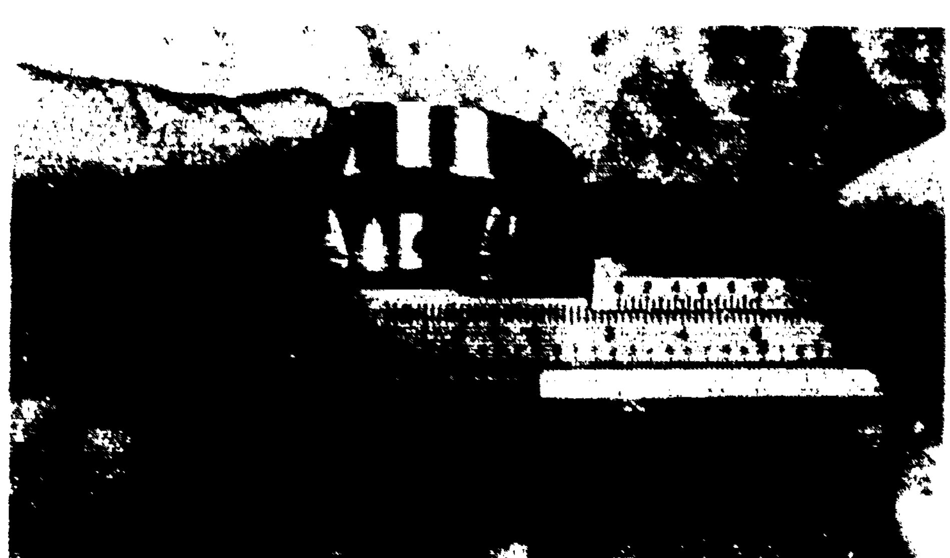


Fig. 2.17

A vernier caliper can also be used as a depth gauge. The sliding jaw has an extension that fits into the back of the caliper. The end of the extension is made so that it is flush with the end of the caliper frame when the vernier is set at zero. As the jaws are opened, the extension protrudes beyond the end of the caliper and its length is determined by the reading on the vernier scale.

To measure the length of a shoulder (Fig. 2.18) place the end of the caliper against the end of the smaller diameter section. Then slide the moving jaw until the extension touches the shoulder. Use the same method for measuring the depth of holes.

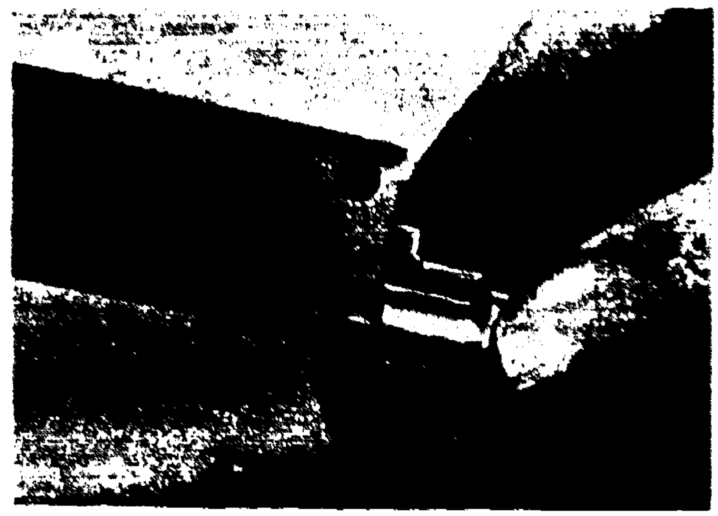


Fig. 2.18

o o o o o o o o

Take a piece of scrap metal, measure all its dimensions, and make a shop sketch of the piece. So that you will become accustomed to using a micrometer and a vernier caliper, measure the piece with both instruments.

File the previously cut pieces to their required dimensions, and remove burrs and finish the edges until they are smooth.

o o o o o o o o

2.7 Finishing the Density Kit

In the experiment for which the density kit is designed, it is important that the student does not see the raw material from which each piece was made. Therefore, it is necessary that each piece be painted the same color.

Before painting metal, rinse each piece with alcohol to remove oil and dirt. This will provide a clean surface to which the paint can adhere.

Project 3: AN ELASTICITY APPARATUS

In this project you will build a piece of equipment that is used to measure the elasticity of different kinds of wire. In the picture of the apparatus (Fig. 3.1) you will see that the wire is fastened to a bolt at one end

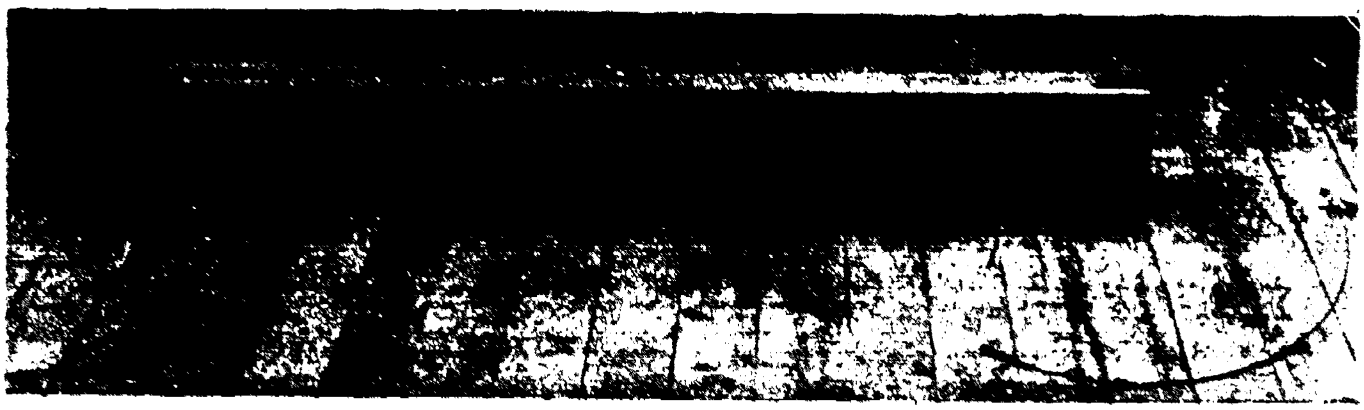


Fig. 3.1

of the board and at the other end to a drum with a pointer attached. When a weight is hung on the wire, the wire is stretched and the drum and the pointer turn, indicating the amount of extension.

3.1 Twist Drills

A twist drill (Fig. 3.2) is made of hardened and tempered steel and can be used for drilling holes in almost any material. Designed mainly for use on metals, these drills differ from auger bits. In the figure you will notice that the end of the drill comes to a point. This point keeps the drill centered while the material is removed by the cutting edges, which are formed by the spiral grooves (flutes) in the body of the drill. The flutes also help to take the chips out of the hole.

Fig. 3.2

Sizes of twist drills are designated in three ways: fractional, number, and letter. Fractional twist drills come in diameters from 1/64 inch to 3-1/2 inches in steps of 1/64 inch. However, the standard set of fractional twist drills contains only the sizes between 1/16 and 1/2 inch.

Number, or wire-gauge, drills are designated by numbers ranging from 1 to 80, with No. 1 the largest and No. 80 the smallest. A standard set of number drills consists of drills from No. 1 through No. 60. Because of their small size, drills with numbers higher than 60 are rarely usec A No. 1 drill is 0.228 inch in diameter, and a No. 60 is 0.040 inch. You can see that there is quite a selection of drill sizes within this group of drills. Because number drills are made from wire-gauge stock, and are classified accordingly, they do not come in uniform steps.

Letter drills range from A through Z, with A being the smallest. These too are made to supplement the fractional drills and therefore do not change diameter in regular steps. They cover the range from 0.234 inch, where number drills leave off, to 0.413 inch in diameter.

TABLE 3.1 SIZES OF TWIST DRILLS

Fractional Size Drills Inches	Wire-Gauge Drills	Decimal Equivalent Inches	Fractional Size Drills Inches	Wire-Gauge Drills	Decimal Equivalent Inches
	60	0.0400		44	0.0860
	59	0.0410		43	0.0890
	58	0.0420		42	0.0935
	57	0.0430	3/32		0.0937
	56	0.0465		41	0.0960
	55	0.0520		40	0.0980
	54	0.0550		39	0.0995
	53	0.0595		38	0.1015
1/16		0.0625		37	0.1040
	52	0.0635		36	0.1065
	51	0.0670	7/64		0.1094
	50	0.0700		35	0.1100
	49	0.0730		34	0.1110
	48	0.0760		33	0.1130
5/64		0.0781		32	0.1160
	47	0.0785		31	0.1200
	46	0.0810	1/8		0.1250
	45	0.0820		30	0.1285

TABLE 3.1 SIZES OF TWIST DRILLS (Cont)

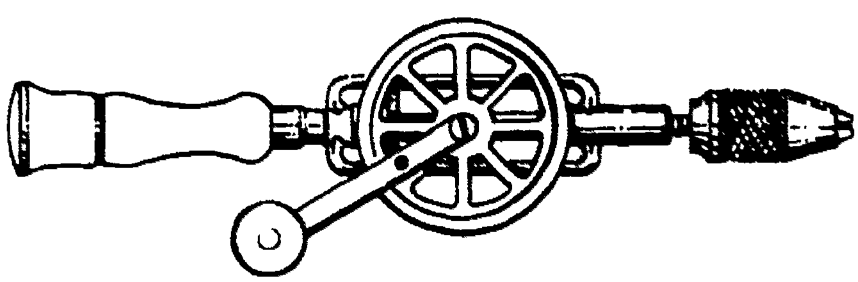
Fractional Size Drills Inches	Wire-Gauge Drills	Decimal Equivalent Inches	Fractional Size Drills Inches	Wire-Gauge Drills	Decimal Equivalent Inches
	29	0.1360		D	0.2460
	28	0.1405	1/4	E	0.2500
9/64		0.1406		F	0.2570
	27	0.1440		G	0.2610
	26	0.1470	17/64		0.2656
	25	0.1495		H	0.2660
	24	0.1520		I	0.2720
	23	0.1540		J	0.2770
5/32		0.1562		K	0.2810
	22	0.1570	9/32		0.2812
	21	0.1590		L	0.2900
	20	0.1610		M	0.2950
	19	0.1660	19/64		0.2969
	18	0.1695		N	0.3020
11/64		0.1719	5/16		0.3125
	17	0.1730		O	0.3160
	16	0.1770		P	0.3230
	15	0.1800	21/64		0.3281
	14	0.1820		Q	0.3320
	13	0.1850		R	0.3390
3/16		0.1875	11/32		0.3437
	12	0.1890		S	0.3480
	11	0.1910		T	0.3580
	10	0.1935	23/64		0.3594
	9	0.1960		U	0.3680
	8	0.1990	3/8		0.3750
	7	0.2010		V	0.3770
13/64		0.2031		W	0.3860
	6	0.2040	25/64		0.3906
	5	0.2055		X	0.3970
	4	0.2090		Y	0.4040
	3	0.2130	13/32		0.4062
7/32		0.2187		Z	0.4130
	2	0.2210	27/64		0.4219
	1	0.2280	7/16		0.4375
	A	0.2340	29/64		0.4531
15/64		0.2344	15/32		0.4687
	B	0.2380	31/64		0.4844
	C	0.2420	1/2		0.5000

The size of a drill is stamped on the shank, except for some smaller sizes where there is not room. Never use an unmarked drill, or one with the size mark obliterated, just because it is in the drill index, or holder, in the place for the correct size. Always check the size of the drill with a micrometer by measuring the diameter across the cutting edges.

3.2 The Hand Drill

An "eggbeater" hand drill like the one shown in Fig. 3.3 is often used with twist drills to make holes in wood. The twist drill is placed in the chuck, which is hand-tightened by holding the crank and turning the chuck counterclockwise as seen from the handle end. Make certain that the drill is centered in the three jaws of the chuck and that it is not inserted too far, making the jaws clamp down on the flutes.

Fig. 3.3



To use the drill, place the point on the intersecting lines of the layout where a hole is indicated. Hold the hand drill perpendicular to the surface and turn the crank clockwise. Because a twist drill's point has no screw to pull it into the wood, you must apply force directly downward on the drill. When the hole is nearly through, reduce the pressure so that the drill will not break through the back side of the wood and chip the material. To extract the drill from the hole, gently pull the hand drill upward while turning the crank. If a hole is deep, you may need to withdraw the drill occasionally to clear chips out of the flutes.

o o o o o o o o

Take the laboratory stand that you made in Project 1 and drill a hole in each side as shown in Fig. 3.4. This hole is used to support a guide arm that you will make later in this project.

o o o o o o o o

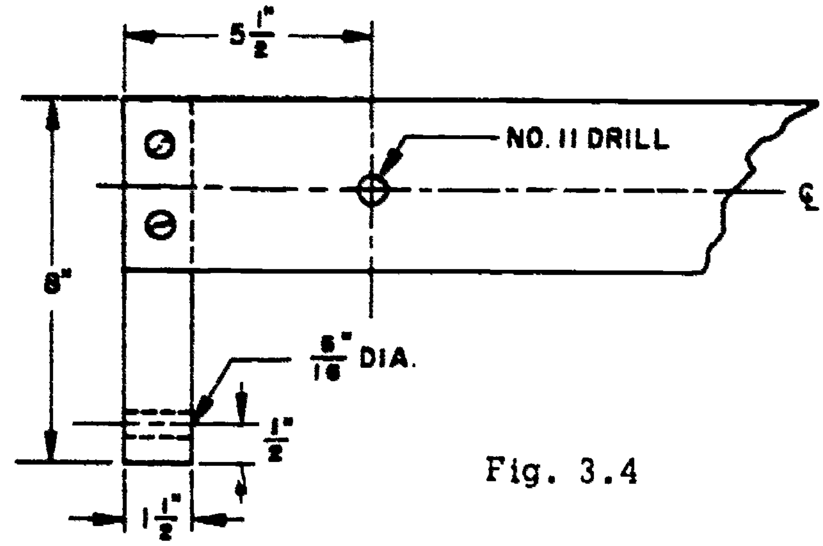


Fig. 3.4

3.3 The Drill Press

Apart from the chuck, the tool in Fig. 3.5 does not look at all like a hand drill, but it is made to do exactly the same job. As you begin to use other power tools, you will notice that they do the same things as hand tools, but they do them much faster, more accurately, and with much less effort on your part. However, power tools are more dangerous than hand tools, for two reasons: First, the power is provided from an outside source. If anything goes wrong while you are drilling a hole with a hand drill, you simply stop turning the handle and the drill stops. With a power tool,

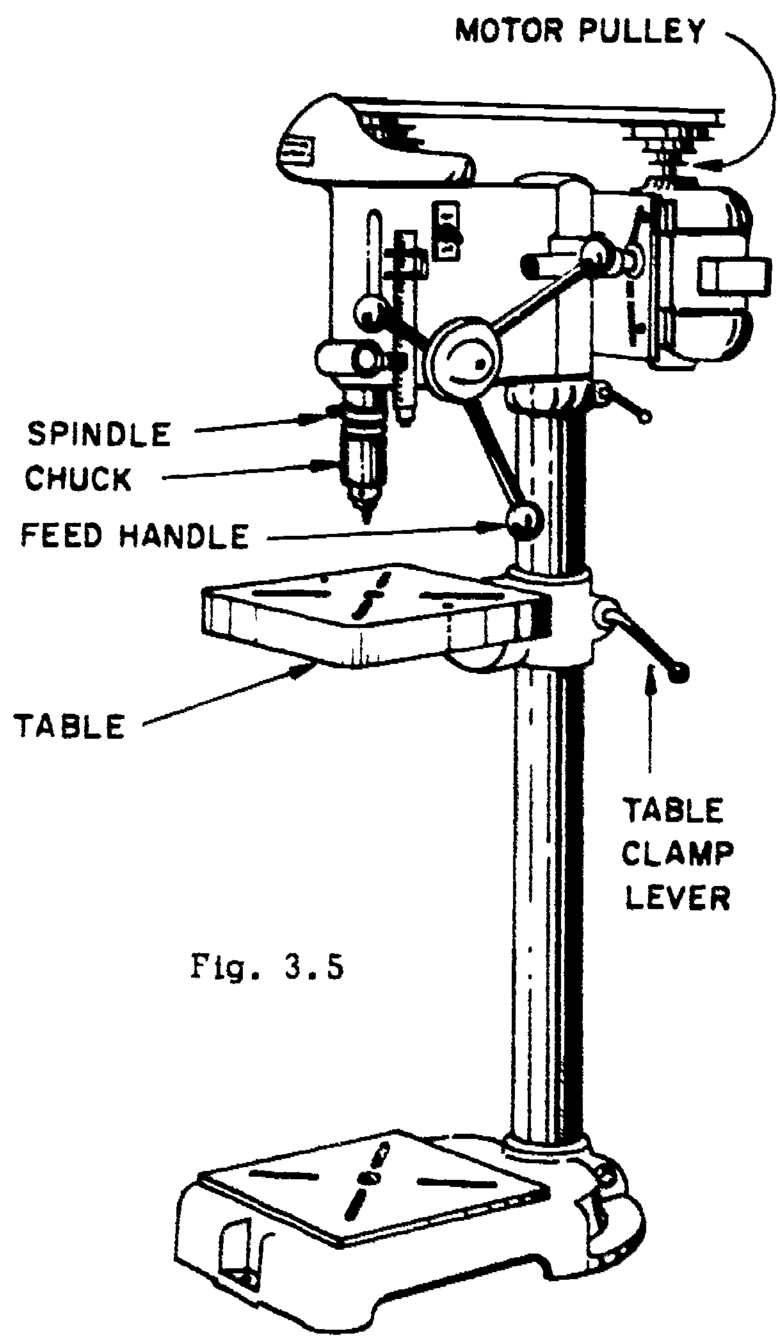


Fig. 3.5

however, if something goes wrong, an electric motor must be turned off and then it must slow down and stop before the operation ceases. The second reason power tools are more dangerous is the freedom that they allow the hands. With hand tools, in most cases, both hands are used to perform the operation; with power tools, one hand is usually free to wander around and get into trouble. When working with power tools, keep your hands and loose clothing away from moving parts. It is important to develop a respect for power tools and to use them carefully and thoughtfully.

The drill press is simple to operate but takes skill to use accurately. Figure 3.5 is an illustration of a drill press and has the most important parts labeled. A chuck is fastened to a spindle, which goes up through the head of the machine to a set of pulleys. The spindle can be lowered by rotating the top of the feed handle toward the operator. It is usually spring loaded so that it will go up when the pressure is eased on the feed handle. The chuck operates the same way as the chuck on the hand drill, with one exception: Because the drill press is more powerful and can handle larger drills, the chuck must be turned much tighter than for that of a hand drill. A chuck key is provided to do this. Simply insert the geared end of the key into one of the holes on the side of the chuck and rotate it clockwise until the chuck is tight. Always remember to take the key out of the chuck when you are through; otherwise when the motor is started the key may be thrown out and strike someone.

There is a limit to the distance the spindle can travel downward, and so it is often necessary to adjust the height of the table to accommodate the length of the drill and the thickness of the stock to be drilled. This is accomplished by loosening the table clamp, lifting or lowering the table, and retightening the clamp. The table is heavy, so be careful not to let it slip from your grasp.

On top of the drill press depicted in Fig. 3.5 there are two sets of pulleys — one connected to the spindle and the other to the motor — making it possible to change the speed of the drill press. Some drill presses have other, more convenient, means of changing speeds by simply turning a dial.

The speed at which a drill is turned is determined by two factors: the diameter of the drill and the material being drilled. In general, a large drill must be turned more slowly than a small one because the outside edge is moving faster than that of the small drill turned at the same number of revolutions per minute. Because steel is harder than wood there is more friction between the drill and the workpiece, making it necessary to turn the drill more slowly. If a drill is run at too high a speed, it will heat up and quickly become dull. However, if it is run too slowly, it may chip or break.

Estimating the proper speed for a given size of drill in drilling a given material is a complicated process. To simplify the matter, Fig. 3.6 is provided. Do not be concerned if the exact speed shown for a specific material cannot be obtained on the drill press you are using; simply use the next slower speed rather than the next higher.

When you drill a hole clear through a piece of stock make certain you do not drill into the table of the drill press. Position the table so that the drill will go through the hole in the middle, or place a piece of scrap wood under the piece you are drilling.

3.4 Types of Fits

There are two types of fits found in shop work. The fit in which two pieces mate but can move against each other is called a clearance fit. An interference fit is one where two parts mate and, because of their relative sizes, cannot be moved in relation to each other. For example, a window that is designed to open and close by sliding up and down must have a clearance fit between the window and the sash. However, if the wood swells because it absorbs moisture and the window sticks, it could be termed an interference fit. In this project you will make use of both of these fits.

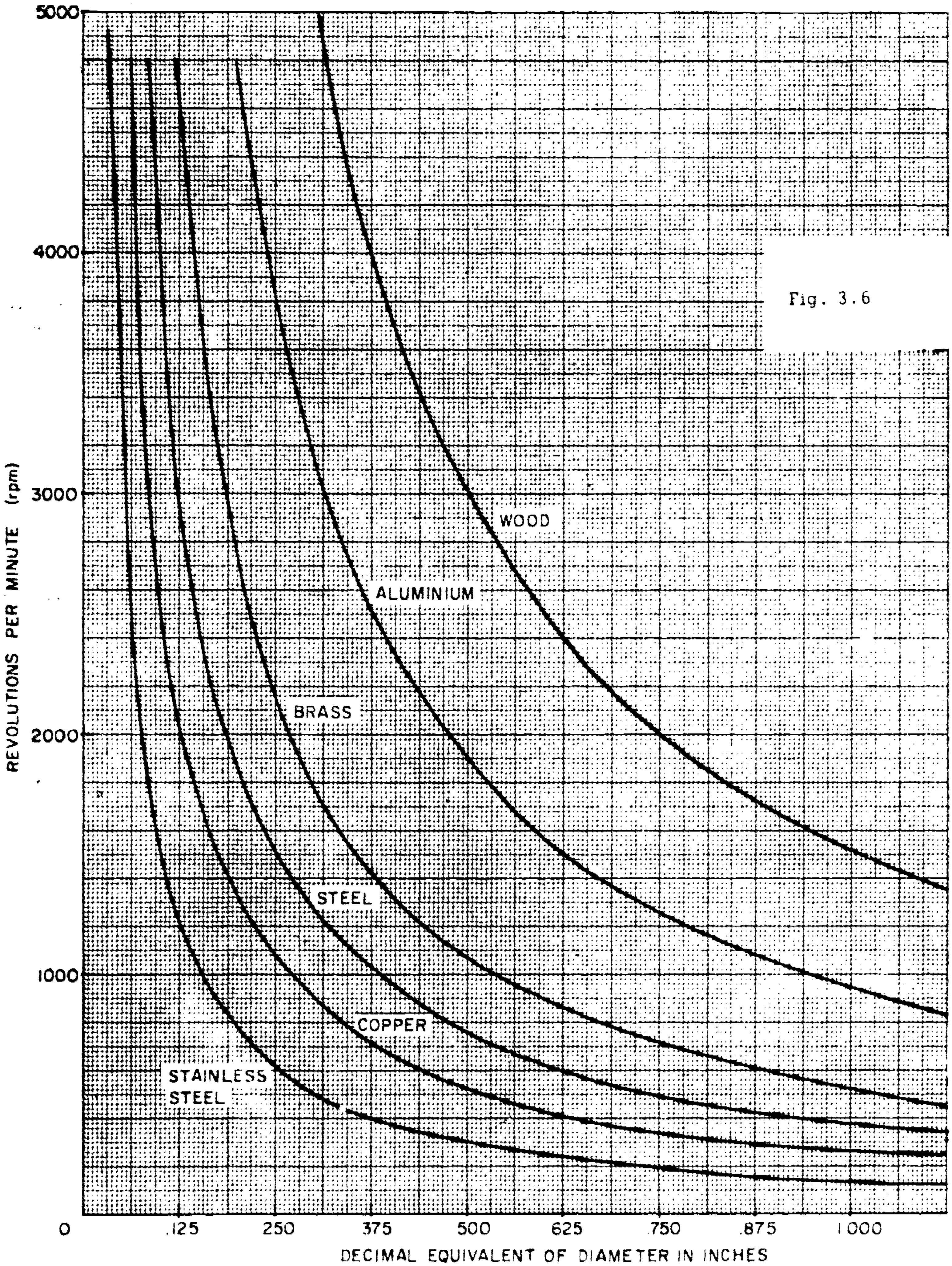

5000
4000
3000
2000
1000
0
REVOLUTIONS PER MINUTE (rpm)
WOOD
ALUMINIUM
BRASS
STEEL
COPPER
STAINLESS
STEEL
.125
250
375
500
625
.750
.875
1.000
DECIMAL EQUIVALENT OF DIAMETER IN INCHES

Fig. 3.6

Figure 3.7 is a shop sketch of the elasticity apparatus. Two pieces of brass tubing that will act as bearings for the pointer of the apparatus are inserted into holes A and B. To insure that the tubing does not move, an

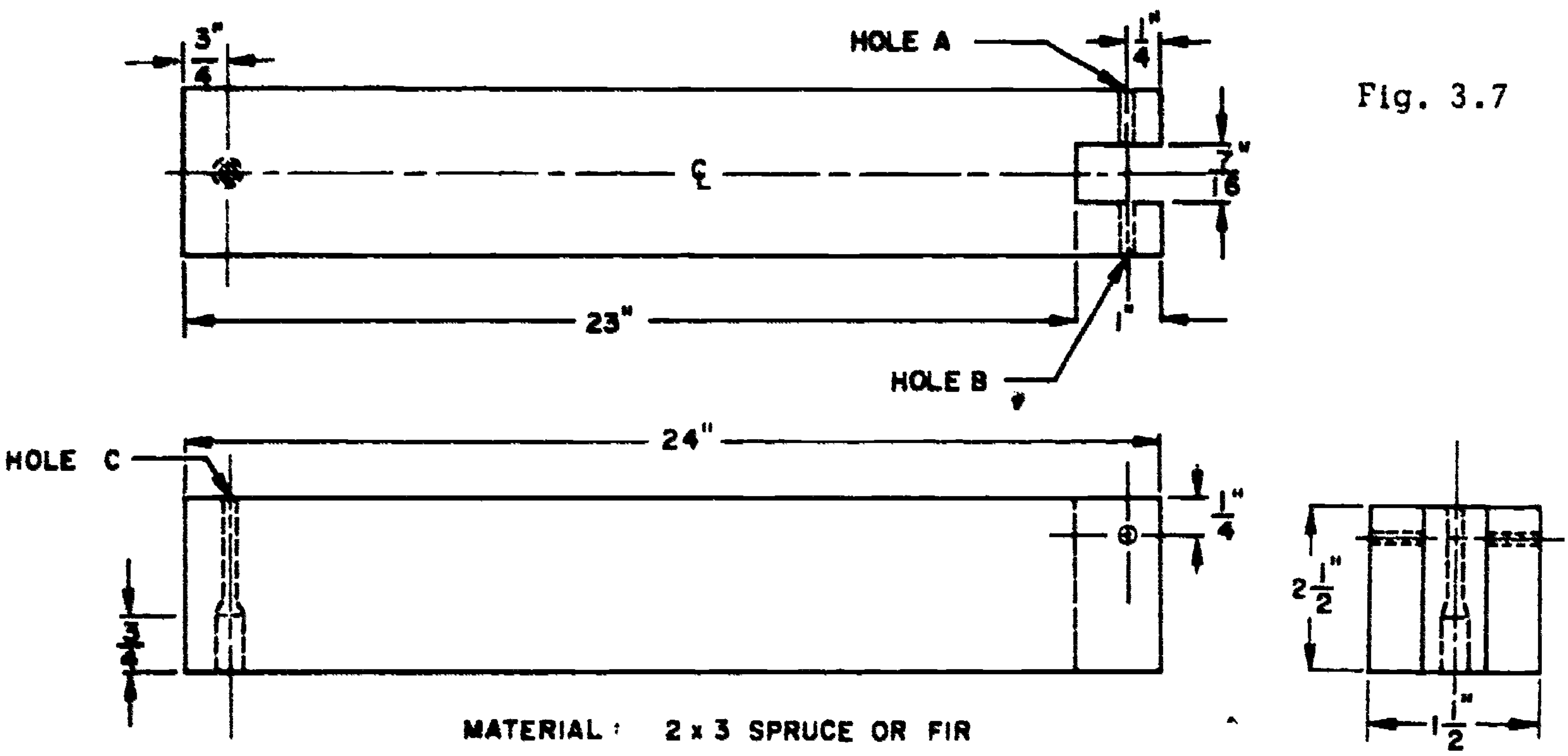


Fig. 3.7

interference fit must be used between the wood and the tubing. However, because the shaft must turn in the bearings, there must be a clearance fit between the two.

The amount of allowance for a clearance fit (the difference in size of the two mating parts) varies according to the application. A bearing that supports a heavy load and must maintain the axial alignment of the shaft may have an allowance of less than 0.001 inch. Where two pieces are not spinning against each other, the allowance may be on the order of 0.010 inch — for example, a clearance hole for a screw. Because it is important to reduce friction in the elasticity apparatus, and the load on the bearings is light, the contact between the shaft and the bearings is minimized by making the bearings much larger than the shaft.

In metal the allowance for interference fits is about 0.0015 inch per inch of diameter. For example, a hole diameter for an interference fit of a

1/2-inch shaft would be about 0.499 inch. Since wood is much softer than metal, the allowance should be at least double that of metal. However, the material into which the bearing is pressed may crack if the hole is too small.

The first step when considering an interference fit is to measure the diameter of the inserted piece. It is only after a precise measurement is obtained that the proper drill for the hole can be selected. The hole size is determined by using the allowance for the material and size. Once you have done this, both holes A and B should be drilled together to insure alignment; in other words, drill one hole clear through the stock. After the end is slotted, the piece will look like the drawing in Fig. 3.7.

o o o o o o o o

After cutting the wood stock to length and finishing both ends, measure the brass tubing obtained from your instructor. Select the proper drill for an interference fit, and drill the hole in the wood.

o o o o o o o o

3.5 Slotting

To slot the end of the stock for this project, you will use two hand tools, a saw and a wood chisel (Fig. 3.8). After the handsaw is used to make the sawcuts along the edge of the slot, you can use the chisel to remove the material between the sawcuts.

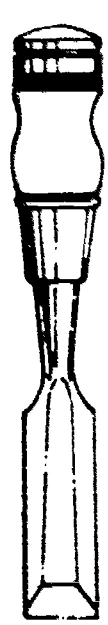


Fig. 3.8

If you look at a chisel from the side, you will notice that it resembles the blade of a plane. In fact, it functions like a plane in places where a plane cannot be used (for example, recessing latches in a door jamb). A chisel is either pushed by hand or struck lightly with a hammer when more force is needed. Chisels can be purchased in widths ranging from 1/4 inch to 2 inches.

To make the sawcuts, lay out the slot on both the top and the bottom of the stock and place it in a vise (see Fig. 3.9). Start the saw, and as the cut is made, gradually adjust the saw until it is perpendicular to the stock as shown in Fig. 3.10.

Fig. 3.9

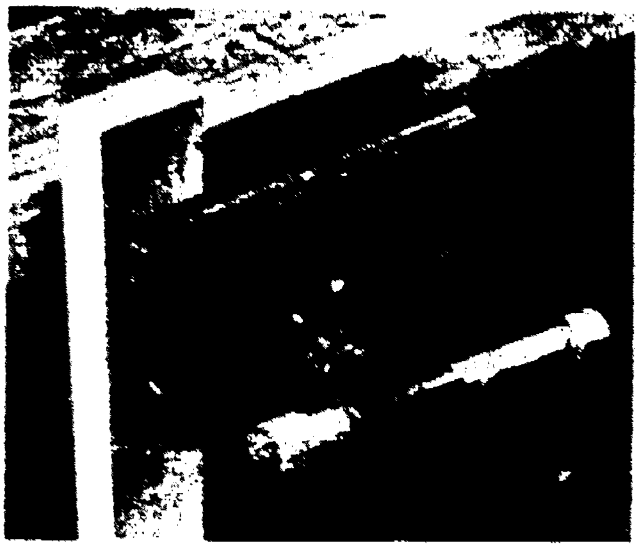


Fig. 3.10

Once both sawcuts are made, use the chisel as demonstrated in Fig. 3.11 and Fig. 3.12. First drive it into the wood at the base of the slot about 3/16 inch (Fig. 3.11). Then split out the stock (Fig. 3.12). Do not split out a section deeper than the 3/16-inch cut, for this will cause the bottom of the slot to be very rough. Repeat this sequence until the stock is slotted about halfway through. Then turn the stock over in the vise and remove material from the other side to prevent splitting.

Fig. 3.11

Fig. 3.12

Fig. 3.13

o o o o o o o o

Slot the end of the stock for the elasticity project by cutting the slot undersize and removing the material with a chisel. Then smooth the walls and bring them to dimension as illustrated in Fig. 3.13. Use both hands to guide the chisel, making sure the stock is securely clamped.

o o o o o o o o

3.7 <u>Machine Screw Threads</u>

During this project you will make two metal pieces that require machine screw threads. The first is a guide arm used with the laboratory stand. It is threaded on one end and attached to the side of the stand with two nuts. The thread, which is cut on the outside of the rod, is called an <u>external thread</u>. The roller in the elasticity apparatus is the second metal piece you will make. Here, an <u>internal thread</u> is required so that a wire can be attached to the roller by means of a <u>machine screw</u>.*

Both internal and external machine screw threads are classified by the number of grooves per inch and by the diameter of the thread. The thread diameters are given by numbers starting from very small threads up to a 1/4-inch diameter. The diameters are then given in fractions of an inch. The

*Unlike wood screws, which taper to a point and form their own threads in the wood, machine screws are straight with a uniform thread and require mating threads to be cut in the metal.

smallest of the threads classified in this way is a No. 0, which is 0.060 inch in diameter. The diameter then increases by 0.013 inch for each number of the screw. There are always two numbers given to describe a thread. The first is the diameter, and the second number is the threads per inch. Thus, a 6-32 screw has a No. 6 diameter (0.138 inch) and 32 threads per inch.

Threads come in various groupings, but the most common are the National Coarse (NC) and the National Fine (NF) series. The National Coarse series has sizes ranging from a No. 1 to as large as 4 inches in diameter. The National Fine series ranges from a No. 0 to 1-1/2-inch diameter. Table 3.2 lists the threads available in these two series. Only the commonly used sizes are given.

TABLE 3.2

National Coarse	National Fine
2-56	2-64
4-40	4-48
5-40	5-44
6-32	6-40
8-32	8-36
10-24	10-32
12-24	12-28
1/4 -20	1/4 -28
5/16-18	5/16-24
3/8 -16	3/8 -24
7/16-14	7/16-20
1/2 -13	1/2 -20

3.8 Cutting Threads

To cut an external thread, you use a tool called a die (Fig. 3.14). The teeth on the inside of the die are tapered to remove material gradually until the full threads are formed on the rod. Because of the taper (Fig. 3.15), the die must be started from one side only, often marked "Start from this side." The die is held in a tool called a die stock (Fig. 3.16) by means of a screw in the side of the die stock that engages in the side of the die and is tightened snugly.

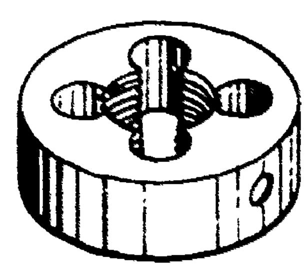


Fig. 3.14

Fig. 3.15

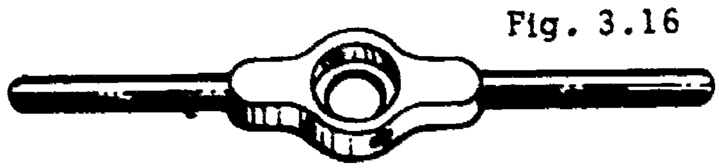
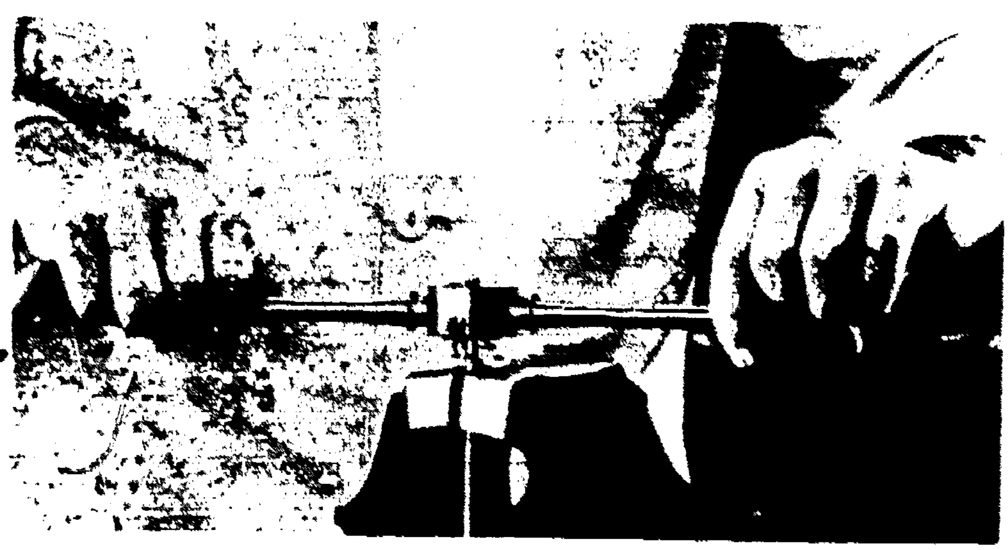


Fig. 3.16

To prepare a piece of rod for threading, use a file to chamfer the end (see Fig. 3.17). Then clamp the rod in a vise, and place the die squarely on the chamfered end. As the die stock is rotated clockwise, a certain amount of downward force is required to start the die cutting. Be certain that the die is perpendicular to the rod or it will produce a crooked thread. After the first few threads are cut, the downward force is not needed. As the die cuts, chips form on the rod. They must be removed to produce a clean, accurate thread. After each clockwise revolution of the die, turn back one-half a revolution. As you do, you will feel the chips break off. The use of oil on the die will help clear the chips and make the die cut more easily. After the rod is threaded to the proper length, back the die off by rotating it counterclockwise. Figure 3.18 shows the threading operation in progress. To check the thread, try screwing a nut of the proper size onto the rod.

Fig. 3.17

Fig. 3.18



o o o o o o o o

Figure 3.19 is a guide arm that can be used with the apparatus stand (<u>Project 1</u>). Cut the stock to length, bend it to 90 degrees, and thread the end.

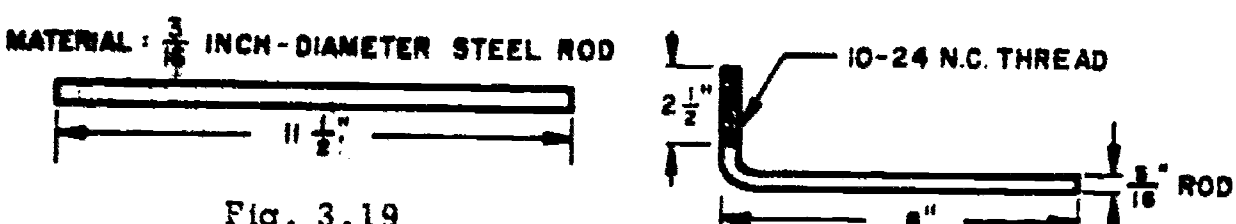
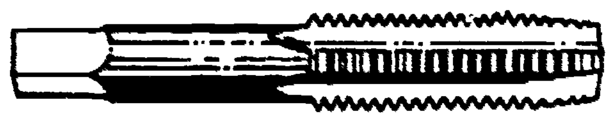


Fig. 3.19

o o o o o o o o

A tool called a tap (Fig. 3.20) is used to cut an internal thread. Three types of taps are generally available — a starting tap, a plug tap, and a bottoming tap. Starting taps have a long chamfer on the cutting end of the tap for easier starting. They are used mostly for holes in thin material. A

Fig. 3.20



plug tap, the type most generally used, has a shorter chamfer. A bottoming tap is used when threads must be cut in a hole that does not go clear through a piece of stock. A plug tap should always be used before the bottoming tap.

In cutting an internal thread it is necessary to drill a hole that is smaller than the outside diameter of the thread to be cut. The size of this hole is called the tap drill size and depends not only on the diameter of the thread but also on the number of threads per inch. Table 3.3 lists the various thread sizes and the tap drill size that should be used for each.

TABLE 3.3

Thread Size	Tap Drill Size
2-56	50
4-40	43
5-40	38
6-32	36
8-32	29
10-24	25
10-32	21
12-24	16
3/16-24	16
1/4 -20	7
5/16-18	F
5/16-24	I
3/8 -16	5/16
3/8 -24	Q
1/2 -13	27/64

A tap is held in a tool called a tap handle. Figure 3.21 illustrates two types that are often used. The square end of the tap is placed in the chuck of the tap handle, and the chuck is tightened down on the tap itself. To start the tap, place the cutting end in the hole, exert downward pressure, and rotate the handle clockwise. Make sure that the tap is perpendicular to the stock. Proceed as you did in using a die, backing off the tap occasionally to break off chips. Use cutting oil on the tap. Figure 3.22 demonstrates a tapping operation in progress.

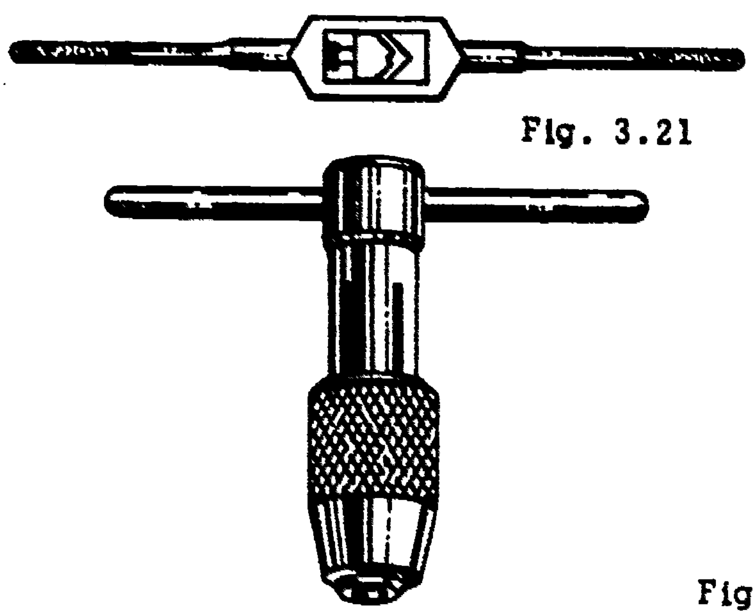


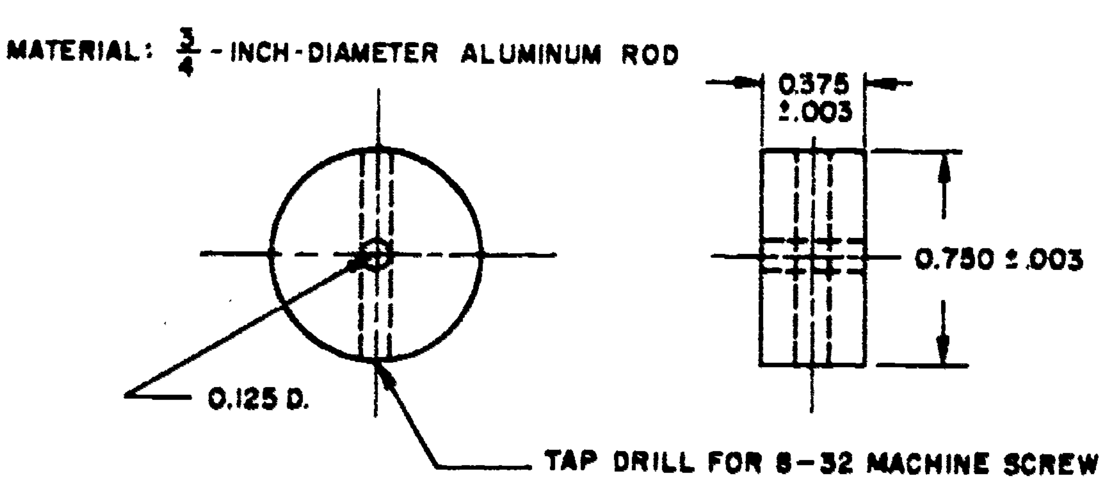
Fig. 3.21

Fig. 3.22

3.9 Drilling Round Stock

Figure 3.23 is a shop sketch of the drum, or roller, that is used with the elasticity equipment. Note that two holes are drilled in it — one along the axis and one perpendicular to it.

Fig. 3.23



When drilling a hole in metal, a drill may wander and start in the wrong place. To prevent this, a small hole is made at the intersection of the layout lines on the stock with a tool called a center punch. It looks like a nail set except that the end comes to a point. Because the hole will guide the drill, the center punch must be used accurately.

Place the point at the intersection of the layout lines and tap the center punch lightly with a hammer. Check the indentation on the metal to see if it is correctly positioned. If so, replace the center punch (you will feel the point drop into the previous indentation) and enlarge the hole by tapping the center punch once again. If the mark is incorrectly placed, tilt the center punch and tap it with a hammer, moving the indentation in the direction you wish. Then straighten it and tap it again with a hammer.

To drill the hole accurately through the diameter of the stock, V blocks are used. When a drill is positioned so that it lines up with the bottom of the V, the resulting hole passes through the center of the stock. Two methods used to insure this are depicted in Fig. 3.24 and Fig. 3.25.

In Fig. 3.24, the stock is placed in the V blocks after the hole is laid out on the side. While the clamps are loose, the hole position is marked with a center punch. The square is used to reference the circumference of the

Fig. 3.24

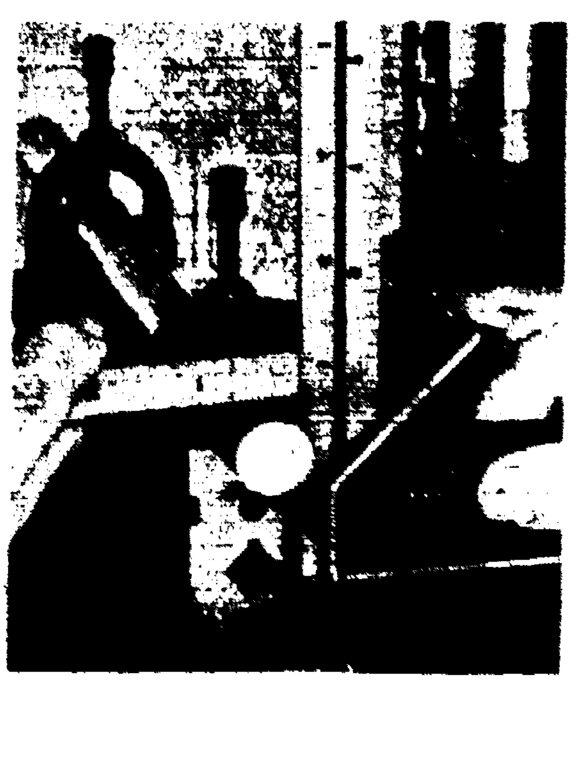
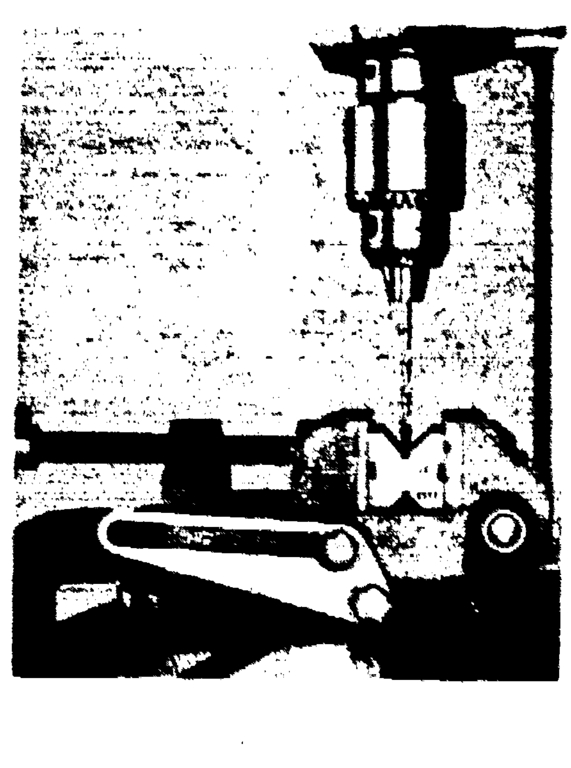


Fig. 3.25



stock. The stock is rotated in the V blocks until the distance between the square and the center mark is one-half the diameter of the stock. Then the clamps are tightened and the measurement is checked from both sides of the stock to make sure that it has not shifted. Then the setup is moved until the drill is positioned correctly and the hole drilled. Because the material is metal, oil is used on the drill and the feed is slower.

Another method is to clamp a V block in a drill vise (see Fig. 3.25). Position the vise so that the drill lines up with the bottom of the V, and clamp it to the drill press table. This method, however, has two drawbacks. The stock must be held by hand, which is difficult and possibly dangerous. Although it is more direct than the first, this method takes more time to set up. In using either method, be sure that if the drill is to go clear through the stock that it will not go into the V block as it comes out the bottom side.

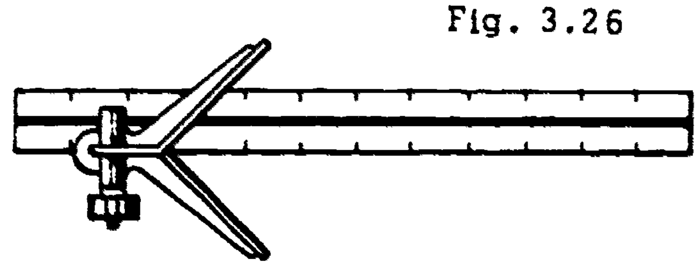
o o o o o o o o

After squaring one end of the stock used for the drum in Fig. 3.23, drill the hole along the diameter of the stock. Then cut the stock to length and file to dimension.

o o o o o o o o

To drill the hole along the axis of the drum, it is necessary to find the center of the stock. Figure 3.26 shows a center head, the tool used to lay out the center of round stock. A diameter line is drawn by placing the

Fig. 3.26



stock in the "V" of the center head and scribing a line along the steel rule as shown in Fig. 3.27. By scribing any two diameter lines, the center is located at their intersection. Use a vernier caliper to check the position of the center point. Remember that the dimensional tolerances are ±0.003 inch, and so you must drill carefully.

To prevent the stock from tipping when you drill the hole, place a piece of scrap wood under the stock before clamping the piece in a drill vise.

Fig. 3.27

o o o o o o o o

Drill the hole along the axis of the roller.

Tap the hole along the diameter. Because most 8-32 taps are not long enough, tap from both ends of the hole. In the final assembly of the apparatus, two machine screws are screwed into the drum, one to hold the wire to the drum and a second to hold the drum to the pointer. The screw holding the wire is shorter; therefore, the hole does not have to be tapped so deeply. However, the hole for the second screw must be tapped at least halfway through to allow the screw to tighten on the pointer.

o o o o o o o o

3.10 Counterboring

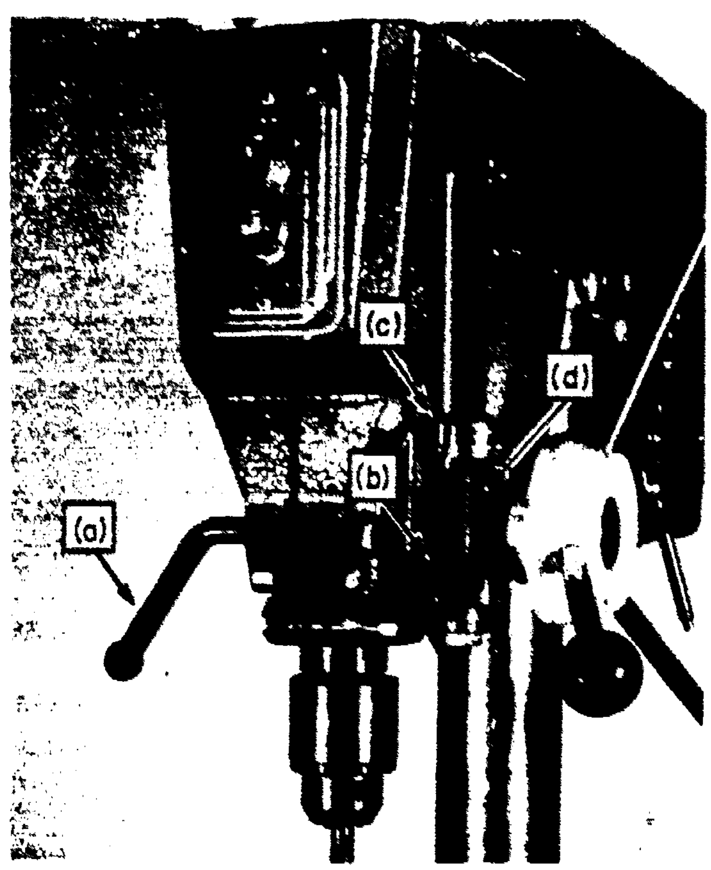
The shop sketch of the elasticity apparatus, Fig. 3.7, indicates that the hole or the right end (hole C) has two diameters. This hole is made by drilling with two separate drills, one the diameter of the smaller section of the hole and the second the diameter of the larger. Drilling the second hole is called counterboring.

The most common use of counterboring is to form a hole that will receive both the shaft and the head of a machine screw without exposing the head of the screw. In the case of the elasticity apparatus, the hole is counterbored for two reasons. First, if the head of the screw were to extend beyond the surface of the wood, the piece would be unstable. Second, because the hole is counterbored, a shorter screw can be used.

There are special tools for counterboring. In most cases, a flat-bottomed hole is required. However, it is not important here, and so a drill is used that results in the bottom of the hole being tapered. The first step in counterboring is to drill a clearance hole through the stock for the screw. The second step is to drill a clearance hole for the head of the screw. The second hole does not go clear through the stock; therefore, it is necessary to stop the feed of the drill press when the drill reaches a specified depth.

Figure 3.28 shows the parts of the drill press that are used to drill to a specified depth. Mark the depth of the second hole on the side of the

Fig. 3.28



(a) SPINDLE LOCK
(b) DEPTH STOP
(c) DEPTH-ADJUSTMENT NUT
(d) DEPTH SCALE

stock. Then lower the spindle until the drill is even with the line. Tighten the spindle lock by rotating it toward you. Now release the lock on the depth-adjustment nut and spin the nut until it rests against the depth stop. Retighten the lock on the depth-adjustment nut to prevent it from moving. Then release the spindle lock and the setting is completed.

o o o o o o o o

Drill and counterbore hole C (Fig. 3.7).

Cut the stock to length for the pointer (Fig. 3.29), bend it to 90 degrees, and file the end to a point as shown.

Cut two pieces of brass tubing 1/2 inch long. File the ends square, and deburr and bevel the outside of the ends.

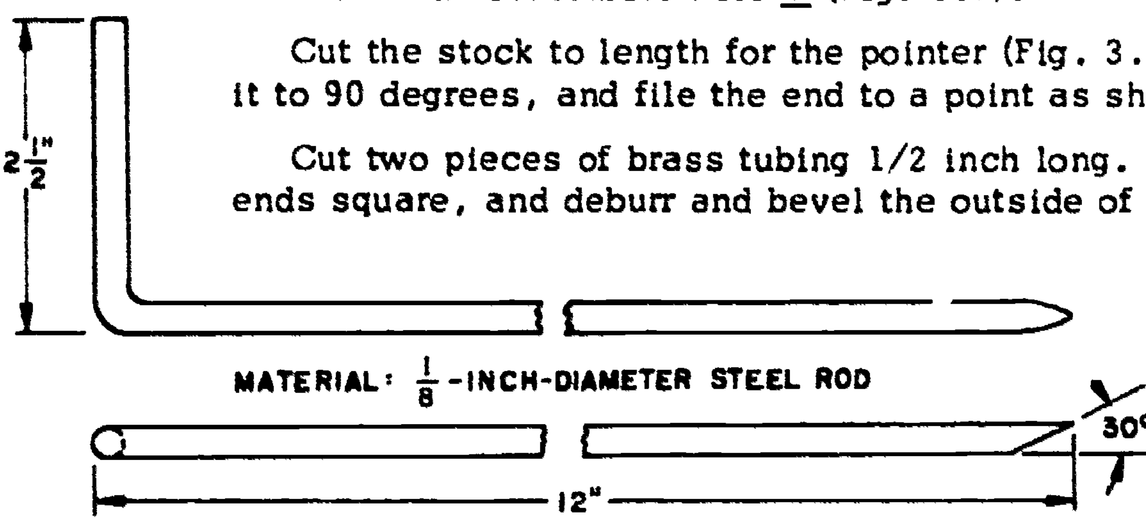


Fig. 3.29

Assemble the elasticity apparatus as shown in Fig. 3.30. A vise may be used to press the brass tubing into the wood. Place the tubing over the hole, making sure that it is square to the surface of the wood. To reduce the chance of splitting, place a piece of wood, which barely fits, into the slot behind the hole. Then tighten the vise.

o o o o o o o o

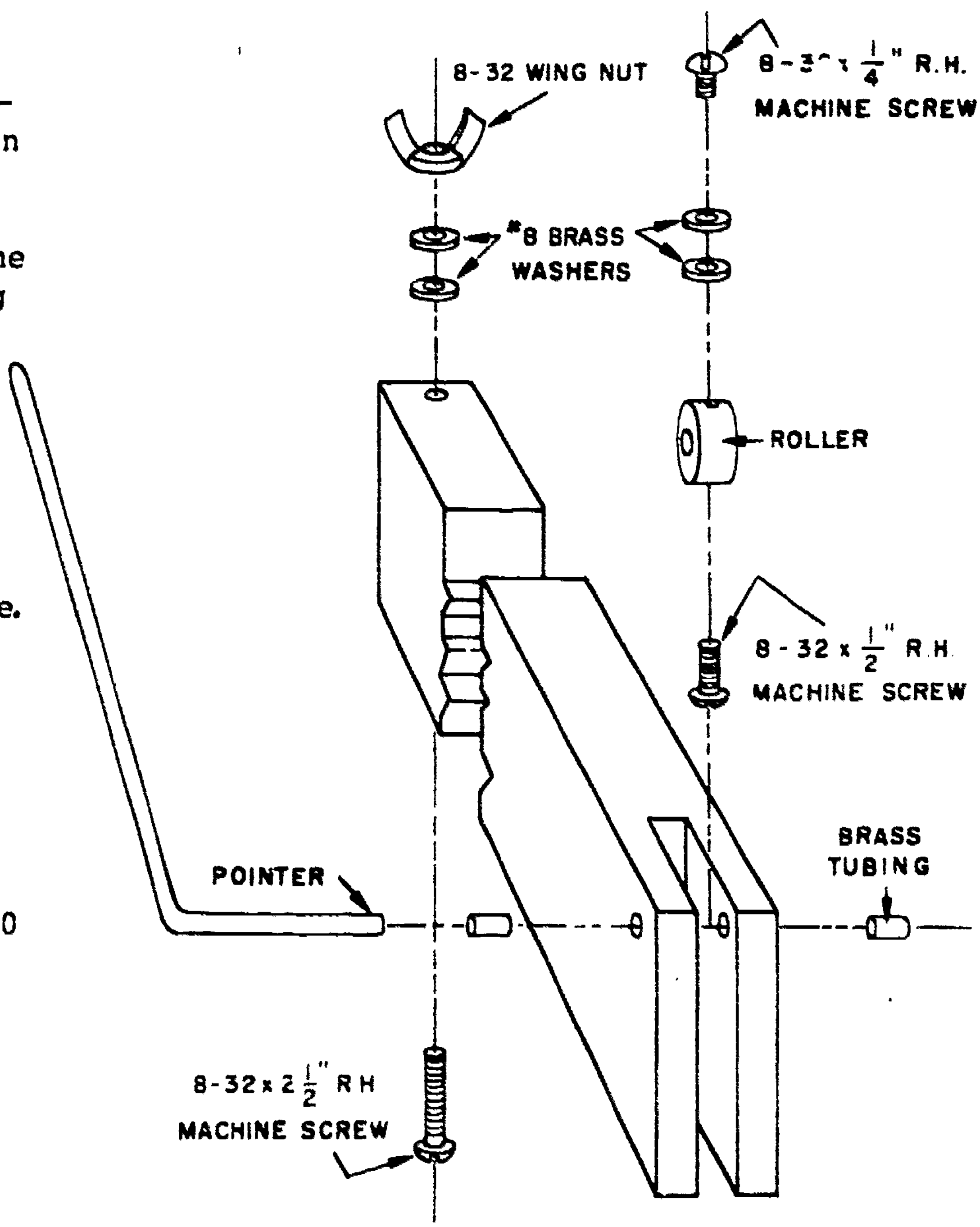


Fig. 3.30

Project 4: A WOODEN FRAME

In this project you will make the wooden frame shown in Fig. 4.1. The principles behind its construction lend themselves to other pieces of apparatus. A wooden frame can hold a piece of glass, plastic, or thin wood, and it then can be used for an aquarium cover, a display case top, or a frame for charts and maps. Some frames are purely functional, whereas others (picture frames) can be more decorative.

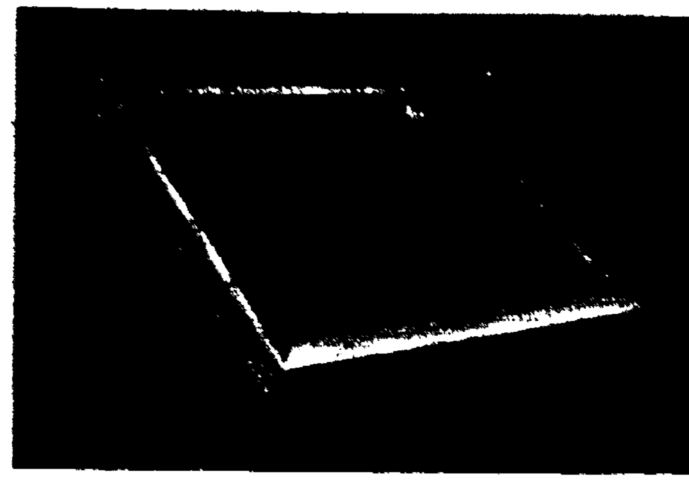


Fig. 4.1

Figure 4.2 is a shop sketch of one of the sides of the frame you will build. Four pieces of wood are needed — two sides, a top, and a bottom. Because the sides are a different length from the other two pieces, this dimension has been omitted, and you will determine it later. Because the cross section of each piece is to be the same (view C), a long board (long enough to make all four pieces) is cut to the proper width and height and then grooved, as shown, before each piece is cut to length. This method is faster and more accurate than cutting each piece separately.

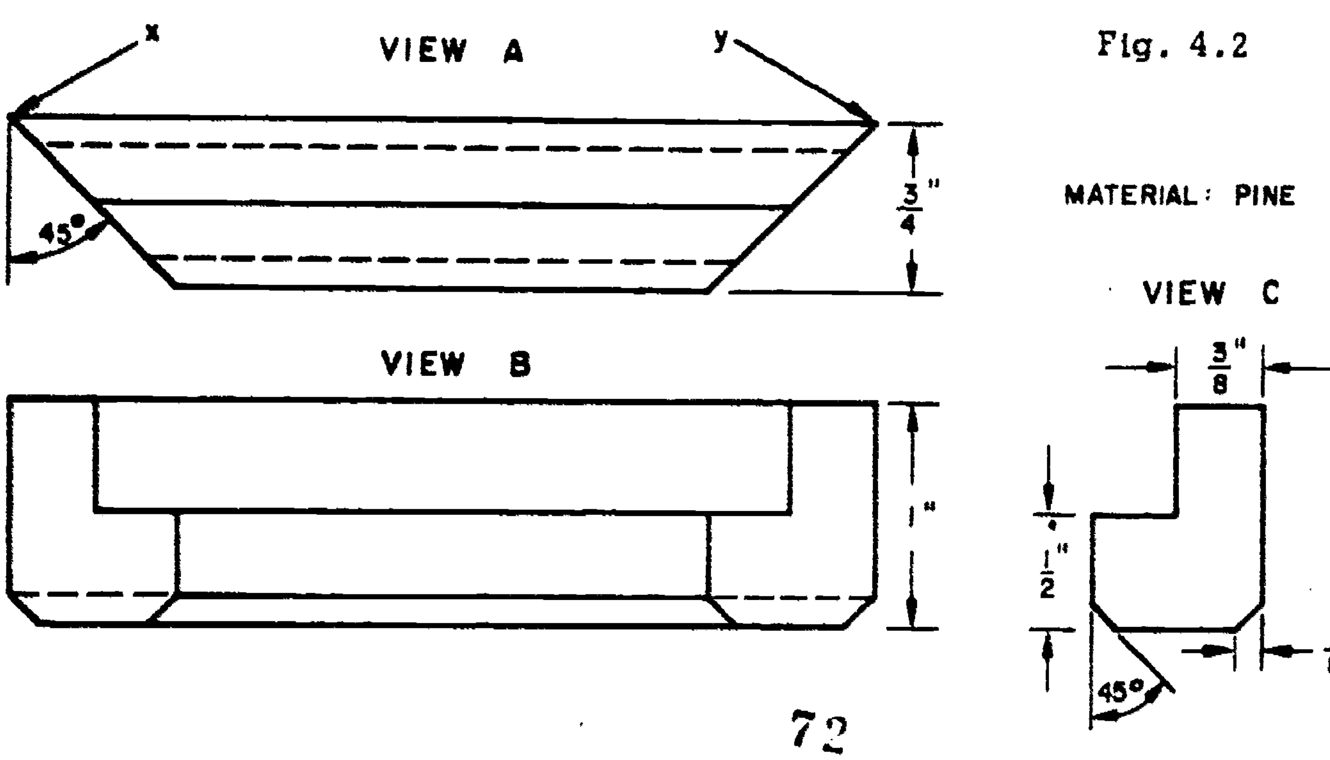


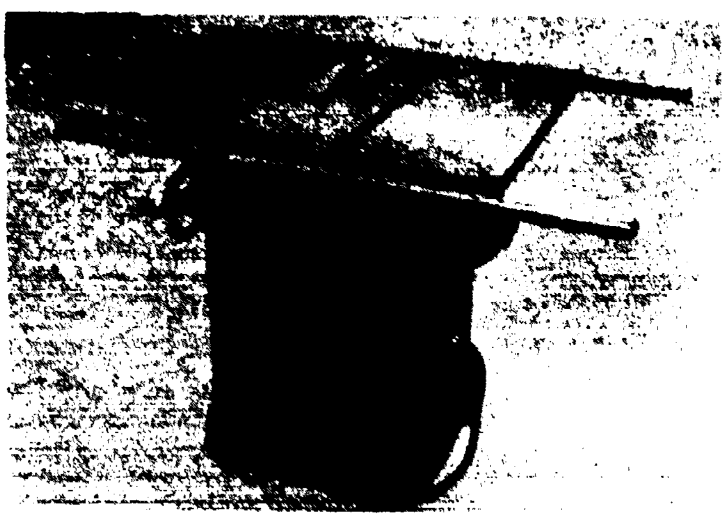
Fig. 4.2

4.1 The Table Saw

The table saw depicted in Fig. 4.3 can do the same things as a handsaw, but more quickly and easily because the power is supplied by an electric motor connected by pulleys and belts to a circular saw blade. The wood is fed in as the top of the blade rotates toward the operator, forcing the wood down against the table as it is being cut. The height of the blade can be adjusted by a crank generally located on the front of the machine. On most table saws the angle of the blade also can be adjusted by a crank on the side of the machine.

Two pieces of equipment are required when using the table saw. The rip fence (Fig. 4.4) is used as a reference when making sawcuts along the length of a board. The mitre gauge (Fig. 4.5) can be adjusted to make sawcuts at various angles.

Fig. 4.3



4.2 Circular Saw Blades

A circular saw blade is a flat disc of steel having saw teeth ground around the circumference. There are blades made for ripsawing, and others for crosscutting. The teeth on these blades are very similar to those on the corresponding kinds of handsaws except that they are larger.

Fig. 4.4

Fig. 4.5

So that the blade does not need to be changed, the one most commonly used with a table saw is the combination blade, which combines both rip teeth and crosscut teeth. Around the circumference are several segments, each consisting of a series of small teeth for crosscutting and one large tooth that performs the ripping operation.

Circular saw blades can be purchased with or without set. Blades with set are used for doing rough work where clearance is needed to reduce friction. Blades without set are used when smooth-finish cuts are required.

Saw blades are cl ssified according to the type of teeth – crosscut, rip, and so on. They are also classified by the diameter of the blade (which is limited by the capacity of the table saw) and the diameter of the shaft on which the blade is used.

There are many other types of blades that can be used in table saws. Some blades are made for cutting plastics, others for cutting composition boards such as chipboard and Masonite, and still others for cutting metal. The blades discussed in this section and also some of the other blades available are shown in Fig. 4.6.

When it is necessary to change a blade in a table saw, because it is the wrong blade or has become dull, ask someone who is familiar with the table saw you are using to show you how to do it. Be sure that the blade is installed in the proper direction and is tightened snugly. <u>Always</u> unplug the saw while the blade is being changed. A serious accident could occur if someone should happen to hit the starting switch.

When preparing to make a sawcut, adjust the blade so that the teeth are just a little higher than the thickness of the stock. The less the blade is exposed, the less risk there is of accidents.

4.3 Making Sawcuts with the Rip Fence

The distance between the rip fence and the saw blade can be adjusted to cut a piece of wood to any width by sliding the fence along the front and rear support bars until it is at the proper distance from the blade and then by clamping it in position. Most rip fences have a built-in clamp that can be

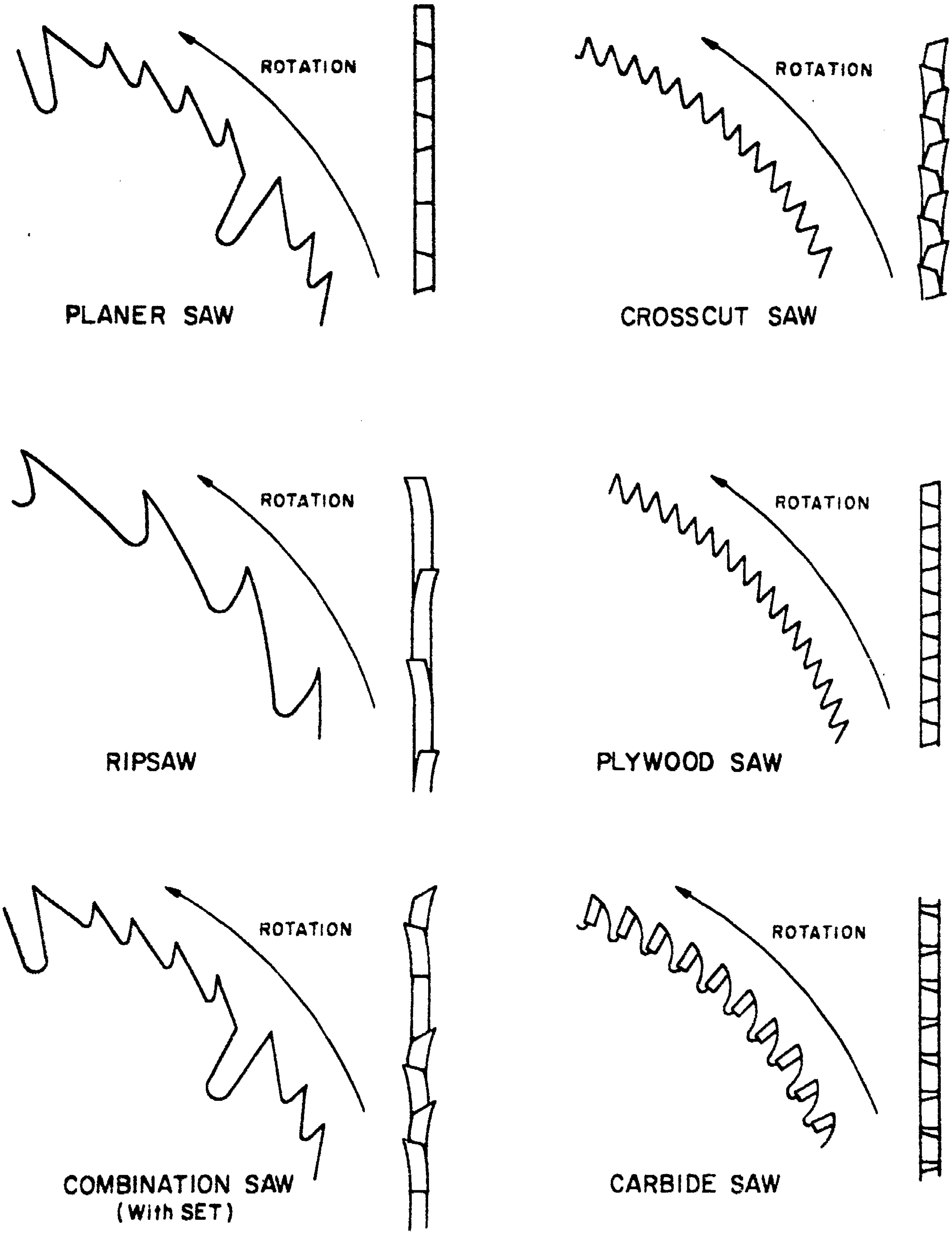

ROTATION
PLANER SAW
ROTATION
CROSSCUT SAW
ROTATION
RIPSAW
ROTATION
PLYWOOD SAW
ROTATION
COMBINATION SAW
(With SET)
ROTATION
CARBIDE SAW

Fig. 4.6

set by turning a knob or pressing a lever.* Always recheck the dimension because the fence will move slightly as the clamp is tightened. The most accurate way to set the distance between the fence and the saw blade is to use a scale or a steel measuring tape to measure the distance from the fence to the nearest tooth on the blade. Remember that some blades have set teeth and others do not. On most table saws the front support bar is graduated in inches measured from the blade. The proper dimension can be set from this scale and the fence clamped. This method is not so accurate and should be used only when rough work is being done.

Before making a cut, be certain there is enough room around the table saw so that the board will not hit anything. You may have to turn the saw around to provide the necessary clearance. Make sure there is nothing near the saw blade, and then turn the saw on. Place the stock firmly against the fence and push it into the blade (see Fig. 4.7), always keeping your hands well clear of the blade. Push the stock through until the back side of the blade is no longer in contact with the wood (Fig. 4.8). Never let the stock stand still while it is being cut. If it does, friction will cause the wood to burn and heat up the blade, which will dull or even warp it. Take care that

Fig. 4.7

Fig. 4.8

*Some fences have two clamps on them, one for each end of the rip fence. Be sure to determine which type is used on your saw. If one clamp is not tightened, the fence may move during a cut, which is very dangerous.

the wood does not pull away from the fence, thereby causing the wood to bind between the blade and the fence. Warped or twisted wood is more likely to do this than straight wood is.

If the wood should bind for any reason, do not back up or let go of the wood because it could be thrown by the blade. Hold it firmly against the table with one hand and shut off the saw with the other.

Fig. 4.9

In ripping a narrow piece of stock, do not use your fingers to push the stock between the blade and the fence. Use an awl or some type of wooden pusher, as shown in Fig. 4.9.

After you have finished a cut, turn off the saw before doing anything else. Then clear any chips of wood that are near the blade, otherwise they could vibrate into the blade during the next cut and be thrown across the room. Never remove scraps while the blade is rotating and be careful to turn the saw off in such a way that you are clear of the path of any chips that might be thrown.

Because the table saw is potentially the most dangerous tool you will ever use, this section contains many warnings and negative instructions. However, since it is also one of the most useful tools, you must learn to use it cautiously by thinking ahead and planning for anything that might happen during the operation. If you approach the table saw in this manner, you will find it a safe tool to use and have no reason to fear it.

o o o o o o o o

Only after your instructor has demonstrated the correct way to use the table saw and has watched you make some practice cuts should you begin to rip the stock for the wooden frame shown in Fig. 4.2. Remember, BE CAREFUL!

o o o o o o o o

4.4 Chamfering with a Table Saw

In the description of end planing (Project 1) you were told to use a plane to chamfer the end of a board to reduce the chance of splitting. The wooden frame in Fig. 4.2 requires a chamfer, but for a purely decorative reason. The frame would function just as well without it. As before, a plane can be used by planing lengthwise along the edge of the board. However, this operation is done with more ease, more accuracy, and more speed on a table saw.

Before the previous sawcut was made, the distance between the blade and the fence was set with the aid of a scale. However, to chamfer a board the blade must be tilted at an angle; and because the blade is angled, it is easier to make a chamfer by trial and error than to set the fence to a specific dimension.

First set the blade at 45 degrees by turning the crank on the side of the table saw, and check the angle by making a trial cut. Lay out the width of the chamfer on the edge of the board. Then raise the blade until its vertical height is greater than the thickness of the board. Position the fence so that the blade removes just a little material and make a sawcut. Measure the distance between the edge of the sawcut and the layout line. Readjust the fence accordingly and make the final cut.

o o o o o o o o

Chamfer the edges according to Fig. 4.2. Be certain that whatever you use to push the wood does not touch the blade during the cut.

o o o o o o o o

4.5 Slotting with a Table Saw

Note in view C of Fig. 4.2 that a section of wood has been removed. When the frame is assembled, this section, called a rabbet, forms the recess into which the glass will fit. The rabbet is the result of two sawcuts, as illustrated in Fig. 4.10(a) and 4.10(b).

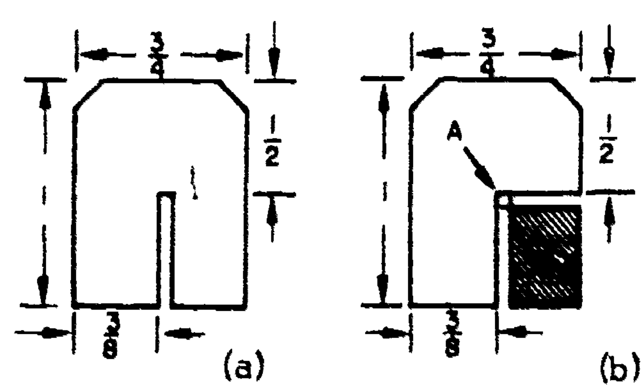


Fig. 4.10

The first sawcut is basically a rip cut except that the blade does not cut clear through the wood. The height of the blade is the same as the depth of the slot in Fig. 4.10(a) and is set by using the scale as demonstrated in Fig. 4.11. Next, the rip fence is adjusted so that the distance between the blade and the fence corresponds to that specified in the drawing. Then the sawcut is made.

The second sawcut removes the material represented by the shaded section in Fig. 4.10(b). The two sawcuts must meet precisely at point A for the glass to have a proper fit. The method used for this cut is the same as the previous one. However, more care is required because the piece will be less stable during the cut. To prevent tipping the wood during the cut, place the awl — used to push the stock — between the blade and the fence.

Fig. 4.11

o o o o o o o o

Make the rabbet cut for the wooden frame. Take care that the board does not lift from the table at the end of the cut and cause the sawcuts not to meet properly.

o o o o o o o o

4.6 Making Sawcuts with a Mitre Gauge

A mitre gauge is generally used to make crosscuts with the table saw. It rides back and forth in a slot in the top of the table saw. The mitre gauge you use is the same as the one used with the belt sander in Project 1. For accurate work you must make a trial cut, measure the angle of the end, and readjust the mitre gauge if necessary.

Before making a sawcut with a mitre gauge you must mark the board where it is to be cut. The best place for your layout mark is on the front edge of the board toward the saw blade. To obtain better control of the piece during the operation, always hold the board against the mitre gauge by the end that will be the longest after the sawcut. Remember which end is to be the finished piece so that you will know on which side of the layout line to saw.

Before turning on the saw, move the mitre gauge forward until the stock to be cut is very close to the saw blade. Then slide the wood along the surface of the mitre gauge until the layout mark lines up with the edge of the blade. (Don't forget what to do if a blade has set.) As you hold the wood firmly against the mitre gauge, move the gauge toward you until the wood is well clear of the blade. Start the saw and push the stock into the blade, being sure not to slide it along the face of the mitre gauge (Fig. 4.12).

Fig. 4.12

After the cut is through, hold the board against the mitre gauge, move it away from the saw blade, and slide the mitre gauge back toward you. Then shut off the saw.

Always be careful to keep your hands away from the saw blade. If you are cutting a narrow board, use only one hand to hold it against the mitre gauge. If the board is wide, you will have to hold the board against the gauge with one hand and push it with the other.

Eight 45 degree sawcuts are needed for the frame, two on each piece. Making a crosscut at an angle other than 90 degrees is simple. However, in the case of the wooden frame, each sawcut must be very accurate because every error is multiplied by the number of sawcuts. If every sawcut were off by 1/2 degree, when the frame is assembled a gap of 4 degrees would result at one corner. Thus the setting of the mitre gauge is very critical. The best way to check the setting is to make two cuts on scrap wood and fit them together, checking with a square that they add to 90 degrees.

NEVER use the rip fence with the mitre gauge to make a crosscut. There is a very good possibility that the stock would bind because there is not enough wood against the fence to act as a good reference. If many boards must be cut to the same length, a stop can be clamped on the mitre gauge making it possible to cut each board to the same length.

o o o o o o o o

In Fig. 4.2, the length of the piece is not specified. If the frame is to fit around a piece of glass that is 8 by 10 inches, how long should each piece be? (Give the distance from point a to point b.)

Make the 45 degree cuts on the long board you have already chamfered, cutting each piece to length in the process. To reduce errors, be sure each cut is made in the correct direction without resetting the mitre gauge each time.

Use glue and small-diameter brads to assemble the frame. It may be easier to assemble the frame if you clamp one board to the table while you nail the other to it. Wipe up any excess glue with a damp cloth. Glue prevents stain from being absorbed by the wood if you choose to stain the frame a different color.

Sand the frame to remove marks left by the saw blade but do not round any of the corners in the process.

o o o o o o o o o

Project 5: A TEST-TUBE RACK

The piece of apparatus shown in Fig. 5.1 is used for holding test tubes during a chemistry experiment. Its construction is not very complicated, but building it will require some thought on your part. Up to this point, you have been given step-by-step instructions. In this project you must decide what operations to perform and in what order.

Fig. 5.1

5.1 Power Bits

Another type of drill, a power bit, is illustrated in Fig. 5.2. These drills are designed for drilling 1/4- to 1-1/2-inch-diameter holes in soft materials such as wood or plastic. They are

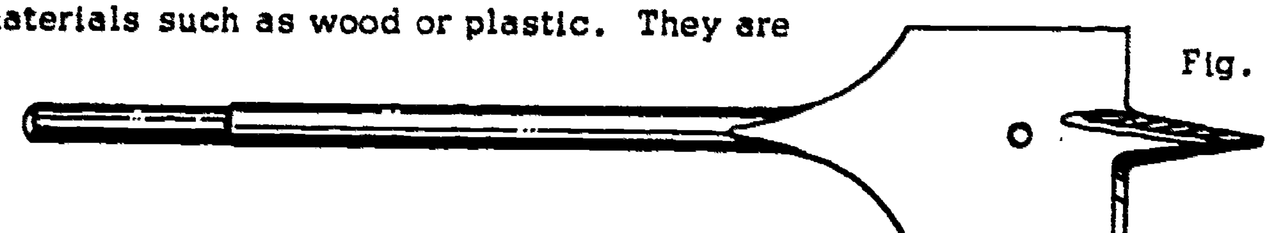


Fig. 5.2

mainly used with a drill press, and so the shaft has three or six flat sections on it to prevent it from slipping in the chuck.

The point serves as a guide to keep the drill centered while the cutting edges remove the material. It is always necessary to place a piece of scrap wood under the workpiece to keep the drill centered as the point goes through the first piece. Whenever large power bits are used, the work should be clamped to the drill press table with C-clamps. Before starting the drill press, make sure that the C-clamps are not in the way.

o o o o o o o o

All the information you need to make the test-tube rack is contained in Fig. 5.3. However, because of the nature of the piece, the actual dimensions used for setting the table saw are not given directly.

On a piece of paper, list in order all the operations you must perform to make the test-tube rack. Describe every step in <u>detail</u> as if the person reading your instructions has seen the tools used but has never used them.

At first, the 45 degree sawcut may appear difficult to make. It will help if you remember how you used the height of the blade and the distance between the blade and the rip fence to make the rabbet cut in Project 4.

Take the list to your instructor. After you receive approval, proceed to carry out the project as you have outlined it.

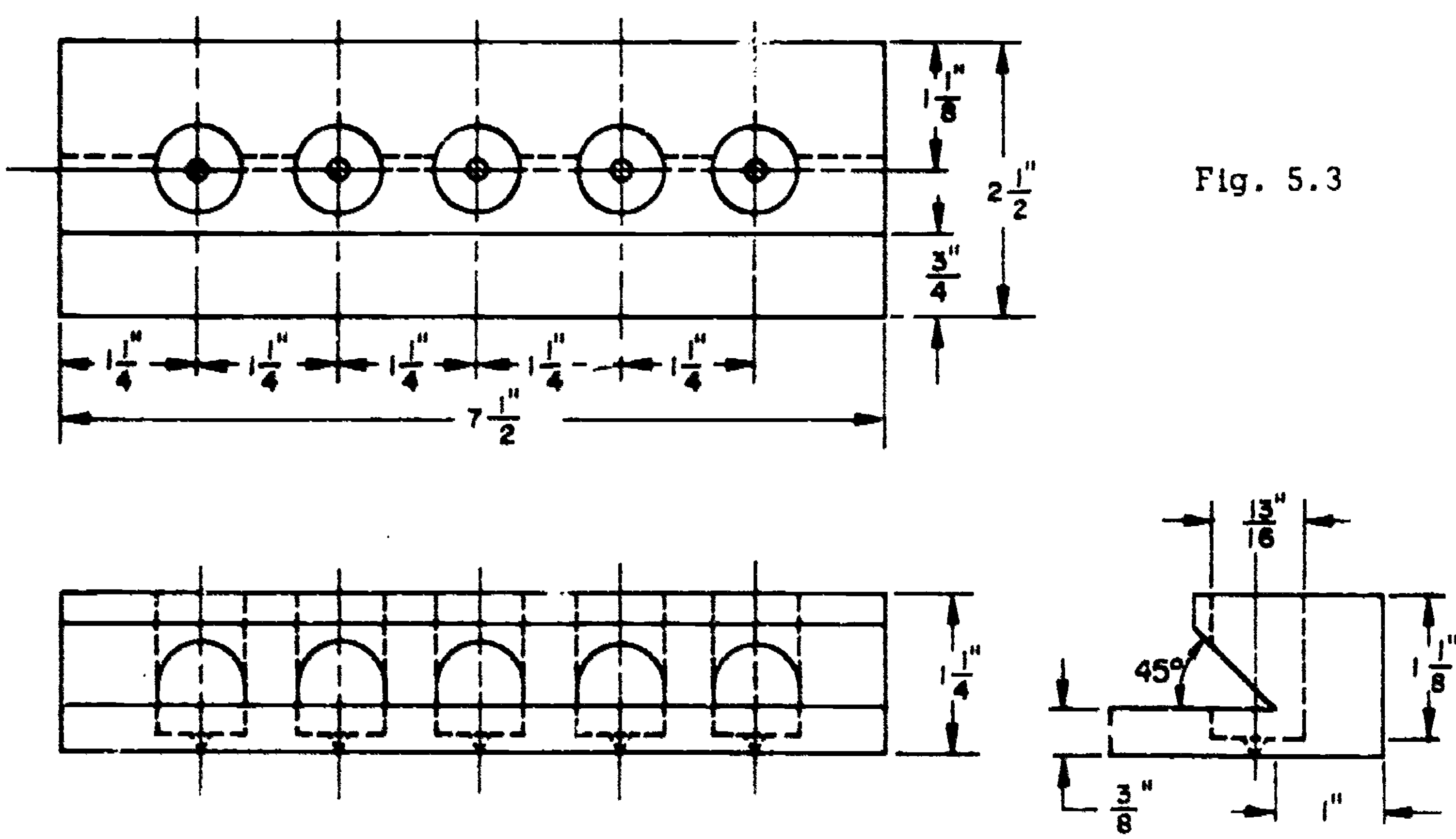


Fig. 5.3

o o o o o o o o

Project 6: A LAB CART

Your sixth project is to construct the piece of equipment shown in Fig. 6.1. This lab cart is used to investigate the relationship between force, mass, and acceleration. It consists of a piece of 2 × 4 with three wheels attached and a spring-loaded piston that can accelerate the cart. The mass of the cart can be changed, usually by stacking bricks on the top.

Fig. 6.1

6.1 Wood Screws

The only additional information you need to make the lab cart is the method used to fasten the wheels to the 2 × 4. In Project 1 we briefly discussed different types of wood fasteners. The method that is most appropriate here is the use of wood screws.

Two styles of wood screws are: round head (R.H.) and flat head (F.H.) (see Fig. 6.2). Their diameters range from a No. 2 up to a No. 24, with a selection of lengths for each diameter. The most commonly used diameters are between No. 4 and No. 10, roughly corresponding to the sizes of machine screws. Because the bottom of the head is flush with the surface, the length of a round-head screw is measured from the bottom of the head to the tip of the screw. The top of a flat-head screw is usually flush with the surface through which it is used; therefore, its length is measured from the top of the head to the bottom tip of the screw.

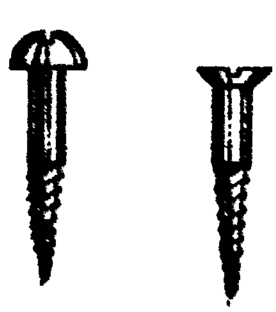


Fig. 6.2

There is no set rule for choosing the size of the screw to be used for any particular job. The sturdier a project must be — because of the weight or stress it must bear — the larger the diameter of the screw. If you want to attach a large machinist's vise to a bench top, you have to use a screw larger than a No. 6 or a No. 10. For building a book cabinet out of 1-inch pine, you might use a No. 8 or a No. 10 screw. If you are going to screw a lid on a box and the only reason for fastening the lid is to hold it in place, you might use a No. 4 or a No. 6.

Once the diameter is chosen, it is a simple matter to select the proper length. It should be equal to the thickness of the stock through which it passes plus 2-1/2 to 3 times the diameter of the screw. For example, if you were fastening a piece of 1 × 4 to the side of a 2 × 4 and used a No. 10 screw, the length of the screw should be about 1-3/4 inches. A feeling for selecting the proper size develops with experience. Table 6.1 lists sizes for wood screws.

To prepare two pieces of wood for fastening with wood screws, you must drill a hole in each of the boards. A clearance hole must be drilled through which the shaft of the screw will pass. An easy way to check what size drill to use is to try the screw in the holes of a drill gauge, which has holes made by drills of various sizes. The second board requires a pilot hole for the screw, which makes it easier to start the screw and prevents the wood from splitting. Figure 6.3 shows how to select the pilot-hole size for soft woods such as pine. Simply estimate the proper diameter by placing the drill in front of the screw. The drill should be just small enough so that the full thread of the screw will be embedded in the wood. For harder woods the pilot-hole size should be slightly larger, because hard woods have much more holding power and a greater tendency to split.

Fig. 6.3

TABLE 6.1

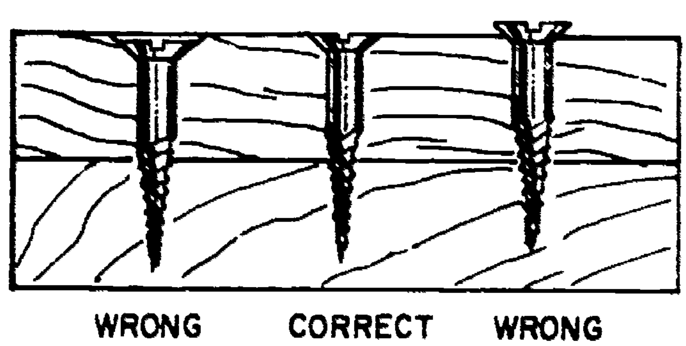
Length (inches)	Diameter of Screw															
	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#14	#16	#18	#20	#24
1/4	x	x	x	...	...	...	...	...	...	...	...	...	...	...	...	...
3/8	x	x	x	x	x	x	...	...	...	...	...	...	...	...	...	...
1/2	x	x	x	x	x	x	x	x	x	...	...	...	...	...	...	...
5/8	x	x	x	x	x	x	x	x	x	x	x	...	...	...	...	...
3/4	x	x	x	x	x	x	x	x	x	x	x	x	...	...	...	...
7/8	...	x	x	x	x	x	x	x	x	x	x	x	...	...	...	...
1	...	x	x	x	x	x	x	x	x	x	x	x	x	...	...	...
1-1/4	...	...	x	x	x	x	x	x	x	x	x	x	x	x	...	...
1-1/2	...	...	x	x	x	x	x	x	x	x	x	x	x	x	x	...
1-3/4	...	...	...	...	x	x	x	x	x	x	x	x	x	x	x	...
2	...	...	...	...	x	x	x	x	x	x	x	x	x	x	x	...
2-1/4	...	...	...	...	x	x	x	x	x	x	x	x	x	x	x	...
2-1/2	...	...	...	...	x	x	x	x	x	x	x	x	x	x	x	...
2-3/4	...	...	...	...	...	...	x	x	x	x	x	x	x	x	x	...
3	...	...	...	...	...	...	x	x	x	x	x	x	x	x	x	x
3-1/2	...	...	...	...	..	...	...	...	x	x	x	x	x	x	x	x
4	...	...	...	...	...	...	...	...	...	...	x	x	x	x	x	x
4-1/2	...	...	...	...	...	...	...	...	...	...	...	x	x	x	x	x
5	...	...	...	...	...	...	...	...	...	...	...	x	x	x	x	x

In the case of flat-head screws, a tool called a <u>countersink</u> (Fig. 6.4) is used after the clearance hole has been drilled. It is placed in the drill press and the depth stop set so that the resulting hole will accept the head

Fig. 6.4

of the screw, as depicted in Fig. 6.5. The speed of the drill press should be about half of the normal speed for the diameter hole produced by the countersink; otherwise, it will chatter leaving a rough finish. Countersinks are also made for use with a wood brace. The angles of countersinks differ; for most machine screws and wood screws the angle is 82 degrees.

Fig. 6.5



o o o o o o o o

Refer to the drawings in Fig. 6.6 and list in sequence the steps necessary to make the lab cart.

Why do you think a 1/4-inch wood screw is used to hold the skate wheels to the 2 × 4? Could you do it another way?

Assemble the lab cart as shown in Fig. 6.7.

o o o o o o o o

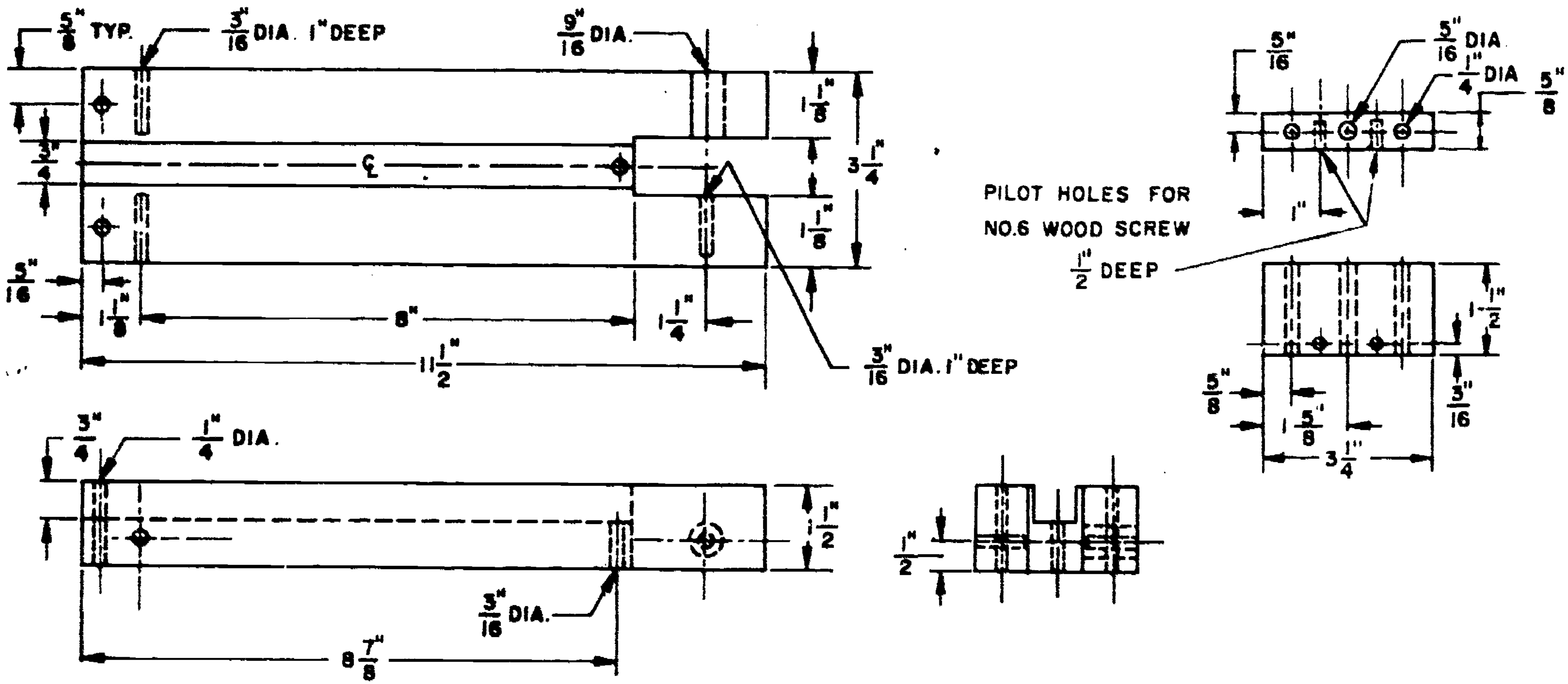
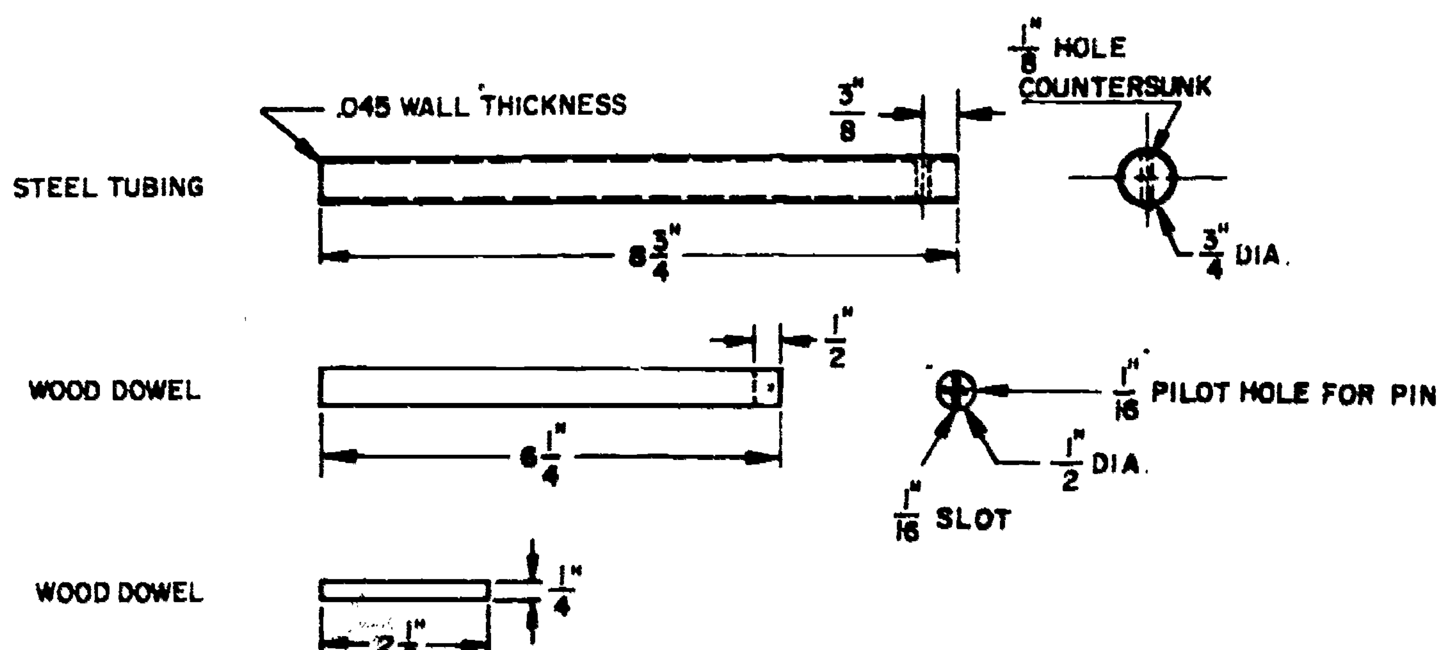
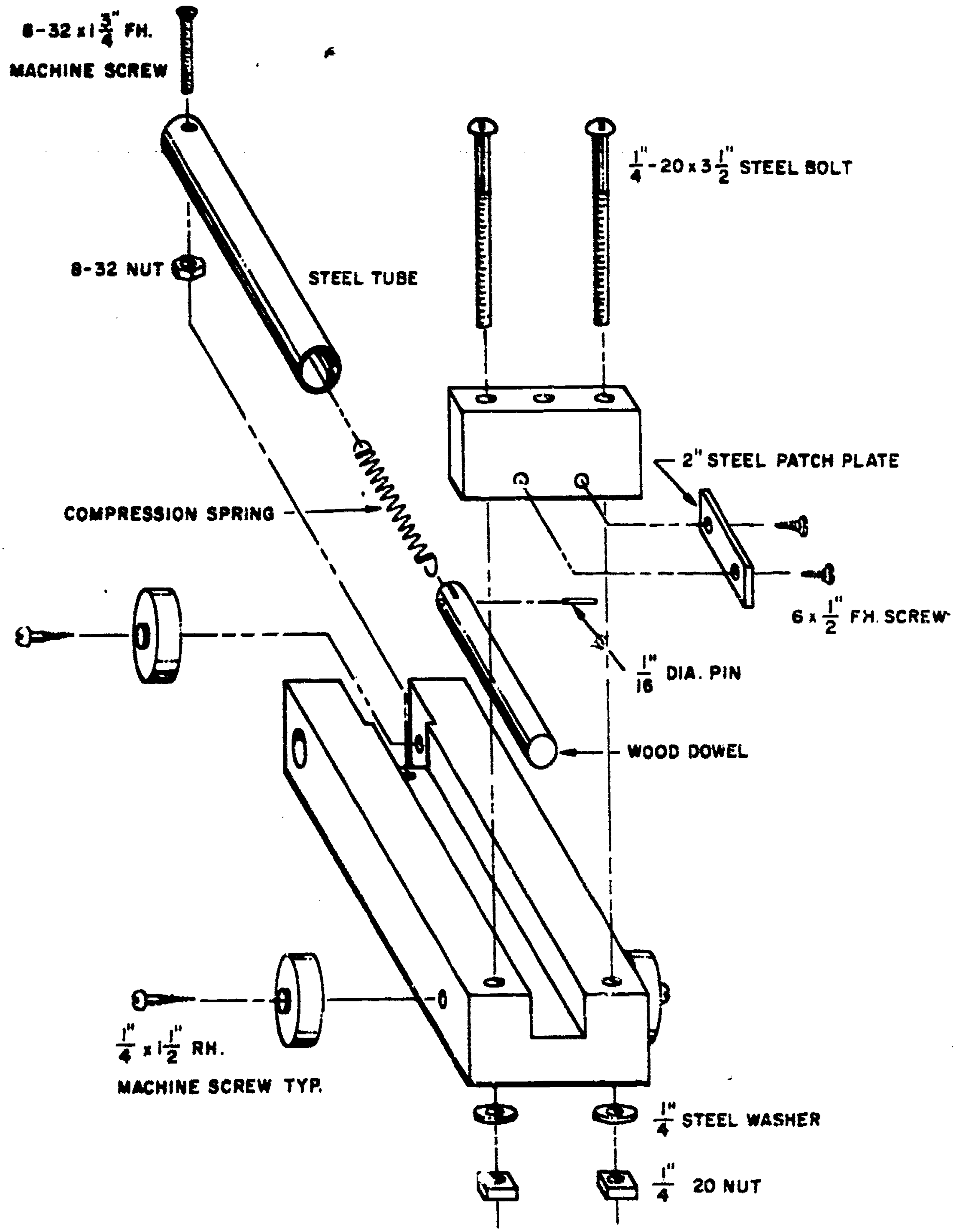

5/8" TYP.
3/16" DIA. 1" DEEP
9/16" DIA.
3/16" DIA. 1" DEEP
1/4" DIA.
3/16" DIA.
5/16" DIA
1/4" DIA
PILOT HOLES FOR
NO.6 WOOD SCREW
1/2" DEEP

Fig. 6.6


.045 WALL THICKNESS
STEEL TUBING
1/8" HOLE
COUNTERSUNK
3/4" DIA.
WOOD DOWEL
1/16" PILOT HOLE FOR PIN
1/2" DIA.
1/16" SLOT
WOOD DOWEL

- 81 -

Fig. 6.7



8-32 x 1 3/4" FH.
MACHINE SCREW
1/4"-20 x 3 1/2" STEEL BOLT
8-32 NUT
STEEL TUBE
2" STEEL PATCH PLATE
COMPRESSION SPRING
6 x 1/2" FH. SCREW
1/16" DIA. PIN
WOOD DOWEL
1/4" x 1 1/2" RH.
MACHINE SCREW TYP.
1/4" STEEL WASHER
1/4" 20 NUT

CIRCUITS

Until now you may never have built an electronic circuit because you thought electronics in general to be too complicated. Actually there are many circuits that require only a few basic skills in order to build and test them. Mastering these skills is the principal aim of the next three projects.

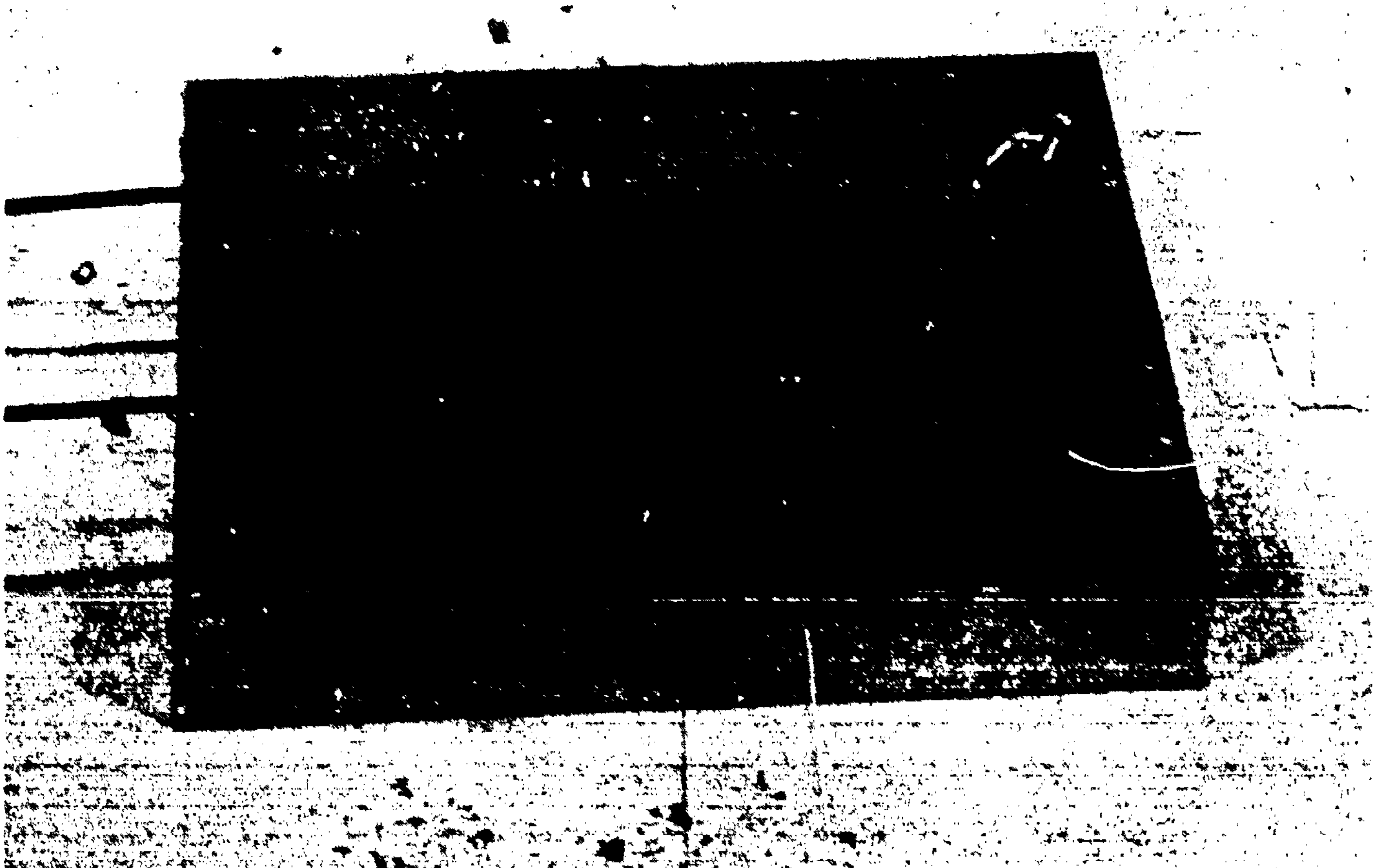
Suppose you come across a useful circuit in a scientific journal, a magazine, or a textbook. First you must be able to read the circuit diagram and to identify the various components. The next step is to lay out the parts and then to solder them together as indicated in the circuit diagram. The final step, of course, is to test to see if the circuit works. Each of these steps, especially the last, can become quite complicated for a sophisticated circuit; however there are many circuits that you will be capable of building.

In other parts of this book, the quality of your work depends on the accuracy to which you made a piece of equipment and its appearance to the eye. In building an electronic circuit it is nice to have the circuit look neat but the placement of the components is not the crucial factor. The important point is: Does it work?

Project 7: NEON BLINKER

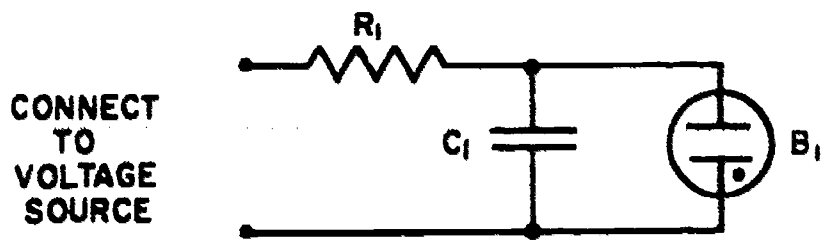
We begin this project with the very simple but practical circuit shown in Fig. 7.1. The cylindrical glass tube in the right-hand side of the photograph is a neon bulb, which can be made to flash at a steady rate determined by the other two components. The two leads on the left are connected to a voltage source. Because the bulb blinks on and off at a constant rate, this circuit can be used as a timing device — especially for a photographic study of motion. In an actual application, of course, the components are wired together more compactly to suit the experiment.

Fig. 7.1



Usually you will not be given a photograph of a circuit; rather, you must work from a circuit diagram and a list of components (Fig. 7.2). It is then up to you to assemble the components into a working circuit.

Fig. 7.2



Resistor R_1 — 470 kΩ ±10% 1/2-watt carbon
Capacitor C_1 — 0.1 microfarad 200 V paper
Neon bulb B_1 — NE-2H 1/4 watt

The circuit diagram is a schematic and only tells you which components are connected to which. Their final placement and how they are interconnected are determined by a host of factors, such as the size and the shape of each component, and by the way in which the circuit will be used. When testing a circuit to see how it works and how it might be improved, the components are spaced far apart and the connections are made so that they can easily be changed. This construction is referred to by the term breadboard. After a circuit is ready for use, the final layout is determined by considerations of size, mechanical rigidity, and the electrical interaction of various components.

For this project you will use a thin phenolic sheet (see Fig. 7.3). Special metal pins are inserted in the holes and serve as tie points for wires and components. Because the pins can be positioned wherever you like, this material is ideal for breadboard circuits. In many cases, the final circuit can later be placed in a protective box to make a finished product.

Fig. 7.3

7.1 Resistors

Probably the most common of all circuit elements is the resistor, which is denoted in circuit diagrams by the symbol —/\/\/\—. The voltage V measured across a resistor is proportional to the current I through it. This is usually written symbolically as

$$V = IR$$

and is referred to as Ohm's law. The factor R is the resistance of the component and is given in ohms (Ω). It is this linear relationship between the current and the voltage that distinguishes resistors from other components. For many other components, such as diodes and neon bulbs, a direct relationship also exists between the current and voltage; but doubling the current for these components does not necessarily lead to a doubling of the voltage. Since this relationship is not linear it cannot be expressed simply but must be looked at in detail. For commercial resistors the values of resistance range from fractional parts of an ohm to several millions of ohms. For some the resistance value is stamped on the component, whereas the value for others is given by a color code.

Several types of resistors are shown in Fig. 7.4. The size variations are due principally to their power rating; that is, their ability to dissipate heat. The two resistors on the left are made from resistive wire and are generally used when a high-power rating is needed. Those on the right, by far the most common and least expensive, are made from a substance containing carbon. The power ratings for carbon resistors go from 1/10 watt to 2 watts. In contrast, the wire-wound resistors in Fig. 7.4 are 25 watts and 10 watts respectively.

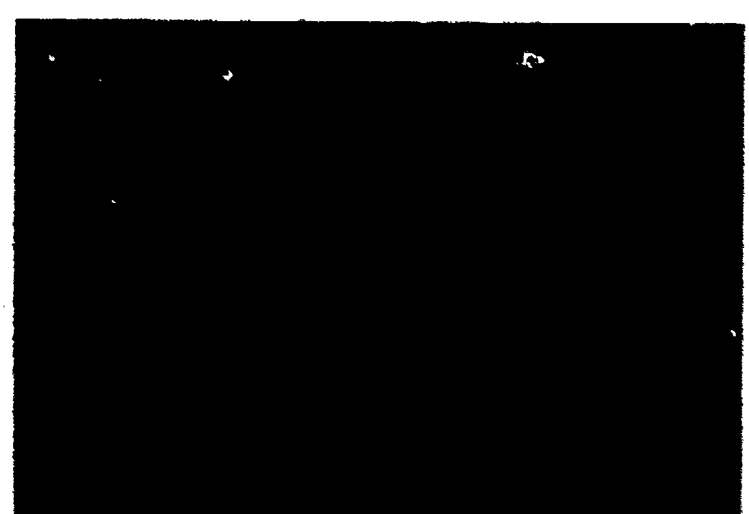


Fig. 7.4

When the color code is used to designate the resistance, the value is expressed by two digits and a decimal multiplier.

Thus, a 560,000 Ω resistor is encoded to give the two digits 5 and 6 and the multiplier 10^4. Table 7.1 provides a list of the colors and what each indicates.

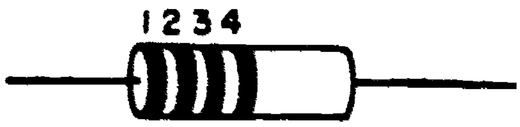


TABLE 7.1

Color	Number	Decimal Multiplier	Tolerance
Black	0	10^0	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Gold	—	10^{-1}	± 5%
Silver	—	10^{-2}	±10%
No color	—	—	±20%

The code uses four colored bands with the first band positioned at one end of the resistor. The first two bands give the digits; that is, green and blue for the example in the preceding paragraph. The third band gives the decimal multiplier; for 10^4 the color is yellow. If the value of the resistance were ten times larger or smaller than 560,000 Ω, the colors of the first two bands would remain the same colors and only the third band would change. The fourth band gives the tolerance of the resistance value. Therefore, a silver fourth band means that a resistor marked 220,000 Ω actually might deviate from this value by as much as 2200 Ω. We shall not be concerned with the significance of any additional bands that are sometimes found on resistors.

It is usually no problem to determine which of the bands is the first, since the code begins at one end of the resistor, as shown in Table 7.1.

However, for some resistors that are small in size the colored bands extend from one end to the other. Because the tolerance band is always the fourth band and is either silver or gold, you can determine in which direction the code is read.

o o o o o o o

What is the color code for the resistor used in Fig. 7.2 ?

o o o o o o o o

As you might imagine, resistors are not available in every value. However, for each power-of-ten there are approximately 25 resistance values; that is, there are 25 resistors with values between 10 Ω and 100 Ω, or between 100 Ω and 1000 Ω, and so on. Generally, one does not need a precise value; but for the few applications where it is necessary, you can wire together several resistors to give the needed value or you can use a <u>potentiometer</u>, a device whose resistance can be varied.

Several types of potentiometers are shown in Fig. 7.5, and the principle of their construction can be seen in the two on the left: A resistor, which in this case is made of wire, has an additional sliding contact that can be positioned anywhere along the resistor. The symbol for a potentiometer is  , the arrowhead denoting the sliding contact. The resistance between the sliding contact and either end depends on the position of the contact and can be varied from zero ohms to the full resistance of the wire. The resistance from one end to the other remains fixed, of course.

The other potentiometers shown in Fig. 7.5 are variations on this design. Some are made of carbon or other resistive material, and some are miniature. The last on the right, called a <u>ten-turn potentiometer</u>, has the resistance wire wrapped in the form of a ten-turn helix.

Fig. 7.5

Because their resistance can be varied, potentiometers are found in many circuits in which some property must be changed; for example, the volume control for a radio or a television.

Generally, potentiometers are larger in size, and a good deal more expensive, than carbon resistors. Therefore, they are used only when necessary — not as a replacement for an ordinary carbon resistor.

7.2 Capacitors

Capacitors also come in many sizes, shapes, and types. In their most elementary form capacitors, symbolized by —|├— , are two conductors separated by insulating materials such as paper, plastic, mica, or even air. The conductors — or plates — can be charged, and the capacitance of each unit is a measure of the amount of charge for a particular charging voltage. The larger the capacitance C the larger the charge Q at a fixed voltage V; that is, $Q = CV$. The unit of capacitance is a farad (1 farad = 1 coulomb/volt); but, in practice, a microfarad (10^{-6} farad) is more commonly used.

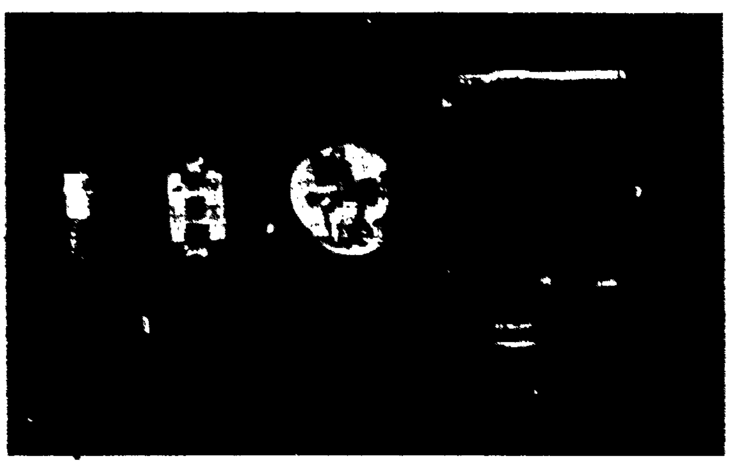


Fig. 7.6

Most capacitors have a fixed value of capacitance, but for some the capacitance can be varied by moving one set of plates relative to the other (see Fig. 7.6). Most of these have low capacitance (10^{-12} farad to 10^{-9} farad) and are used to tune circuits to particular frequencies.

For fixed capacitors the available range is from about 10^{-12} farad (1 picofarad) to several thousand microfarads. These larger values are usually attained by using a chemical film as the insulator. They are called electrolytic capacitors and have the advantage of a large capacitance in a small volume. There is a disadvantage, however; a voltage can only be applied to them in one way. The terminal marked "+" (Fig. 7.7) must always be at a higher voltage than the other terminal. If not, the insulation can be ruined.

Fig. 7.7

The information you need to know is printed on each unit. For an electrolytic capacitor, in addition to its polarity and capacitance being noted, a number followed by WVDC is marked. This number is the maximum working DC voltage the unit can withstand and not be ruined.

7.3 Soldering and Construction

If you are given a circuit diagram and the parts necessary to make it, there is really only one skill that is absolutely essential to get the circuit working: You must know how to make a good solder joint. Knowing the theory behind a particular circuit design is not essential in order to construct circuits. With a few tools and a knowledge of how to solder, you can use someone else's circuit, get it working, and then gradually come to understand its design. Fortunately, the list of needed tools and supplies is not very long: two types of small pliers (needle-nose and diagonal-cutting), a wire stripper, a small screwdriver, a 40-watt soldering iron and a file to clean it, rosin-core solder (60 percent tin and 40 percent lead), and several spools of hook-up wire (No. 24 gauge).

After you have decided where to place the components and have inserted the pins you will need for the wiring (see Fig. 7.3), you can begin to solder the components together. As a general rule, solid, insulated wire is used for wiring a circuit, but for cases in which the wire frequently will be bent or flexed it is advisable to use stranded wire. Solid wire is easier to install but cracks if it is bent too often; stranded wire does not. Both types are easily cut with diagonal-cutting pliers. A wire stripper (Fig. 7.8), which can be set for different wire diameters, is used to remove the insulation without cutting the wire strands.

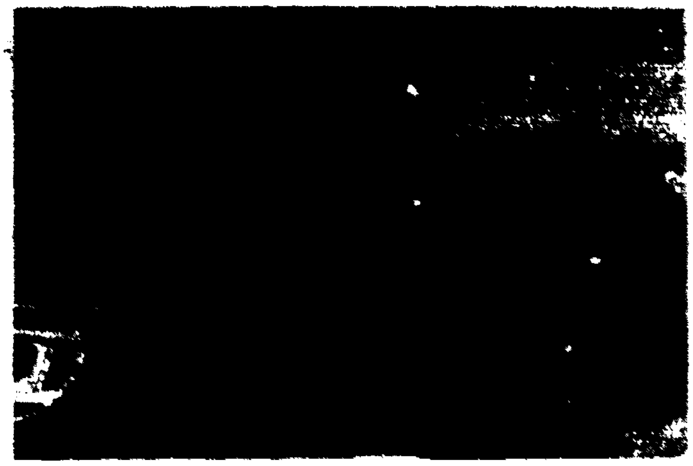


Fig. 7.8

The key to making a good solder joint is to ensure that all the metal parts are hot enough to melt the solder. If they are not, molten solder will solidify on the cooler metal without making a good bond. Initially it may appear to be all right, but sometime in the future the contact may go bad and will be very difficult to locate. However, there is another consideration — too much heat can ruin the components.

To guarantee a good solder joint, a light coating of solder is applied to each of the pieces before they are connected together. This accomplishes two things: Some of the solder for the joint is already where it is needed; but, more importantly, the solder as it melts helps to conduct the heat so that the joint is completed before the components have a chance to heat up. This coating process, called tinning, is recommended for components and hookup wires alike but especially for stranded wire, since it holds all the small strands together. (The pins are pre-tinned by the manufacturer, and so they can be used as is.)

The soldering-iron itself must be tinned before use. The tip is made of copper, and it will oxidize and become difficult to use unless it is tinned. If the tip is in poor shape, it can be cleaned and reshaped with a file. The iron is then heated and solder is quickly applied to the tip before an oxide coating forms.

The pins inserted in the perforated breadboard are ideal for making solder connections. Each wire or component lead is secured to the pin and then soldered together. (If there are too many wires for a single pin, you can

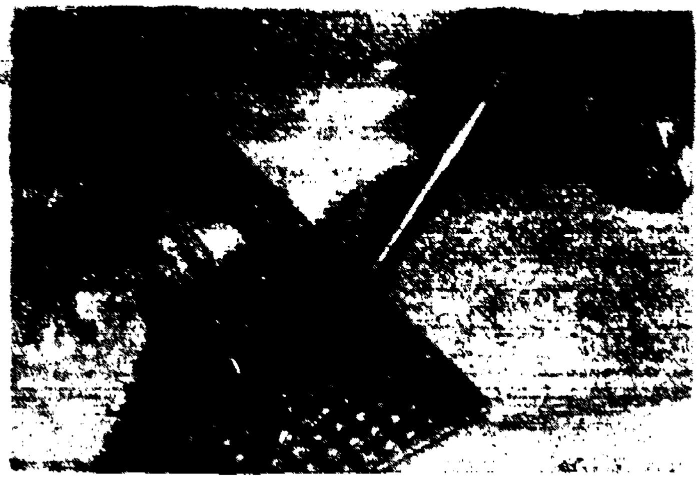


Fig. 7.9

use several pins and interconnect them.) To make the solder joint place the hot iron against a pin as shown in Fig. 7.9 and apply a little solder where they touch. This serves to increase the heat flow between the iron and the pin. (You may also apply an extra bit of solder to the iron before touching the pin.) Now touch some solder to the pin and wires, but not at the point where the iron touches the pin. When the wires and pin are hot enough, the solder will melt and flow over them. Add a bit more solder, but do not overdo it; you just need enough to coat all the surfaces. When you see that the solder has flowed everywhere in the joint remove the iron and let the solder cool. Do not blow on it. With a little practice it is a simple matter to make consistently good solder connections.

When breadboarding a circuit you may want to change components or even remove them later for use in another circuit. Leave plenty of room between components, and do not cut their leads too short. If wires and leads are twisted together before soldering, they are very difficult to unsolder. Twisting is unnecessary if you use soldering pins, which are designed to hold the wires securely. Keep in mind that solder joints are used for electrical connections and not for mechanical rigidity, which the soldering pins provide.

7.4 Neon Bulb

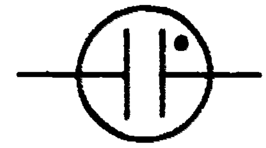


Fig. 7.10

A neon bulb is a small glass bulb, filled with neon gas, in which two electrodes are placed side by side, separated by a distance of about one millimeter. The dot in a circuit symbol for a neon bulb (see Fig. 7.10) indicates a gas-filled tube. For low voltages across its terminals, the bulb acts as an open circuit; that is, there is no current through the bulb. However, when the voltage across the bulb is in the range of 100 V, the neon gas begins to conduct, there is current between the electrodes, and the bulb glows. If the voltage across the glowing bulb is then lowered, the current does not stop immediately but continues until a somewhat lower voltage is reached. For example, a bulb that has a breakdown voltage of 105 V will stay lit until the applied voltage drops to its turnoff voltage of 85 V. As you shall see, it is this property of neon bulbs that makes a blinker work.

Neon bulbs are commonly used as pilot lights since they require very little power — they range from 1/25 watt to 1/3 watt. The disadvantage, of course, is in the voltage needed to operate one.

One word of caution: A neon bulb, if connected to a high-voltage source, will probably draw too much current and burn out. Use them in series with a suitable resistor, usually one with a resistance greater than 50,000 Ω.

o o o o o o o o

Obtain the circuit components, the breadboard, the hookup wire, and the tools required to assemble the neon flasher shown in Fig. 7.2. When the assembly is completed, connect it to a DC voltage source of about 125 V and see if it operates. If possible, vary the source voltage and note how the operation of the circuit changes.

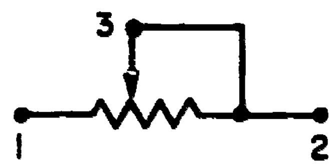
o o o o o o o o

The rate at which the bulb blinks can be varied by changing the values of both the resistor and the capacitor. To see the effect of each, change only one component at a time.

o o o o o o o o

1. Replace the capacitor with one that has a capacitance either ten times larger or smaller than the present one. What change does this make in the rate of blinking?

2. For a fixed value of the capacitance, vary the resistance in the circuit by putting a one-megohm (10^6 Ω) potentiometer in series with the 470 kΩ resistor now in the circuit. Use an ohmmeter to determine which of the three terminals on the potentiometer is the sliding contact. By connecting the sliding contact to one end (as shown), you can vary the resistance between points 1 and 2 from zero ohms to a megohm. How does the rate of blinking vary as the resistance is increased? Decreased?

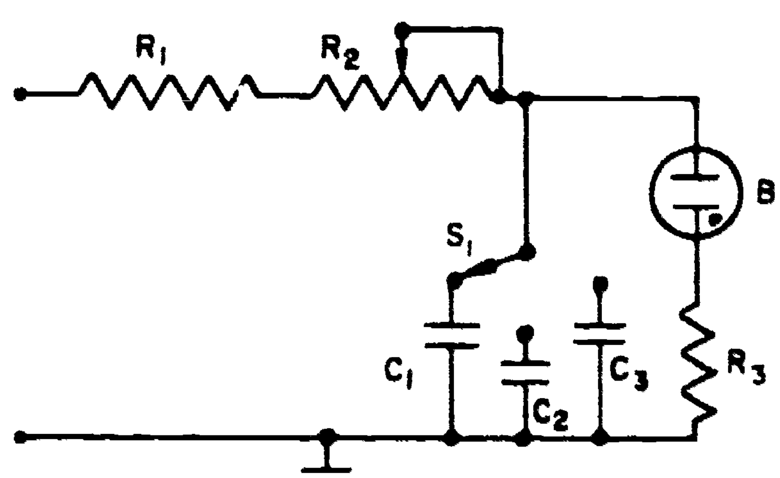


7.5 Variable Neon Blinker

A neon blinker with a fixed blinking rate may be adequate for some applications, but with a few changes the basic circuit can be altered to cover a range of blinking rates. The circuit (Fig. 7.11) incorporates a variable resistor and a switch that selects one of three capacitors. The specifications call for a three-position switch; but most likely you will have to adjust a switch that has many more positions. When the switch is assembled a small metal stop sets the number of possible positions – usually anywhere from one to twelve. If your switch is not properly adjusted, reset the stop for three positions.

Fig. 7.11

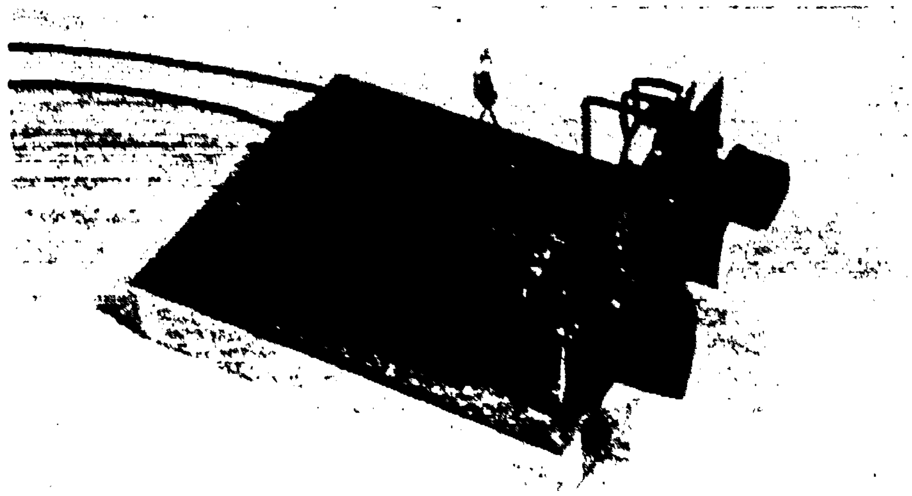
R_1 – 470 kΩ ±10% 1/2-watt carbon
R_2 – 1-megohm variable resistor
R_3 – 100 Ω ±10% 1/2-watt carbon
C_1 – 1 microfarad 200 V paper
C_2 – 0.1 microfarad 200 V paper
C_3 – 0.01 microfarad 200 V paper
S_1-1 Rotary switch – 1 section, 1 pole, 3 position
B_1 – NE-2H 1/4 watt neon



o o o o o o o o

Use an ohmmeter to find the common terminal and the three active terminals for the switch you will use. Assemble the circuit in a way similar to that shown in Fig. 7.12. Remember that you may place the parts anywhere you wish as long as the connections are as shown in the circuit diagram (Fig. 7.11).

Fig. 7.12



o o o o o o o o

For this circuit (Fig. 7.11) the blinking rate can be made to be so rapid that the eye cannot follow it and an oscilloscope* is needed to measure it. Because an oscilloscope measures voltage and not current, the 100 Ω resistor R_3 was placed in series with the neon bulb to monitor the current. The voltage across R_3 is proportional to the current _I_.

Because the circuit must be connected to a power supply and because both the oscilloscope and the power supply are interconnected electrically through the laboratory power line, it is important that the leads between R_3 and the oscilloscope be placed correctly. On both the power supply and the oscilloscope one terminal is marked as "ground." The symbol for "ground" is ⏚, and in Fig. 7.11 this is the common connection at the bottom of the circuit diagram. Be sure that the ground terminal of each of the two instruments is connected here.

*If you are unfamiliar with the operation of an oscilloscope, refer to Appendix 3.

o o o o o o o o

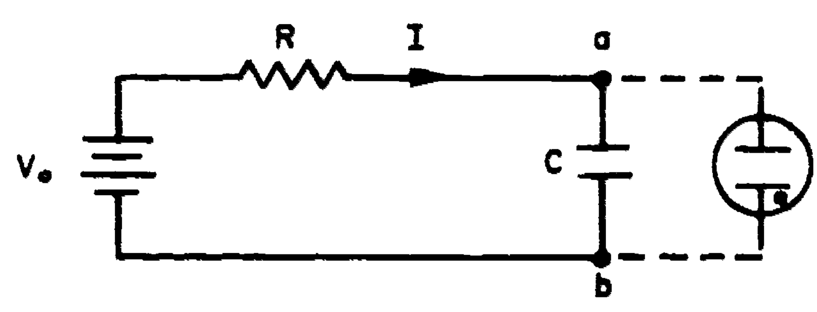
Use an oscilloscope to monitor the current in the resistor R_3. What does the current do as the bulb flashes? What is the range of frequencies through which the flasher will operate? Are all frequencies in this range covered? If not, what changes could you make in the circuit to span the range?

o o o o o o o o

7.6 An Analysis of the Neon Blinker

In its simplest form the blinker circuit consists of a voltage source, a resistor, a capacitor, and a neon bulb in parallel with the capacitor. When the voltage source is connected, charge flows. During this part of the cycle, as the capacitor is being charged, the neon bulb has no effect because it acts as an open circuit, which is why it was drawn with dashed lines in Fig. 7.13. The voltage across it — between points a and b — builds up toward the maximum value V_0, the voltage of the source. Of course, after the capacitor is fully charged the current drops to zero. The time needed for charging depends on the values of the capacitance and the resistance. The larger these values, the longer the time needed for changing.

Fig. 7.13

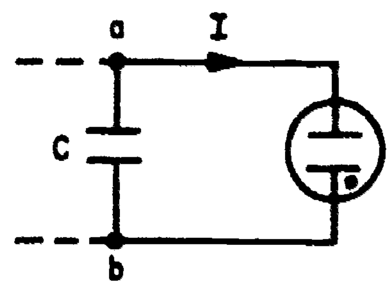


Now, if V_0 is greater than the breakdown voltage V_1 of the neon bulb,* the capacitor will never become fully charged, For, as soon as the voltage across C reaches V_1, the neon bulb conducts, becoming a short circuit, and the capacitor discharges through it. At that point the circuit is

*See Section 7.4.

essentially just the capacitor and the bulb (see Fig. 7.14). The discharge continues until the voltage across the capacitor drops to V_2, the turnoff voltage for the bulb. As long as V_2 is less than V_1 the process will repeat itself — charging to V_1 and discharging to V_2.

Fig. 7.14



The cycle repeats itself in a steady fashion as long as the values of R, C, and V_0 remain fixed. If V_0 is increased, the blinking rate increases because V_1 is reached in a shorter time. On the other hand, increasing the value of either R or C will decrease the rate.

Project 8: ELECTRONIC POWER SUPPLY

Most electronic circuits require a DC voltage source for their operation. Batteries can be used for many circuits and have the advantage of making the equipment portable, but they have the obvious disadvantage of needing to be replaced because of both use and age. An alternative is to use a power supply that operates on the local AC line voltage and provides a suitable DC voltage.

Power supplies can be found in televisions and radios and in most test equipment found in the laboratory. For this project you will construct a power supply (Fig. 8.1) that will be used to power the circuits in Project 9. Since the output provides both a positive and a negative voltage of about 9 volts each, the supply is called bipolar.

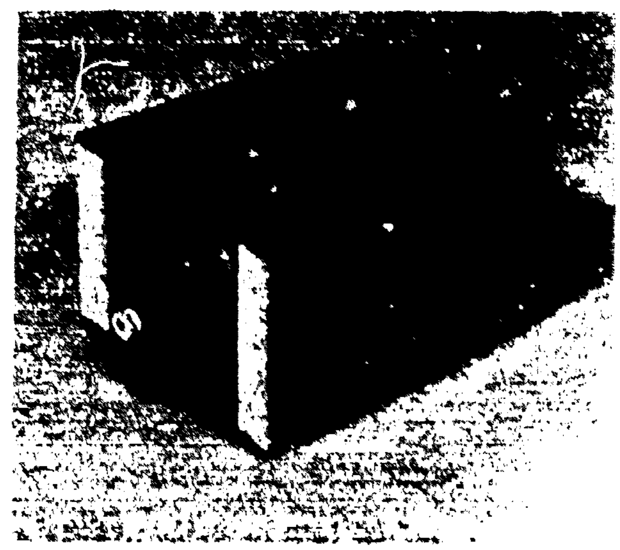


Fig. 8.1

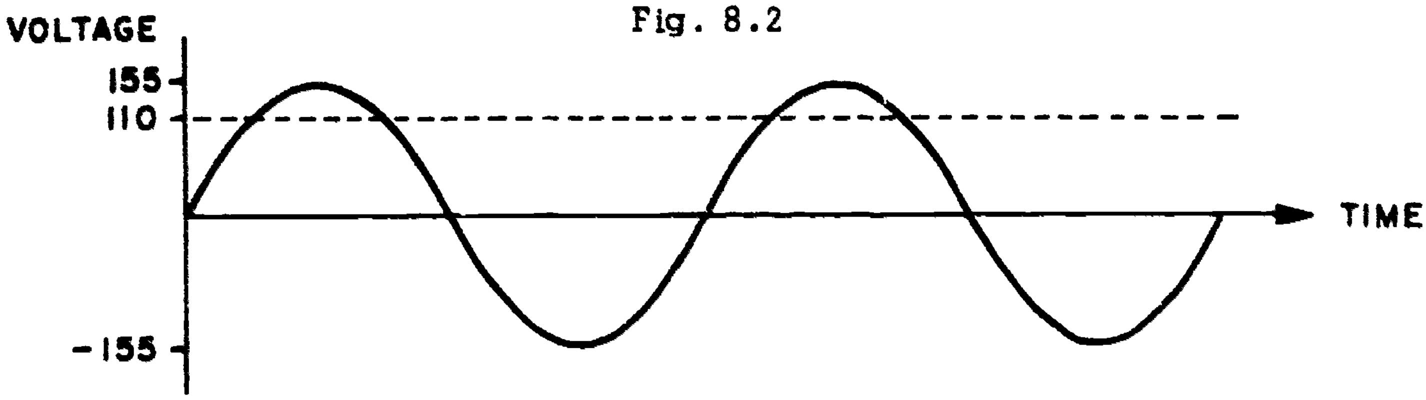
While this particular power supply has its own operating characteristics, the basic ideas behind its design are universal: To convert from AC to DC first requires a device to change the 110 volt AC line signal to whatever voltage level is needed. (In our case we need a reduction by about a factor of 10. An increase by a factor of 100 may be required in a television.) Next, a switch is needed to block or to change some of the AC signal, giving a voltage that still varies with time but one that has a DC component. Since an AC voltage is positive for as much time as it is negative, it has no DC component. Anything that changes this symmetry and makes the voltage more positive — or more negative — gives a net voltage in one direction.

The third step in the conversion from AC to DC is to eliminate the part of the voltage that changes with time, thereby leaving just the DC component. The simple filter in this circuit eliminates most of the voltage that varies with time.

8.1 Transformers

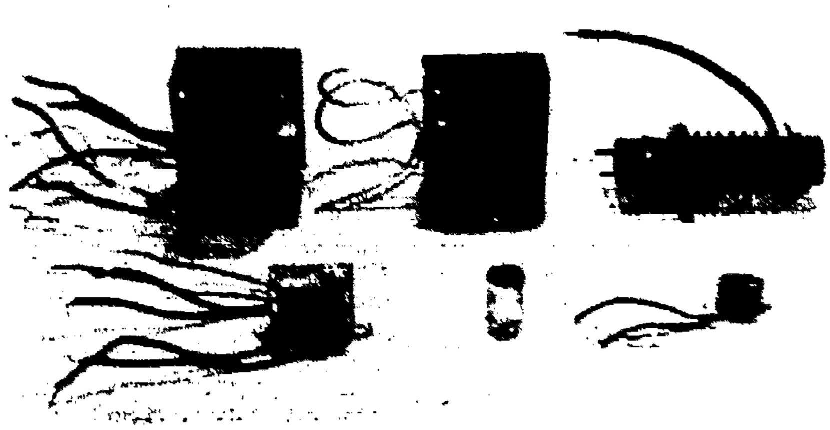
The line voltage — usually referred to as 110 volts, 60 cycle — is an alternating voltage that various sinusoidally with time and has a maximum voltage of approximately 155 V and a frequency of 60 Hz. This voltage, displayed as a function of time, is illustrated in Fig. 8.2. For most applications a voltage of this magnitude is either too large or too small for use in a circuit, and a transformer is used to change its level.

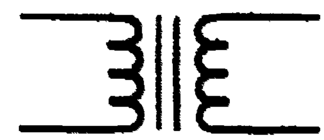
Fig. 8.2



A number of transformers are shown in Fig. 8.3, but not all of them are for use at 110 V AC. Basically, a transformer consists of two coils of wire that are coupled magnetically. As the voltage varies sinusoidally in one, a voltage is induced in the other. If the coils are identical, the induced voltage will be the same as the applied voltage. However, if a transformer has a different number of turns of wire for each coil, the induced voltage will be either larger or smaller than the applied voltage and, accordingly, it is called a step-up transformer or a step-down transformer.

Fig. 8.3

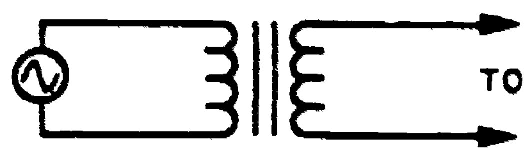




The symbol for a transformer appears at the right. It represents the two coils and the core on which they are wound. The coil for the applied voltages is called the primary winding, or simply the primary. The induced voltage then appears across the secondary. Some transformers have several secondary windings, which make it possible to build power supplies with more than one output voltage.

o o o o o o o o

Use a signal generator to test the transformer used in this project. Apply a 60 Hz voltage to the primary and check the voltage at the secondary. Is there more than one voltage available? How does the secondary voltage change as you vary the amplitude of the input voltage?



o o o o o o o o

8.2 Diodes

The switch, which is used to convert AC to DC in this project, is a voltage-sensitive device called a diode, symbolized by  (Various types are shown in Fig. 8.4.)

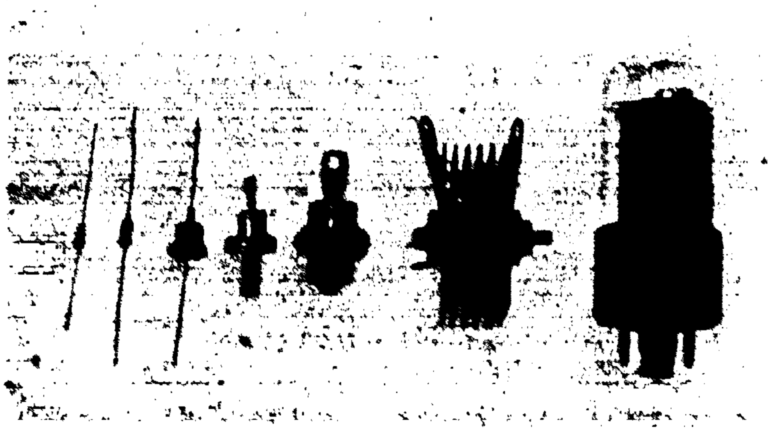
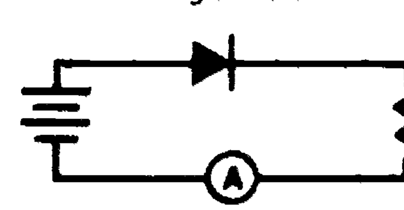


Fig. 8.4

When a diode is placed in a circuit, as shown in Fig. 8.5, a current is observed on the ammeter; but, with the battery reversed, the ammeter reads zero. If instead of the battery, an alternating voltage were applied to the circuit, there would only be a current during each half cycle when the voltage is positive. Therefore, the resulting voltage across the resistor would look like half a sine wave.

Fig. 8.5

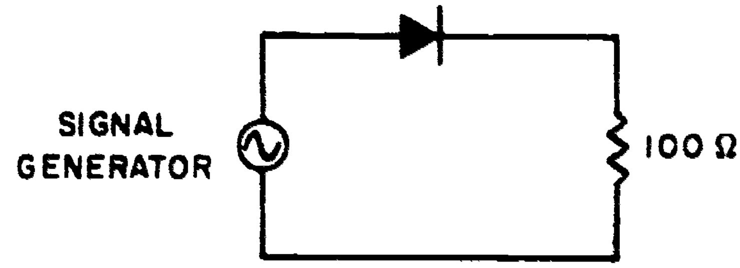


o o o o o o o o

Using a signal generator set at 60 Hz, wire up the circuit shown in Fig. 8.6 and sketch the voltage observed across the resistor. How does it change as you change the value of the input voltage?

o o o o o o o o

Fig. 8.6

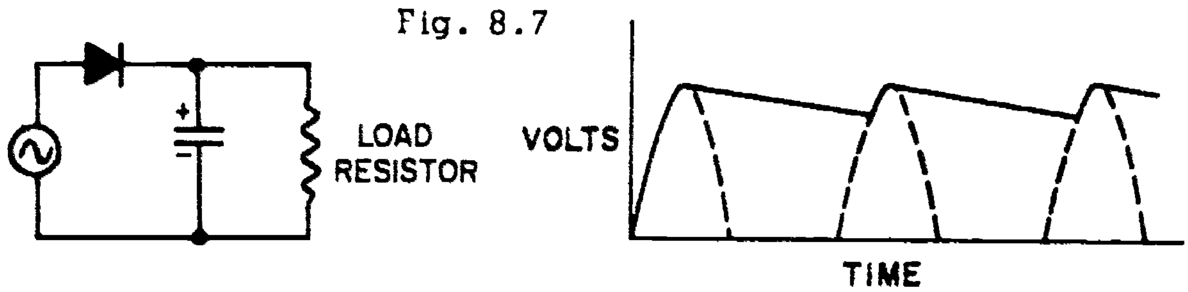


8.3 Filtering

Changing an alternating voltage to one that is only positive – or only negative – is called rectification. The rectified voltage you observed in the last section is said to be half-wave rectified.

The next step is to smooth out this half-wave signal to give a voltage that more nearly approximates a steady DC voltage. This is accomplished most simply by putting an electrolytic capacitor across the resistor, as shown in Fig. 8.7. As you can see from this sketch of output voltage versus time,

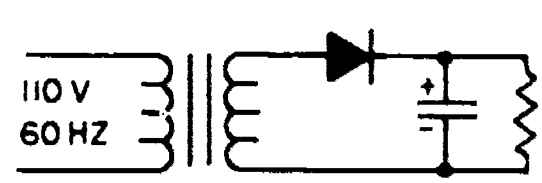
Fig. 8.7



the capacitor keeps the voltage quite steady and only permits it to drop slowly. The rate at which it drops between cycles is determined by the factor RC, and so a larger capacitor means a steadier voltage. The small fluctuations in voltage that still remain are called ripple.

Figure 8.8 shows a half-wave rectifier consisting of a power transformer, a diode, a load resistor, and a filter capacitor.

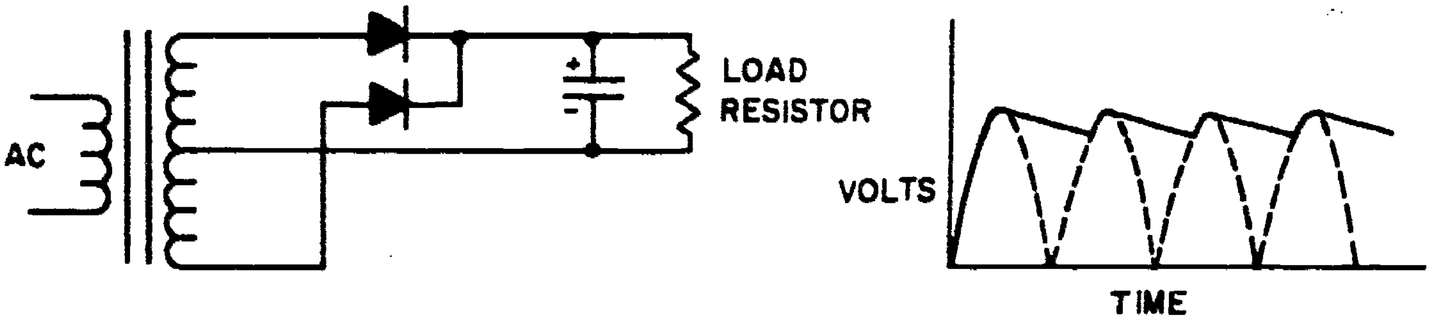
Fig. 8.8



8.4 Full-Wave Rectification

By using two diodes it is possible to make a full-wave rectifier that operates during both halves of the AC cycle. The transformer has a tap at the center of the secondary winding so that one end of the secondary is positive and the other end is negative with respect to this center tap. The circuit diagram for this full-wave rectifier and both the unfiltered and filtered outputs are illustrated in Fig. 8.9. In operation the two diodes always pass current in the same direction but work alternately. Note that since the time between voltage "bumps" is half what it was before, there is less fluctuation in the output voltage.

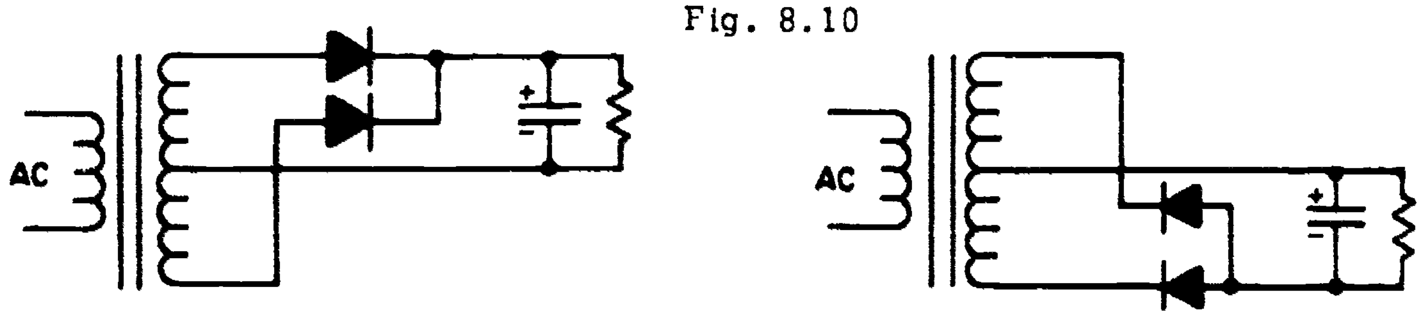
Fig. 8.9



8.5 A Bipolar Power Supply

Many electronic devices require both positive and negative voltages, and so the bipolar power supply you will build combines two full-wave rectifier circuits as diagramed in Fig. 8.10.* The same transformer can be used

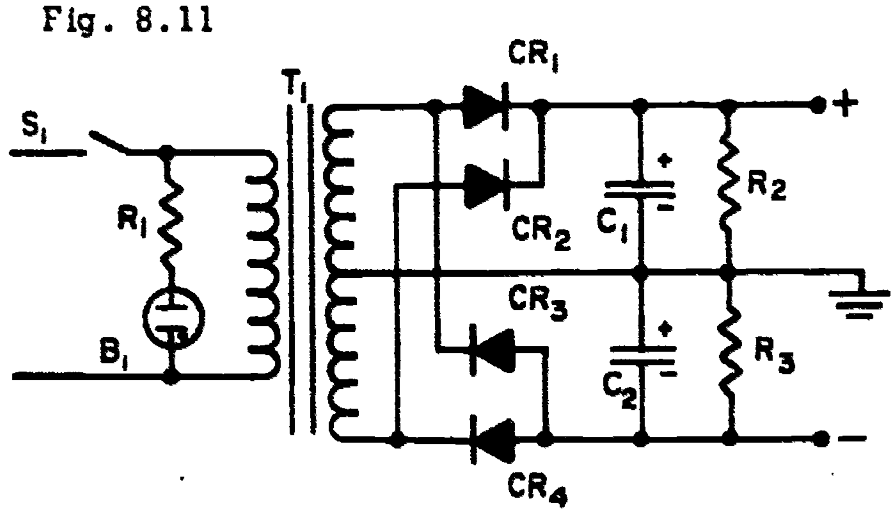
Fig. 8.10



*When two wires cross in a circuit diagram we must designate whether or not they are connected. A dot indicates that a connection is made between the two wires.

for each supply, and the complete circuit (shown in Fig. 8.11) includes an on-off switch and a neon pilot light in the primary circuit.

Fig. 8.11



R_1 – 100 kΩ 10% 1/2-watt carbon
R_2, R_3 – 10 kΩ 10% 1/2-watt carbon
C_1, C_2 – 1000 μf 25 V electrolytic
T_1 – filament, 117 V primary, 12.6 V center-tap secondary
CR_1, CR_2, CR_3, CR_4 – 1N3193 diode
B_1 – NE-2H 1/4-watt neon
S_1 – single pole-single throw switch

The components for this circuit – especially the transformer – are bulky, and some planning should go into how they will be mounted. A simple mounting assembly can be made by using a wooden base with a narrow sawcut across it. The size of the sawcut should provide a snug fit for the perforated board (see Fig. 8.12). Four rubber feet keep the wooden base from touching the table.

Fig. 8.12

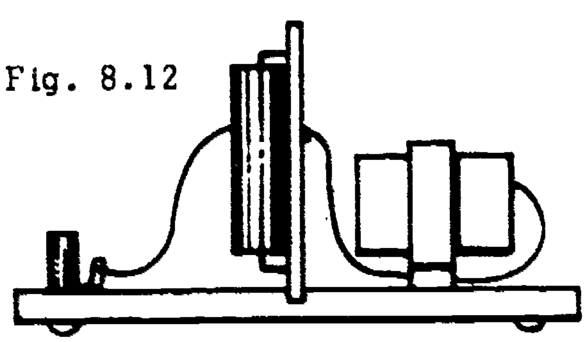


Figure 8.13 shows a possible construction of a permanent case for the power supply. (The top and the side have been removed to show the interior layout.) Solid Masonite, perforated Masonite, and slotted boards are used for the construction.

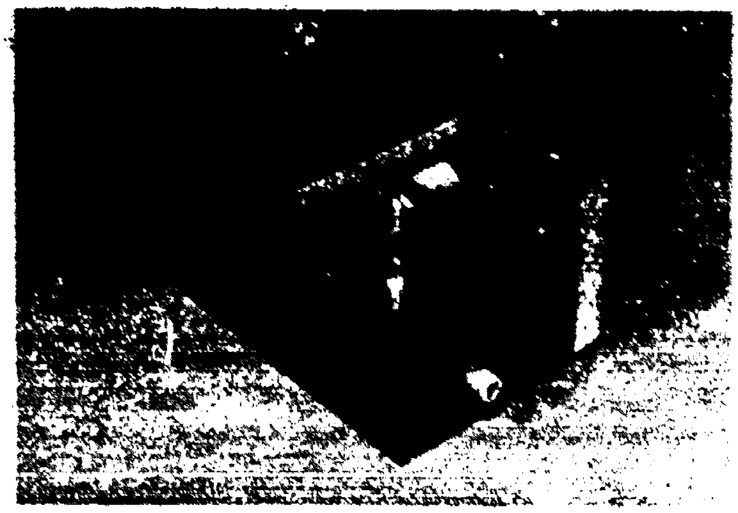


Fig. 8.13

o o o o o o o o

Obtain the parts and the circuit board and assemble the power supply according to the circuit diagram shown in Fig. 8.11.

The resistors R_2 and R_3 discharge the capacitors when the circuit is turned off. They are called bleeder resistors and have only a small current in them.

When the power supply is completed, turn it on and measure the output voltages. Arrange a circuit (Fig. 8.14) that will allow you to measure the out-

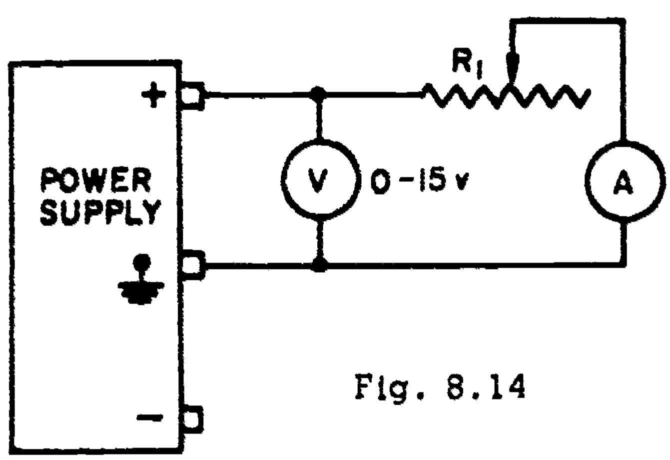


Fig. 8.14

put voltage and the current. Add some load to the circuit, and plot output voltage versus current. By using a 5 kΩ potentiometer you can increase the current up to 40 ma (milliamperes). Look at the output voltage with an oscilloscope and measure the peak-to-peak ripple voltage at 5, 10, 15, and 20 ma output current. This voltage is measured between the bottom and the top of the ripple.

o o o o o o o o

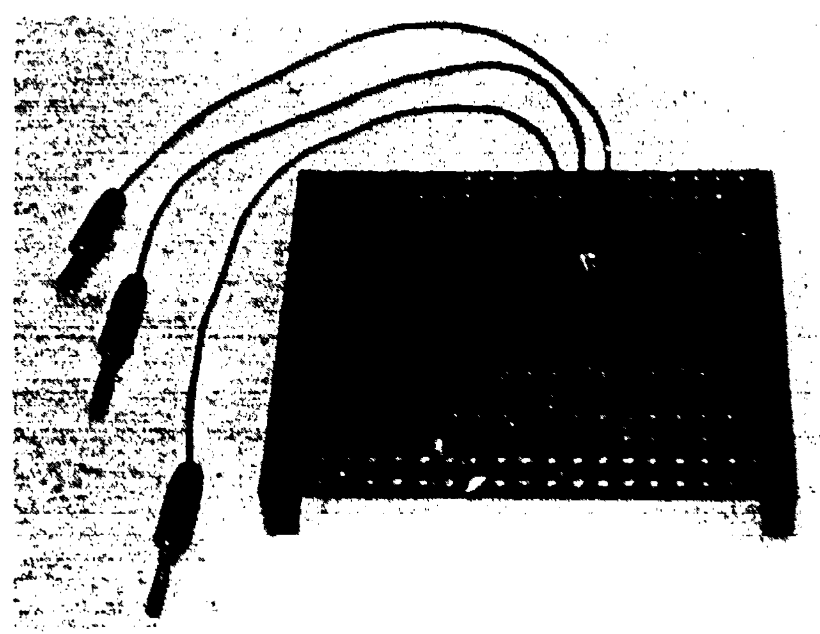
Project 9: OPERATIONAL AMPLIFIER

The small metal device pictured in Fig. 9.1 is an extremely versatile electronic component called an operational amplifier — or "op-amp." Because an op-amp can be connected in so many different configurations, the project begins with the construction of the breadboard shown in Fig. 9.2. When a few resistors are added the circuit becomes an amplifier; with a resistor and a capacitor it is an integrator. Other configurations make the circuit an oscillator, a square-wave generator, or a circuit that can add or subtract voltages. Before these individual circuits can be tested the three leads (see Fig. 9.2) are connected to a bipolar power supply.

The subject of op-amps is extensive and far beyond the scope of this course. The purpose of this project is to teach you how to construct, test, and modify a few simple circuits.

Fig. 9.1

Fig. 9.2

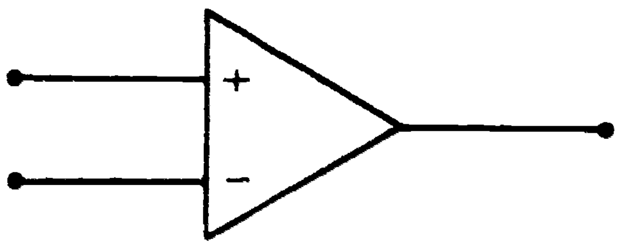


9.1 Operational Amplifiers

You will use a model 741, general-purpose operational amplifier. This is an integrated circuit in which the working parts have been formed together on a chip of semiconductor material and function as a single unit. The circuit contains 20 transistors, 12 resistors, and one capacitor on a surface only a few millimeters on a side. The 741 comes in various packages so that a designer can make a choice. The T0-99 package (Fig. 9.1), which is an eight-lead metal can, is the most suitable for breadboard work and is the one you will use.

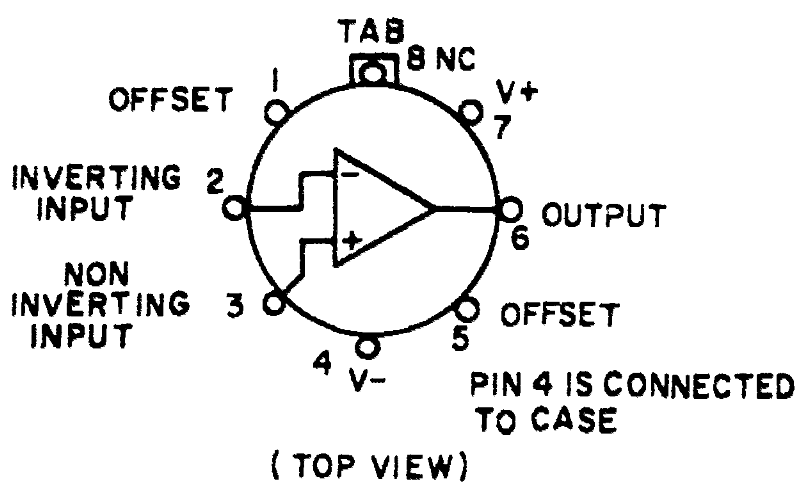
In circuit diagrams it is customary to draw an op-amp as a triangle with only three terminals — two input terminals marked "+" and "-" and one output terminal (Fig. 9.3). Because any op-amp you buy has more than three terminals, your first task is to learn how each is connected.

Fig. 9.3



For a 741 in a T0-99 package the manufacturer supplies an accompanying diagram like that in Fig. 9.4. Pins 2, 3, and 6 correspond to the three terminals shown in Fig. 9.3, and pins 4 and 7 are connected to the circuit's power supply (V^- will be attached to the negative power terminal and V^+ to

Fig. 9.4

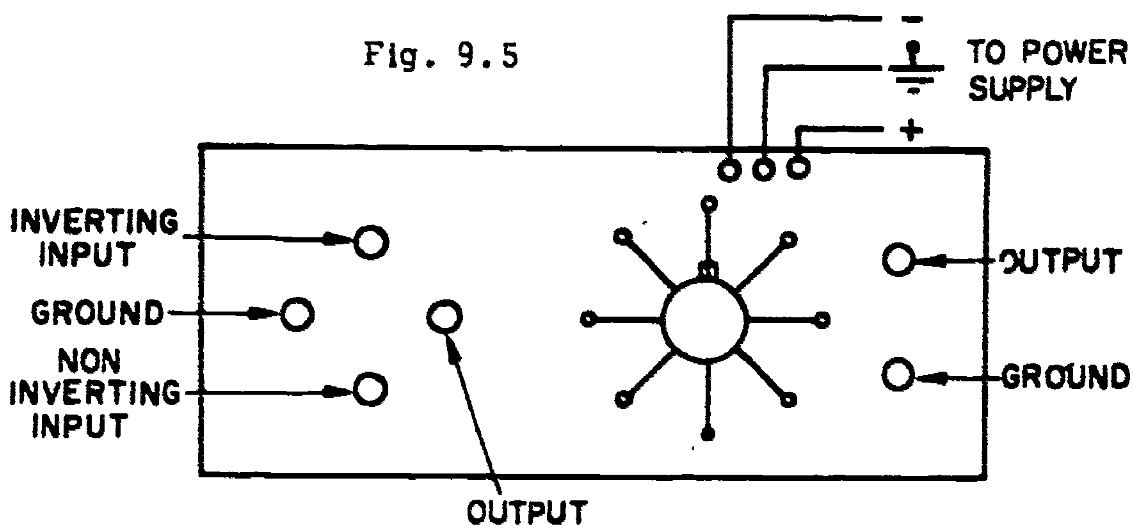


the positive terminal). For the circuits in this project the other terminals need not be connected. (Note in the top view of the op-amp shown in Fig. 9.4 that there is a small metal tab to identify pin 8.)

o o o o o o o o

Figure 9.5 is a top view of the circuit board showing the relative positions of the op-amp and the binding posts. Solder all eight leads to the soldering pins, even though you will not be making connections to all of them.

Fig. 9.5



Like other semiconductor devices, op-amps can be damaged by overheating. Make the solder joints quickly and use a pair of pliers to hold the leads between the soldering pin and the base of the op-amp. The pliers will heat up during soldering and protect the internal circuits.

After attaching the binding posts to the circuit board, turn the circuit board over and connect them to the appropriate terminal of the op-amp. The two ground posts are connected together, as are the two output posts. Both these terminals are duplicated for convenience when breadboarding.

Next add some stranded leads that will be connected to the power supply. The plus and minus leads are connected to V^+ and V^- on the op-amp, and the ground lead goes to the ground in the circuit board. Use different colors for each of the wires to ensure that the proper connections are made at the power supply. If the power leads are connected incorrectly you may damage the op-amp.

<u>CAUTION</u>: Do not confuse the "-" and "+" terminals (pins 2 and 3) with the power terminals V^- and V^+ (pins 4 and 7).

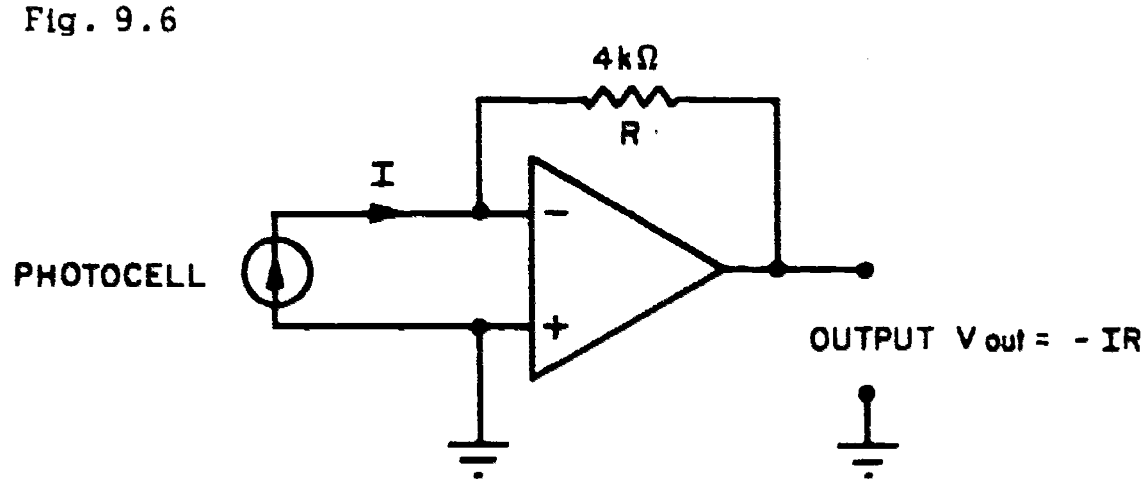
o o o o o o o o

9.2 A Photometer

There are hundreds of circuits that use operational amplifiers similar to the 741. The few we have selected here will give you an idea of how easy it is to set up a circuit and, then, to modify it to suit experimental conditions.

A simple circuit for a photometer is shown in Fig. 9.6. The sensing element is a photocell, which produces a current proportional to the intensity oı he light that strikes it. The photometer circuit converts this current to a voltage that can be read at the output terminals. For a current _I_ the output voltage V_0 is given by $V_0 = -IR$. Thus, a positive current as indicated in Fig. 9.6 produces a negative voltage at the output.

Fig. 9.6



CURRENT - TO - VOLTAGE CONVERTOR

o o o o o o o o

Assemble the photometer circuit shown in Fig. 9.6. (Remember that the connections to the power supply are not shown.) Use a voltmeter with a range of 3 V to read the output voltage.

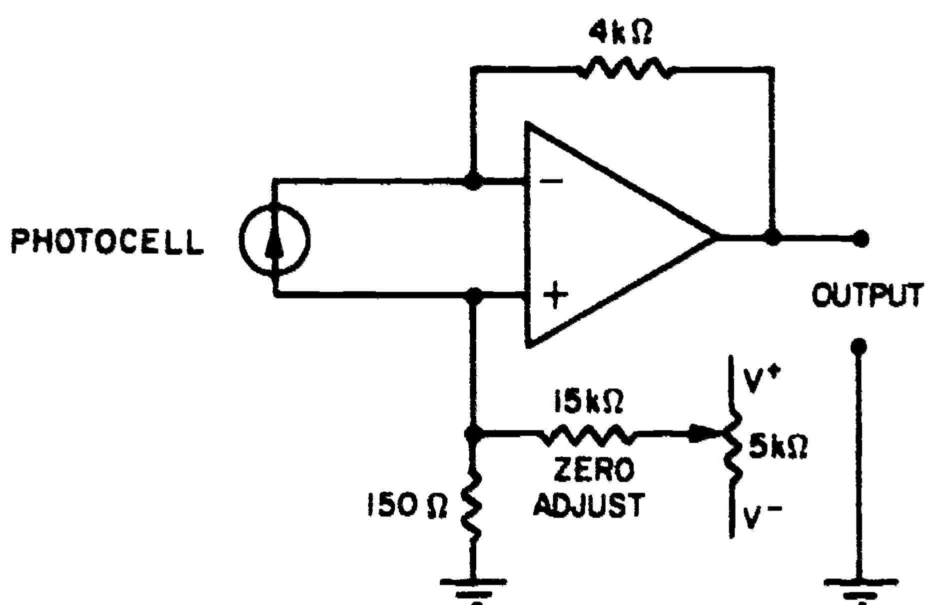
To test the circuit, use a small light source (25-30 watts) and vary the distance between the light and the detector. How can you distinguish between the signal caused by the background room light and that which is the result of the test bulb?

o o o o o o o o

This photometer would be a much more useful circuit if the output voltage resulting from the background light could be eliminated. If you shield the detector with a small cardboard tube, most of the light striking the detector would come from whatever source you wish to measure.

The circuit modification shown in Fig. 9.7 goes one step further. The small variable voltage applied to the noninverting input cancels any effect caused by the room light.

Fig. 9.7



CURRENT-TO-VOLTAGE CONVERTOR WITH ZERO ADJUST

o o o o o o o o

Modify your circuit as shown in Fig. 9.7. With the detector shielded and the test light turned off, adjust the potentiometer so that the output voltage reads zero. Now turn on the test light and check the circuit's operation. How far away can you place the light source and still get a meaningful reading on the voltmeter?

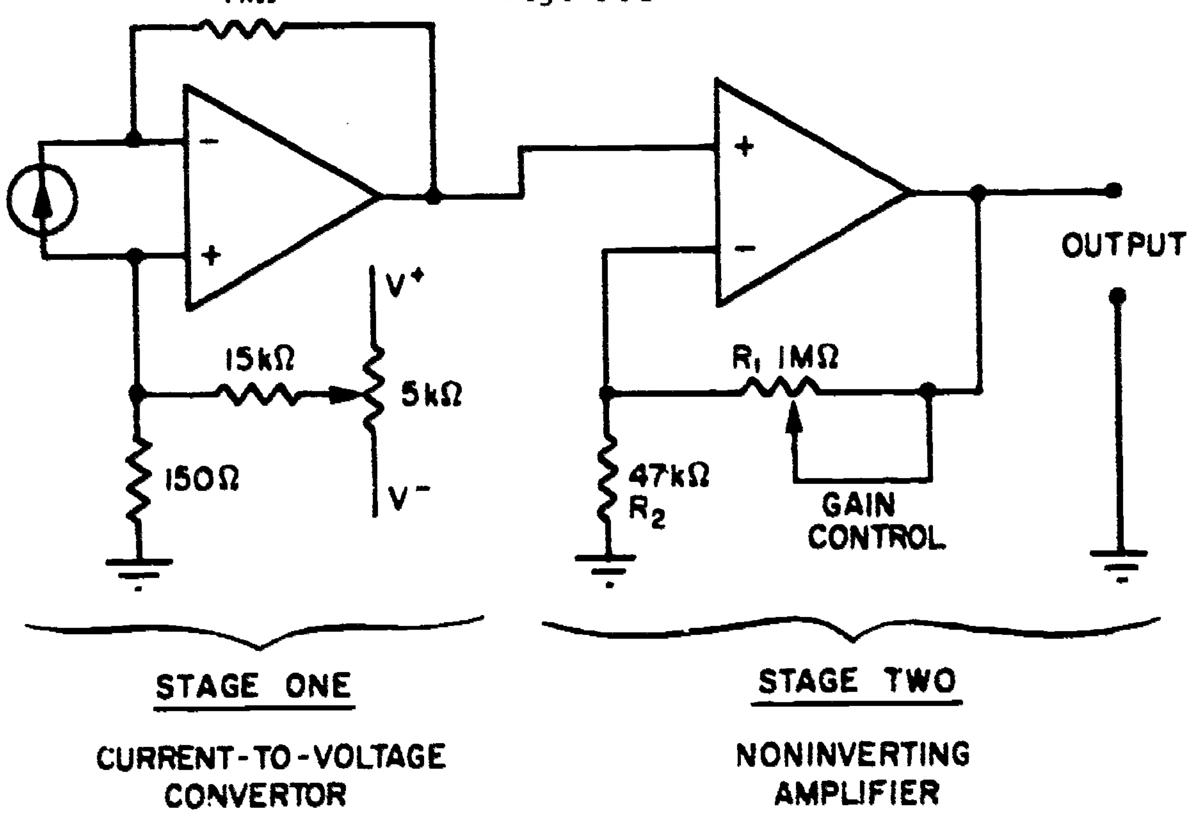
o o o o o o o o

To increase the photometer's sensitivity a second stage is added to the circuit (Fig. 9.8). The second op-amp circuit senses the voltage from the first stage and amplifies it. The output voltmeter is then placed at the output of the second stage. The voltage gain (V_{output}/V_{input}) of the second stage is determined by the values of the two resistors:

$$\text{gain} = (R_1 + R_2)/R_2$$

Therefore, with the resistance values shown in Fig. 9.8 the gain can be varied from one to about 20.

Fig. 9.8



o o o o o o o o

Add the amplification stage to the photometer. The second breadboard is powered by the same power supply that you used for the first.

Test the sensitivity of the overall circuit. What is the maximum light-to-detector distance that is now possible?

How would you calibrate the gain control of the amplifier?

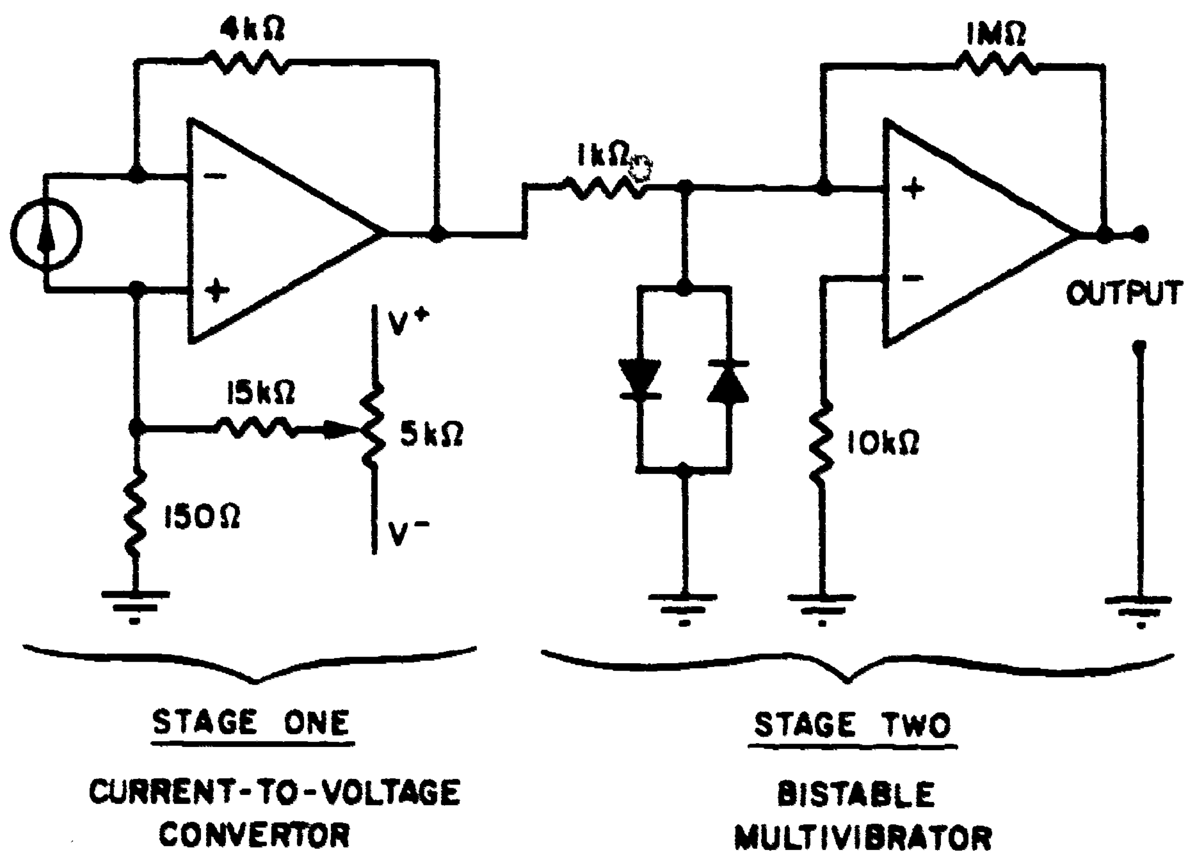
o o o o o o o o

9.3 Other Operational-Amplifier Circuits

The basic photometer circuit (Fig. 9.8) can be used for any experiment in which the variation of light intensity is an important parameter; for example, polarimeters, densitometers, and spectrophotometers.

The circuit in Fig. 9.9 also uses a photocell but the full circuit acts as a switch and not as a photometer; that is, there are only two possible output voltages — one when a light beam strikes the detector and another when it does not.

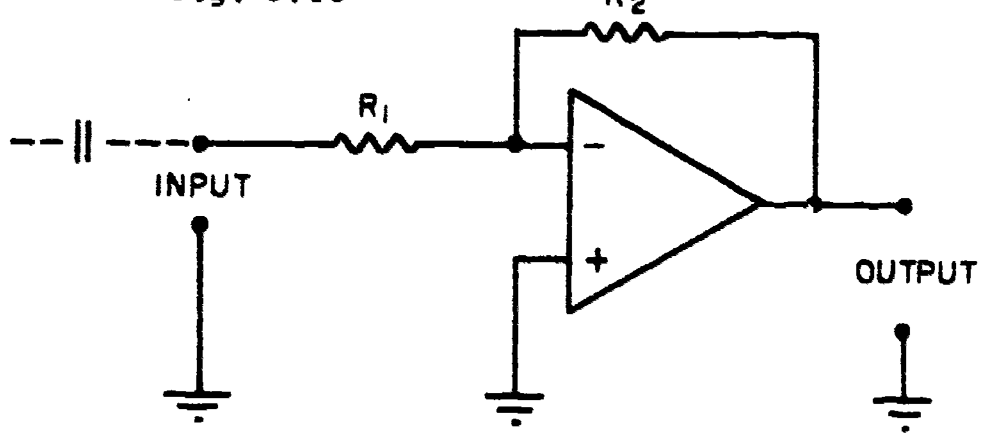
Fig. 9.9



As you can see, the first stage is the same as for the photometer. The second stage is a two-state switching circuit whose output voltages (±9 V) are determined by the power supply. In operation, the output will stay in one state until a large enough voltage of the right polarity drives it to the other. The illuminated detector supplies the signal for one output, and the potentiometer circuit supplies the other.

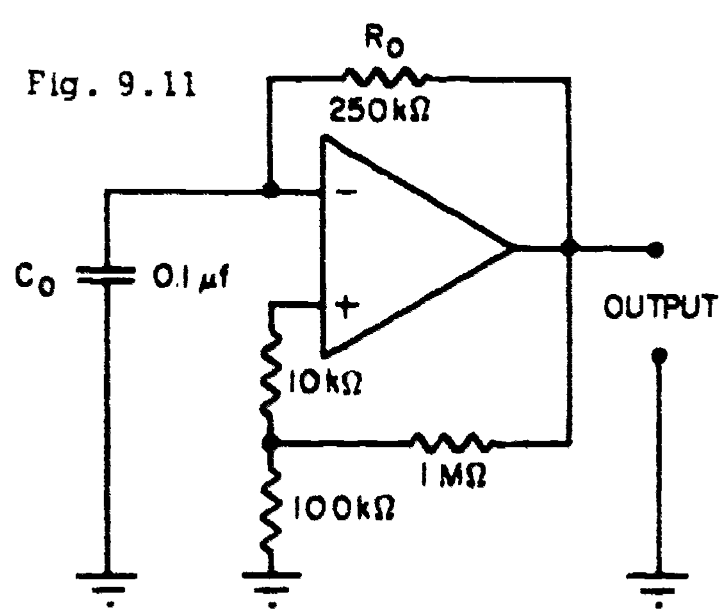
The amplifier you built for the photometer's second stage (Fig. 9.8) is not the only amplifier you can construct. The circuit drawn in Fig. 9.10 is called an <u>inverting amplifier</u> and contrasts with the other, which is <u>non-inverting</u>. In the inverting amplifier a positive input voltage results in a negative voltage output and, hence, a minus sign appears in the expression for the gain. Both amplifiers can be used for AC as well as DC signals. For AC applications a small 0.1 μf capacitor is usually put in series with the input terminal to block any DC voltage that may be present.

Fig. 9.10



INVERTING AMPLIFIER GAIN = $-R_2/R_1$

Fig. 9.11



MULTIVIBRATOR (SQUARE-WAVE GENERATOR)

The circuit drawn in Fig. 9.11 differs from the others in that an input signal is not needed to make it work. It is a simple example of a signal generator and, in this case, the output is a square wave of ±9 V. The output frequency is controlled by the values for R_0 and C_0.

These few circuits may give you some idea of the versatility of operational amplifiers, and because of their low cost, you can use op-amps to do just about any electronic job you may be faced with. However, they are limited in the amount of power they can handle, and so for high-power applications transistors can be added to the op-amp circuit.

GLASS

Many experiments involve the use of liquids or gases that are corrosive to metals such as copper, aluminum, and steel. Therefore, many pieces of equipment require that certain parts be made of glass that is not chemically attacked by most liquids and gases.

Glass is very different from the materials you have previously used. Because it is hard and its surface is smooth, glass is very difficult to cut, drill, or assemble with glues or cements. Therefore, the most common method of working glass is to heat it with a torch until it turns liquid (like thick molasses) and then perform the appropriate operations.

Two pieces of glass can be joined by forcing them together while they are liquid. Holes can be made in glass tubing by heating a small area, blowing the liquid glass into a bubble, and bursting the bubble. Although working glass does not always require blowing, the term glassblowing is used when describing the operations in which a torch is used to work glass.

Earlier in this course power tools were used as substitutes for hand tools because power tools do a better job. The same is true in glassblowing; but because glassblowing power tools are very specialized, they are generally available only to the professional glassblower. Therefore, this portion of the course will cover only the operations that can be done by hand, although the techniques involved are directly applicable to power tools such as the glass lathe.

Project 10: TECHNIQUES USED IN GLASSBLOWING

Learning to blow glass requires a considerable amount of patience, and a "feel" for working glass must be acquired. Seldom will you perform an operation correctly on the first, second, or third trial; it often takes much longer. For this reason, the first project in this section consists of a series of practice operations that will prepare you for making the projects that follow. Do not become discouraged. Practice until you can consistently perform an operation correctly. You will need the confidence gained from experience when the time comes to incorporate the operations you have learned into the construction of a piece of scientific glassware.

10.1 Types of Glass

The types of glass most commonly found in a laboratory are soda-lime and borosilicate glass. Most laboratory glassware is made of borosilicate glass, such as Pyrex and Kimex, because this type has a higher resistance to thermal shock than soda lime. Glass made of 96 percent silica (Vycor brand) is used in extremely high-temperature applications. All of these types have different thermal properties and melt at different temperatures. Soda-lime glass melts at a relatively low temperature, near 700°C. Pyrex melts at 820°C and Vycor at 1500°C. Because of their different thermal properties, types of glass cannot be mixed together although they may flow together when heated. The mixture will crack as it cools and the work that has been done will be ruined because each type of glass has a different coefficient of linear expansion.

Because most laboratory glassware is made from Pyrex, that type of glass will be used in the projects in this course. Types of glass can be distinguished by the rate of softening, by the index of refraction, or by a comparison of the coefficients of expansion of a known glass and an unknown. To compare the expansion coefficients of two pieces of tubing, the pieces are fused together at one end (Fig. 10.1) by heating both until they become soft and then by forcing them together. The fused ends are then heated once

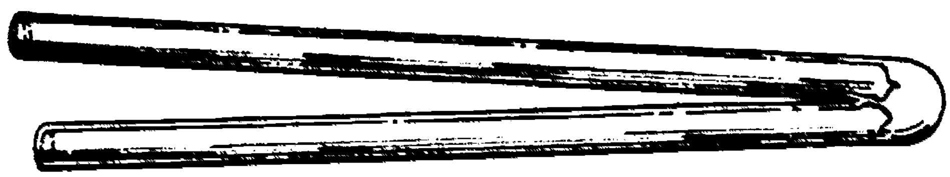


Fig. 10.1

again until they are quite soft. The glass is then removed from the flame and stretched into a thread with a pair of tweezers. If the thread of glass remains straight, the two samples of glass have the same coefficient of expansion. If the thread bends, the sample on the inside of the bend has the greater coefficient (Fig. 10.2).

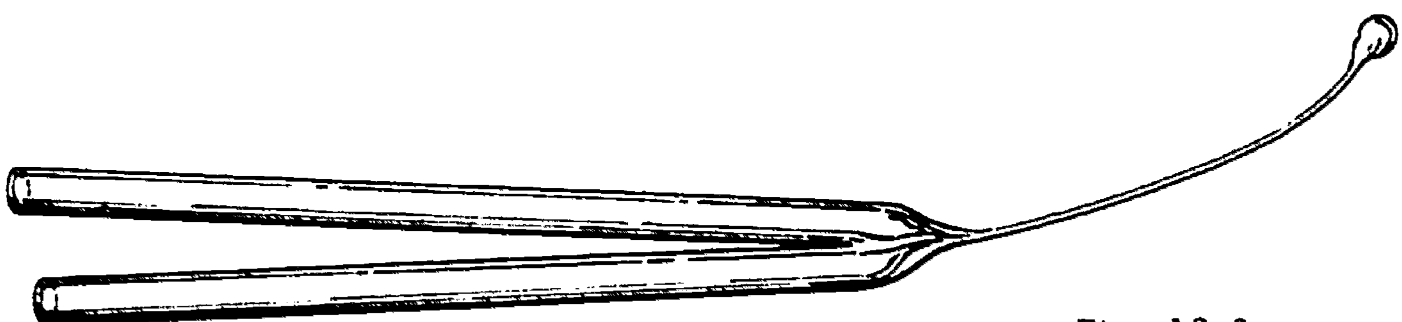


Fig. 10.2

10.2 Torches

Most torches used in glassblowing operate on natural or bottled gas and another gas that helps it to burn more efficiently and thus at a higher temperature. For soda-lime glass, gas and compressed air are used; for Pyrex, a combination of gas, air, and compressed oxygen; for Vycor, oxygen and acetylene.

The gas-air-oxygen torch comes in two basic types. The first type mixes all three gases together by means of regulating valves or special venturi mixers. These torches are usually cumbersome and difficult to regulate, and there is also the possibility of an explosion, called flashback, when this type of torch is shut off improperly. The second type, called a surface-mix torch, is designed so that the air is mixed with the gas and the oxygen at the torch tip rather than inside the torch itself. For this reason there is less danger of flashback with these torches. Flashback can be eliminated entirely if you always remember to shut off the oxygen before shutting off the gas.

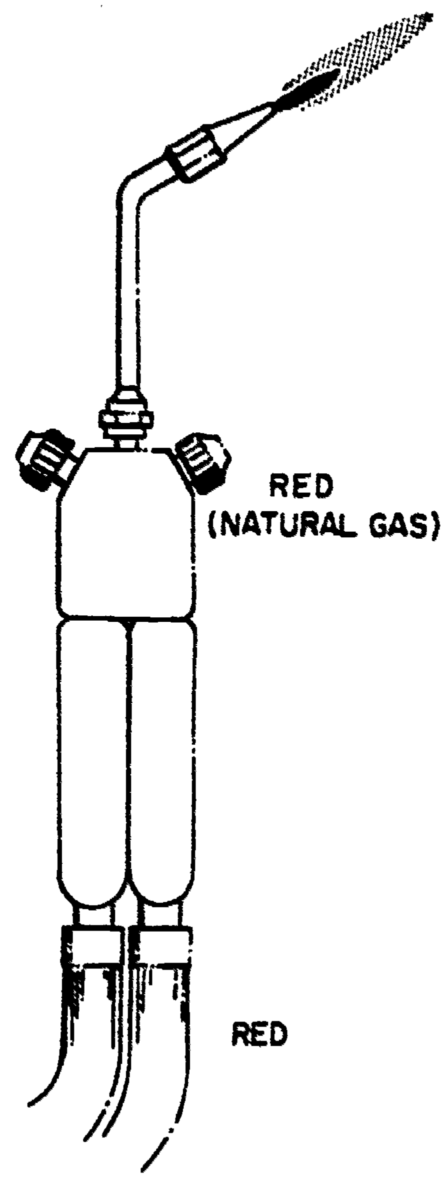


Fig. 10.3

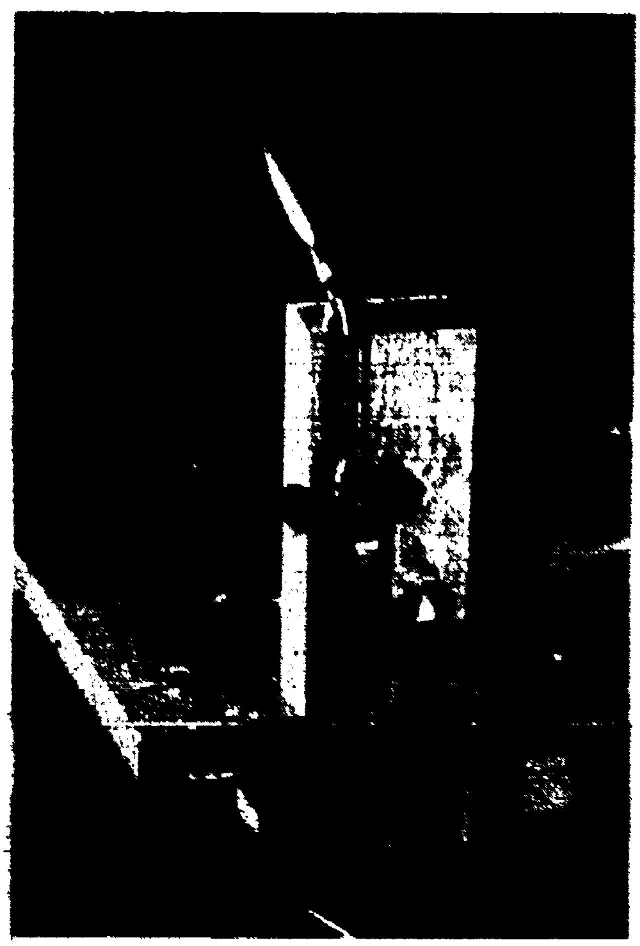


Fig. 10.4

Torches in these two categories range from large "blast" torches to the small hand type, which will be used in this course (see Fig. 10.3).

For versatility the hand torch can be placed on the bench in a holder (Fig. 10.4). It is connected by rubber hoses to a source of natural gas and to a tank of oxygen.

The oxygen tank has a set of gauges and a regulator attached to it. (This tank should always be secured so that it cannot fall over.) One gauge measures the pressure inside the tank, and thus the amount of oxygen. The other gauge measures the pressure as set by the regulator, which controls the flow of oxygen to the torch. The regulator is adjusted by turning the handle on the side until the gauge shows the proper pressure. For glass-blowing, the regulator should be set at 5 to 10 pounds per square inch. On the top of the tank is a valve that should always be closed except when the tank is being used.

Before lighting a torch, be sure that the valves on [illegible] are turned off. Then turn on the source of natural gas and the oxygen tank, and set the regulator. Open the valves on the torch for 10 to 15 seconds to clear out any air that may be in the tubing. Shut off the oxygen valve and turn the gas valve until it is just slightly open. Light the torch with a match, making certain that it is not pointed at anything or anyone nearby.

After the torch is lighted, adjust the gas valve until the yellow flame is about 8 inches long. Then open the oxygen valve, and a light blue cone will appear in the center of the flame as the flame shortens overall. Adjust the center cone until it is 1/2 to 3/4 inch long. This is only an approximate adjustment. The more oxygen you add to the flame, the hotter it will be. You can produce a small, sharp, pointed flame that is very hot, or a relatively cool flame for slow work on small pieces.

When shutting off the torch, gradually close the oxygen valve and shorten up the flame by reducing the gas flow. Then close the oxygen valve completely and finally the gas valve. If the torch is not going to be used again in a few minutes, be sure to shut off the source of gas, close the valve on the oxygen tank, open the regulator valve, and drain the gas hoses by opening the valves on the torch until the pressure is released.

Always be careful when using a torch. The flame is <u>extremely</u> hot. Always think about what you are doing before you make any move near a lighted torch. Make sure that there are no flammable materials anywhere near the flame.

Whenever a torch is being used, everyone nearby should wear safety glasses. There is a difference between regular safety glasses and those worn by glassblowers. When glass is placed in a high-temperature flame, it is surrounded by a bright yellow sodium flame. This makes it difficult to see the glass itself, and for this reason, glassblowers use glasses with didymium lenses to filter out the yellow flame.

10.3 Cutting Glass Tubing

Glass tubing usually comes in four-foot lengths and has to be cut to shorter lengths for easier handling and to definite lengths to fit apparatus.

Small-diameter tubing, 20 mm or less, can be cut by making a notch at the desired place with the corner of a file. Only one stroke is needed, but the stroke must be firm so that the notch is deep enough. Wet the notch with your finger, and grasp the tubing with the notch facing away (Fig. 10.5). Break the tubing with a swift motion by bending it so that the curve is away from the notch.

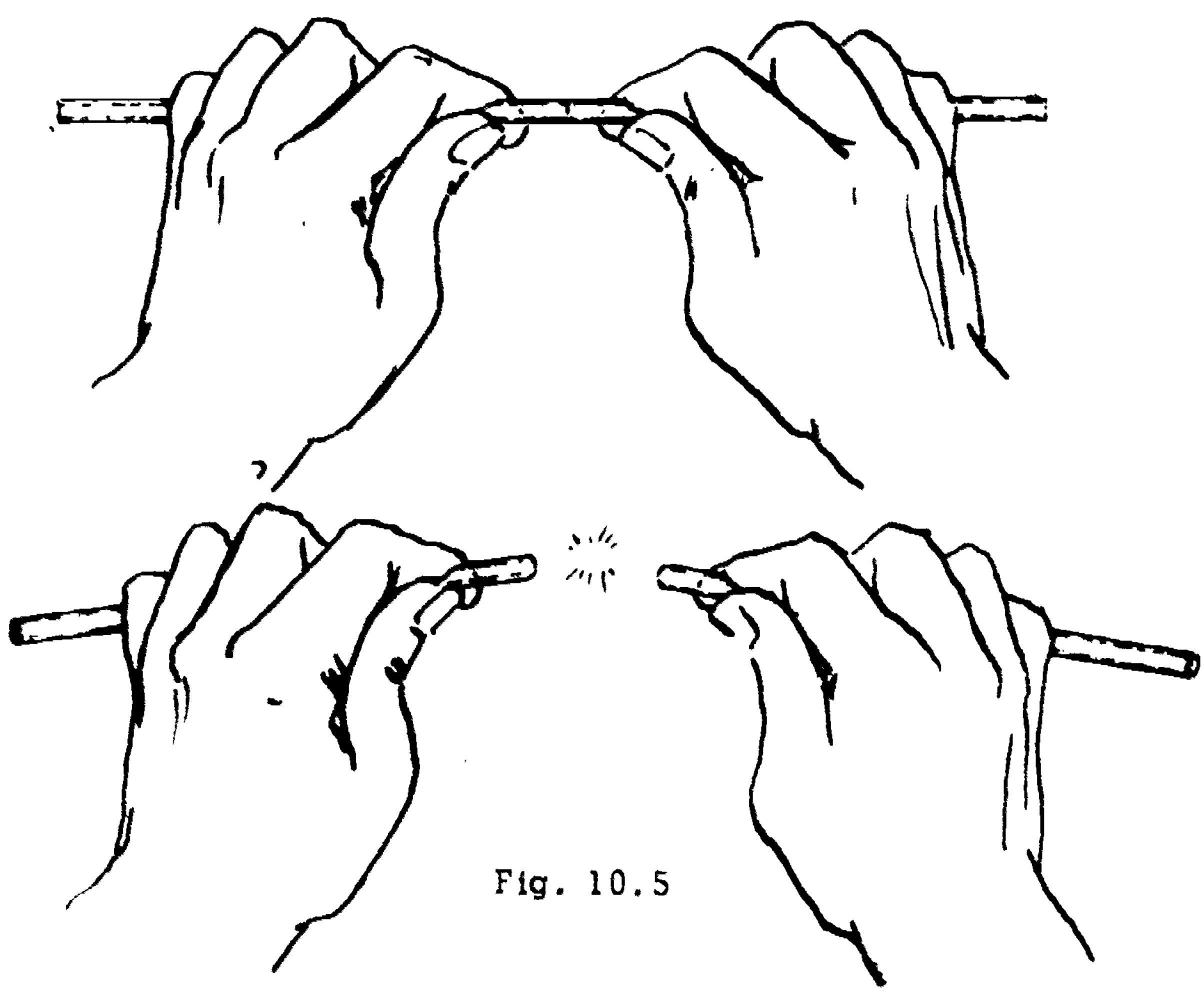


Fig. 10.5

Larger-diameter tubing can be cut by scribing a notch and then touching the edge of the notch with a piece of molten glass rod. This should produce a crack around the tube. If it does not crack, or if the crack does not go completely around the tubing, repeat the process.

You can also cut large-diameter tubing with the help of a piece of nichrome wire and a low-voltage power supply. Loop the nichrome wire around the glass tubing, taking care that the loops do not touch. Then connect the power supply to heat it up. This will heat a small area of the glass tubing. If water is poured over the tubing, the thermal shock should break it. Be sure the power supply is turned off before you pour on the water.

Another technique, called fire-cutting, is used most often when the end of a piece of tubing has to be sealed off. A torch is used to heat a small section of the tubing until it is pliable. The tubing is then stretched along its axis until it is very thin. This thin section is put back into the hottest portion of the flame, and the tubing separates.

10.4 Constricting Glass Tubing

To constrict a piece of tubing a section of glass is heated until it is pliable and the heated section is stretched by pulling both ends of the tubing. As the tubing is stretched the diameter reduces.

The greatest problem in most glassblowing operations is to heat the glass evenly. When working with tubing, the glass is rotated about its axis at a steady rate as it is heated in the flame. While the glass is hard, it is easy to coordinate the hands to rotate the glass continuously. However, as the glass gets hot, it becomes very pliable and less manageable.

The photograph in Fig. 10.6 is taken from overhead and depicts the technique of supporting and rotating glass tubing in a flame. The thumb and index finger of each hand are used to spin the glass while the other fingers form a cradle in which the glass rests. The tubing is rotated by alternately using one hand and then the other so that the tubing never stops in one place, causing uneven heating. With practice you will develop the coordination necessary to keep the tubing in line and prevent it from twisting.

Fig. 10.6

o o o o o o o o

Take a piece of glass tubing about 8 mm in diameter and 14 inches long, and heat a one-inch section in the center. As soon as the tubing becomes quite flexible, remove it from the flame and pull on it until the heated section is approximately one-half the original diameter.

What was the color of the glass when it became pliable enough to stretch?

Be very careful not to touch the heated section of the glass, because you can sustain a severe burn. To check if a section of glass is cool enough, begin by touching the end farthest from the hot section and then slowly slide your finger along the tube.

After the glass is cooled so that you can handle it, cut it at the middle of the constriction. How does the wall thickness there compare with the wall thickness of the original tubing? How might this be undesirable?

o o o o o o o o

Because the wall thickness of the constriction you have just made is thin, the tubing is very weak at that point. To strengthen the constricted part of the tubing, it is necessary to increase the wall thickness. This is done by heating the tubing as before but leaving it in the flame after the tubing has become pliable enough to stretch. If there is no pull by either hand as the tubing is rotated, the wall thickness will increase because of surface tension (Fig. 10.7). At this point the tubing is removed from the flame and is allowed to cool for a second without any force exerted on it. The thin-walled sections cool and harden, and then, as the tubing is stretched, only the thick-walled glass will stretch and become thinner. When the outside diameter of the constriction becomes one-half the tubing diameter, enough glass will be available to make the constriction thick walled.

Fig. 10.7

After completing this operation, you will have learned two of the most important factors used in glassblowing. First, when glass is heated until it is soft, it contracts due to surface tension. Second, thinner sections of glass cool faster than thicker ones. You will make use of these two factors every time you work with glass.

o o o o o o o o

> Take another piece of tubing and constrict the center portion. Practice until you have been able to make three or four good constrictions. Take one tube and cut it at the constricted section. How does the wall thickness compare with that of the previous constriction?

o o o o o o o o

If liquid glass is allowed to cool at its own rate, stresses are set up in it because one portion cools faster than another. This difference in cooling can be the result of variations in thickness or drafts from the surroundings. These stresses can cause the glass to crack when it cools or when it is heated up again. To help alleviate this problem, a process called annealing brings the glass back down to room temperature at a controlled rate so that all of it cools at the same time.

When the glass was made, it was annealed in large ovens. Using an oven is the best way to anneal a piece of glass, but an oven is not always available and often the project may be too large to fit into one. Under these conditions a section of glass can be annealed by placing it in a soft yellow flame from a torch immediately after completing an operation and allowing it to cool slowly until a layer of carbon covers it. The carbon only forms at a low temperature and can be wiped off after the glass is completely cool.

When it is necessary to rework a piece of glass, always heat it very slowly to give the entire area around a seal the chance to warm up. This will help prevent the glass from cracking and the work from being ruined.

10.5 Bending Glass Tubing

Bending small-diameter tubing is easy if the angle of the bend is approximately 90 degrees or more. The tubing is rotated in the flame while the section to be bent is heated until it is pliable. Then the tubing is removed from the flame and the heated section is bent to the proper angle. The length of the section that is heated determines the radius of the bend. The most common mistake in bending glass is to heat too short a section. This produces a bend that is too sharp, as illustrated in Fig. 10.8. A rule of thumb is to heat a section of tubing that is between four and six times the diameter of the tubing (Fig. 10.9).

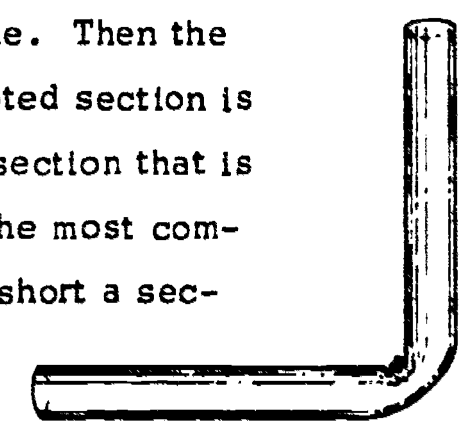
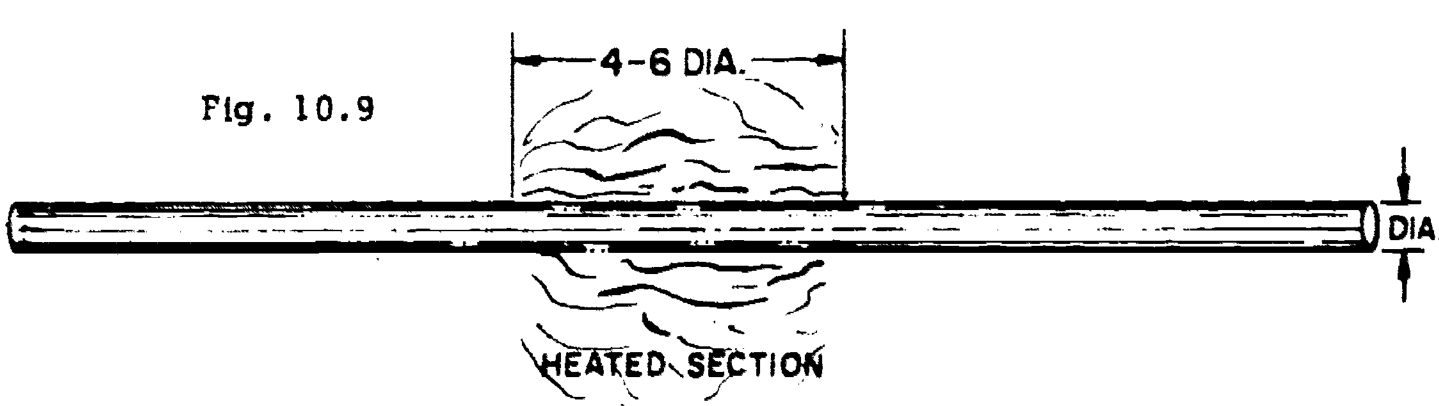


Fig. 10.8

Fig. 10.9


This will produce a smooth bend, as shown in Fig. 10.10.

To make a U bend, the procedure is the same, but the section of tubing that is heated must be longer. If a U bend is considered simply as two 90 degree bends, obviously almost twice as much tubing should be heated, producing a bend that is relatively uniform but with a fairly large radius.

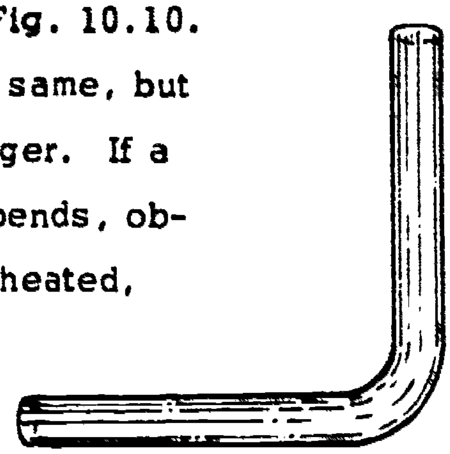
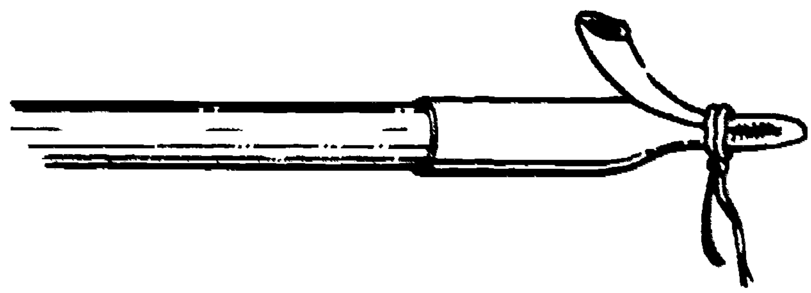


Fig. 10.10

Sometimes it is necessary to make bends with a radius smaller than those mentioned earlier. Figure 10.8 depicts the results of a bend that was too sharp (small radius). One way to prevent the collapse of the bend is to blow into the glass tubing while it is still hot, which expands it to its original diameter. To do this, one end of the piece of tubing must be closed off. If the tubing is very small, a rubber policeman can be used. On medium-size tubing, a piece of snug-fitting rubber hose can be attached to the tube, bent over to pinch off the hose, and tied or taped in position, as shown in Fig. 10.11. Larger-diameter tubing can be closed off with a cork or a rubber stopper.

Fig. 10.11



After one end is closed, you have to provide a means by which to blow into the tube. (Never put the end of a piece of glass tubing in your mouth to blow into it. The edges may be sharp, or the end may be hot from a previous operation.) A rubber hose, fitted with a mouthpiece, can be attached to the glass tube by means of a swivel, which prevents the hose from twisting as the glass is rotated. The swivel is attached to the glass tubing by means of a short piece of rubber hose or a cork or a rubber stopper, depending on the diameter of the glass. Figure 10.12 shows the easiest way of holding a piece of tubing with a blowing hose attached. Much of the weight of the hose is removed from the glass tube by placing the hose around the neck.

Fig. 10.12

The next step is to rotate the tubing in the flame and heat it until it is almost fluid. The tubing is removed from the flame, stretched slightly to remove any irregularities, and bent to the desired angle. Before the glass has a chance to cool, gently blow into it until the tube returns to its original diameter. This must all be done rapidly so that the glass will not cool down too much before the bend is completed.

There is another method that produces a usable though often irregular bend. First the area where the bend is to be made is heated up but removed from the flame before it becomes pliable. The heat is then concentrated in a small area, and a small bend is made. Then the heat is applied a little farther along the tube, and another small bend is made. This is continued until the proper curve is obtained. The series of small bends should blend together to form a smooth curve. This process takes more time but is quite effective, especially when the bend has to fit another piece.

o o o o o o o o

Make a series of right-angle and U bends from tubing ranging in diameter from 6 to 8 mm. Try more than one method. What method do you think would be best for bending capillary tubing? Try it.

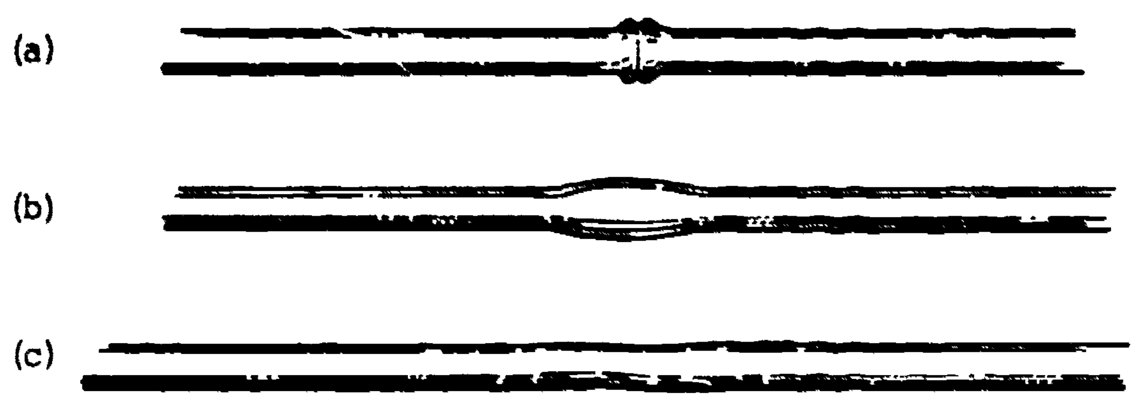
o o o o o o o o

10.6 End-to-End Seals

When almost any seal or joint is made, there are two basic areas of concern. First, the glass from one piece must flow to the other piece to form a good seal, and second, the joint must be strong. When the two pieces are heated thoroughly, and to a high enough temperature, the glass naturally flows together. Because glass tubing tends to constrict when it is heated, it is often necessary to expand the diameter of the seal after it is made by blowing into one end of the tubing while the other end is closed off. If the wall thickness of the joint is approximately the same as that of the tubing itself, the seal is sufficiently strong.

To make an end-to-end seal between two pieces of tubing having the same diameter and wall thickness, one piece is closed off by a rubber policeman or cork stopper, and a blowing hose is attached to the other piece. The two ends to be joined are rotated in the flame in axial alignment, but without touching. When the ends become soft, they are pushed together, as in Fig. 10.13(a), so that they make contact with each other over the entire surface to be joined. Then the tubing is removed from the flame and stretched slightly. The seal is put back into the flame and the tubing is shrunk. The tubing is then removed from the flame and blown into by means of the rubber hose so that the diameter becomes slightly larger than it was before, as shown in Fig. 10.13(b). The tubing is then stretched to bring its outer diameter down to its original size. See Fig. 10.13(c). The blowing and stretching may have to be repeated several times to distribute the glass evenly and to make a relatively neat seal.

Fig. 10.13



This three-step technique is sometimes difficult to master. Another method can be used, but the results are not quite as neat. The beginning of the operation is the same as before: Heat both pieces of glass and push them together when they become soft. Now, rather than trying to fuse the entire seal at one time, try fusing it in sections. Hold the seal in the flame but do not rotate the tubing. Once the glass begins to shrink and flow together, remove the glass from the flame and blow the tubing to its original diameter. Rotate the gla~s and repeat the process until you have worked your way around the seal. Because the seal is made in sections it will not be smooth. However, if made correctly, the seal will be adequate.

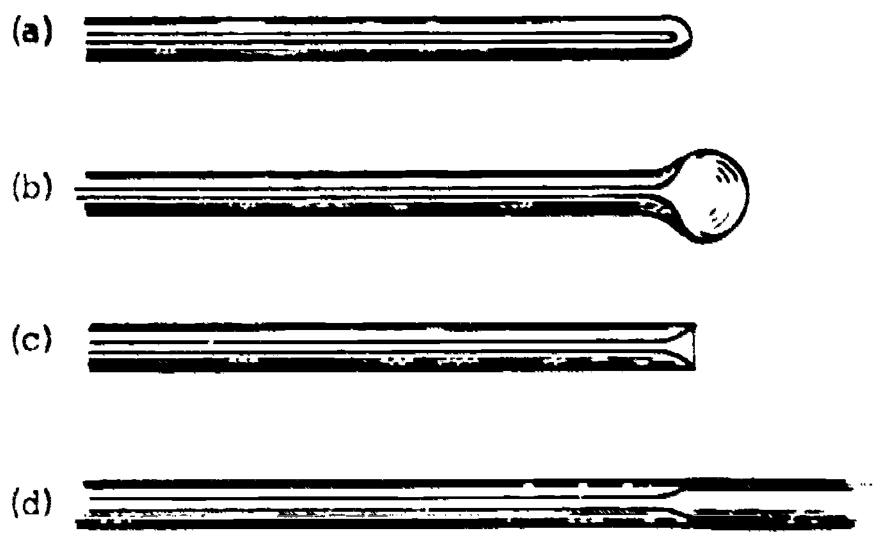
o o o o o o o o

Take two 8-inch pieces of 7- or 8-mm-diameter tubing and make an end-to-end seal. Do not be discouraged if the seals do not turn out well the first time. After practice, making end seals will be a very simple task.

o o o o o o o o

To make end-to-end seals between regular glass tubing and capillary tubing, the procedure is the same as in the previous exercise except for a few additional steps. First, the end of the capillary is closed by heating it in a flame (Fig. 10.14(a)). Then a bubble is blown in the end, as illustrated in Fig. 10.14(b). The bubble is broken off by tapping it with a file, and the end is fire-polished to eliminate sharp edges. This procedure makes the wall thickness of the capillary tubing approximately the same as the tubing to which it will be joined. At this point, except for one factor, the procedure for joining standard tubing and capillary tubing is the same as for joining tubing of the same wall thickness. Because the capillary tubing has thicker walls than standard tubing, it will take longer to heat up as well as to cool down. For this reason, when working the seal, the flame should be concentrated a little more on the capillary tubing than on the standard tubing. The completed seal is shown in Fig. 10.14(d).

Fig. 10.14



In making end-to-end seals between pieces of tubing having different but relatively close diameters, the end of the smaller tube is flared until the end of the flare is the same diameter as the larger tubing (Fig. 10.15). This can be done by sealing the end, blowing a bubble, striking off the bubble, and fire-polishing it. A flare can also be made by heating the end of

Fig. 10.15

the tube until it is molten and forming the end with a pointed carbon rod (see Fig. 10.16). The procedure from this point is the same as for the previous seal.

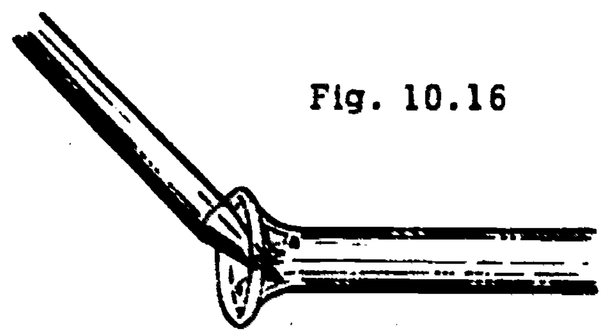


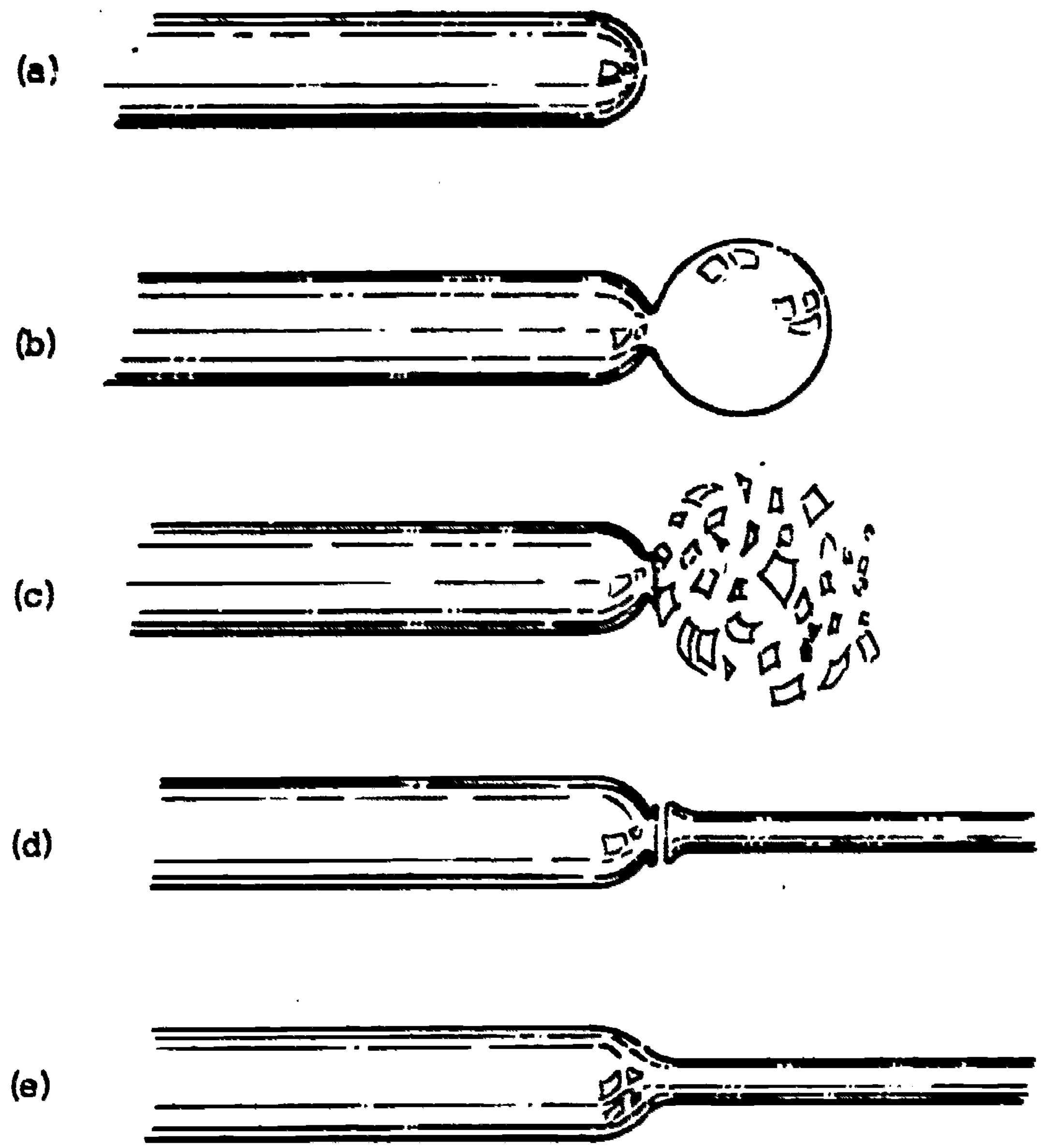
Fig. 10.16

If the diameters of two pieces of tubing differ by quite a bit, it is first necessary to close off the end of the larger-diameter tubing. This is done by fire-cutting the larger tubing, sealing the end, and blowing the bottom end of the tube into a round bottom like that of a test tube.

If you simply stretch the tubing as you fire-cut it, the wall will be too thin and you will burn a hole in the thin wall as you make the seal. As you fire-cut, concentrate the heat on the unused section of the tubing and shrink the tubing as you did in Section 10.4. To round the bottom of the tube, heat the end until it contracts and then blow into the tube forming the round bottom.

The next step is to provide the sealed bottom of the large tube with a hole of the same diameter as the small tube. This is done by heating up a small area in the center of the end of the tube, blowing a bubble the size of the small tube, striking it off, and then fire-polishing to remove sharp edges. The smaller tube is then flared slightly on the end to be sealed. The two surfaces that are to be joined are rotated in the flame until they are red hot and then pushed together. The procedure from this point on is the same as in the previous end-to-end seals. Figure 10.17(a) - (e) illustrates the steps in this operation.

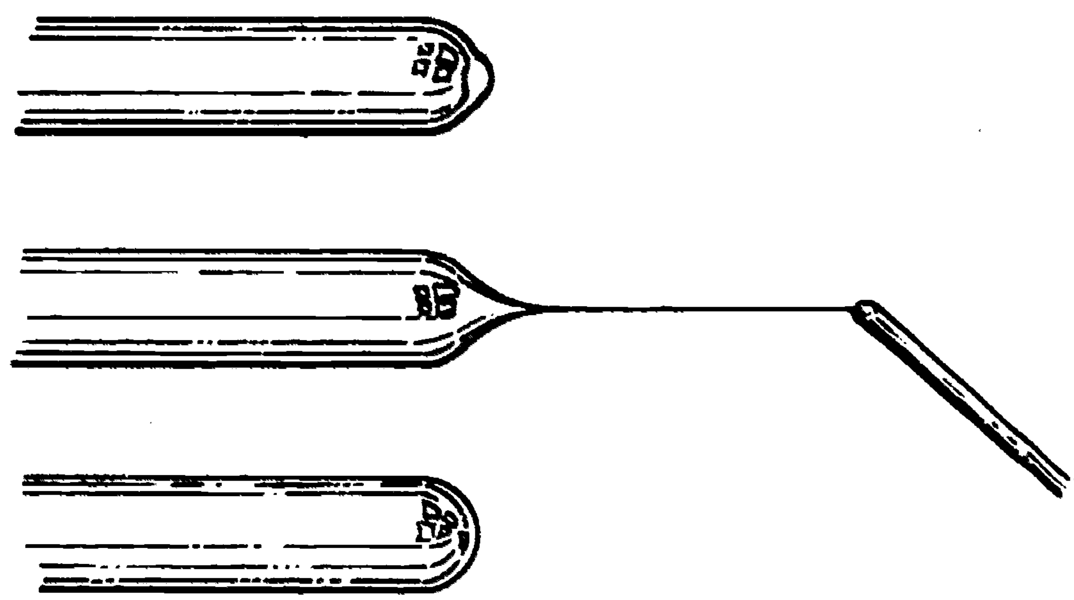
Fig. 10.17



There are two problems that may arise if some of the steps are not carried out correctly. The first problem occurs in making sure that the wall thickness of the end of the large-diameter tubing is consistent. Frequently, when a piece of tubing is sealed off, there is an excess of glass at the very end of the tube, as shown in Fig. 10.18(a). To remove it, heat the thick-walled portion until it is nearly white. Then, after removing it from the flame, touch a piece of small-diameter cold glass rod to the thick portion and pull (Fig. 10.18(b)). This will remove much of the glass, and all that is left to do is to burn off the strand of glass, heat up the end of the tube, and blow to form a round, smooth bottom (Fig. 10.18(c)).

Fig. 10.18

(a)
(b)
(c)



The second problem occurs when very large-diameter tubing is used. It is almost impossible to heat the entire joint (seal) evenly with a small hand torch. Therefore, the seal is made by shrinking and blowing sections of the joint separately and by gradually working around the entire joint, as described earlier.

o o o o o o o o

Take two pieces of glass tubing of different diameters and make an end-to-end seal between them. After this, try making seals between tubings of different diameter ratios.

o o o o o o o o

10.7 T Seals

A T seal is any seal in which one piece of tubing is joined to the side of another at or near right angles to it. Joining a piece of small-diameter tubing to one of a larger diameter is the most common T seal. Side arms in distilling columns or condensers are good examples. There are also occasions when a T seal is made from two pieces of tubing that have the same diameter.

A T seal is produced by first making a hole in the side of the tube that is to be the crossbar of the T, using the same technique that was used in making a hole in the bottom of the large-diameter tubing for the end-to-end seal. The tube is sealed off at one end by a cork, and a blowing hose is attached to the other end. A bubble, having the same diameter as the side tube to be used, is blown in the side of the cross tube. The bubble is blown out or broken off, and the edges of the hole are fire-polished.

The piece of glass tube that is to be used as the side piece is flared. After this has been done, the other end of this tube must be closed off by a cork or similar device.

The area around the hole of the crosspiece and the end of the side tube are heated up at the same time and then pushed together. The joint is then fused and blown in sections, straightened, and stretched slightly. (See Fig. 10.19(a)-(f).)

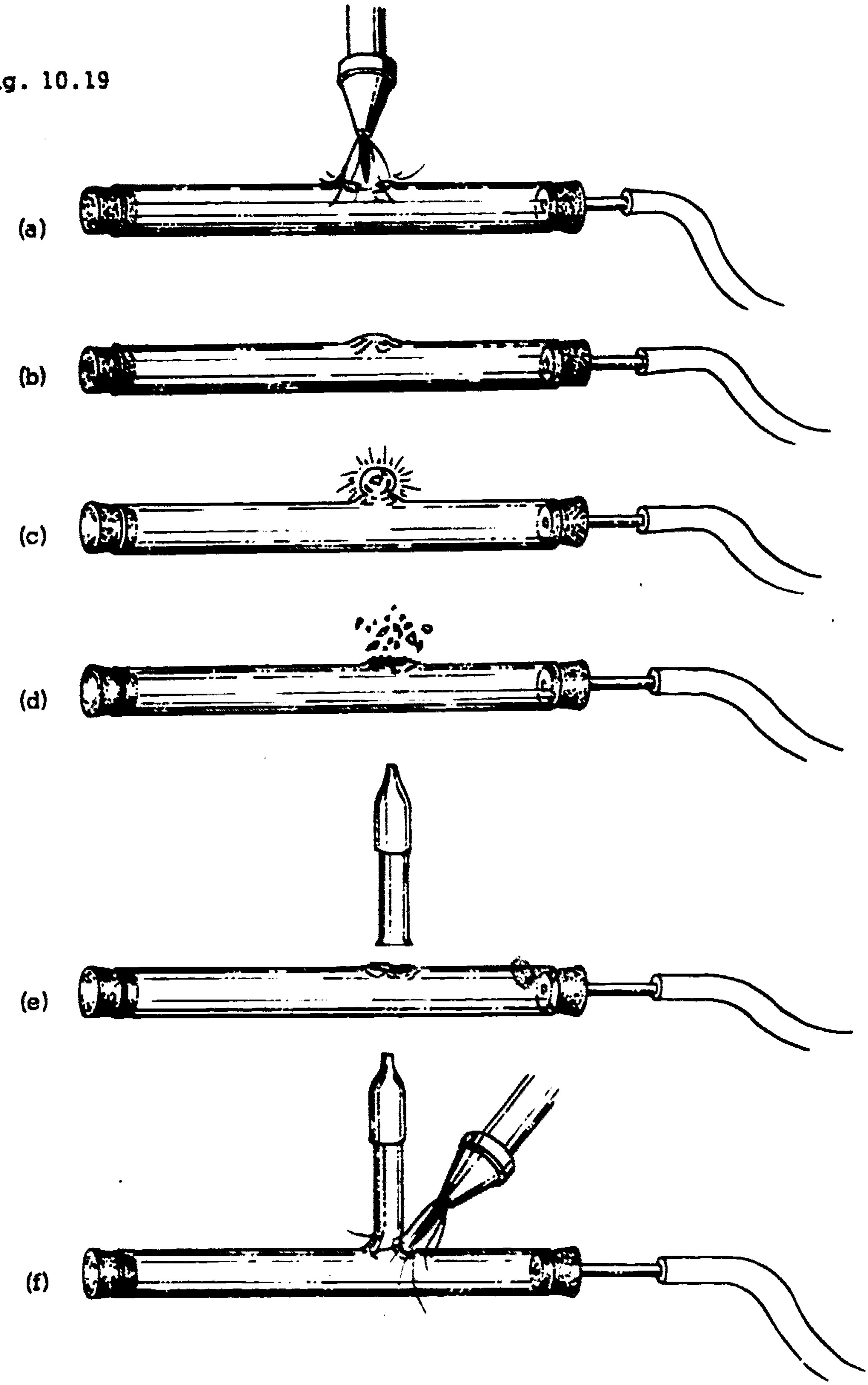
For making a T seal, the torch can be held in a stand while the two pieces of glass are held by hand, or the crossbar can be held by clamps on two ring stands while the torch and side arm are held by hand. In the latter case, updrafts from the torch can burn the hand or make it very uncomfortable. To alleviate the problem, a heat shield can be made by putting a piece of sheet asbestos on the side arm and holding the side arm above this point.

o o o o o o o o

Take an 8-inch-long piece of 10-mm-diameter tubing and make a T seal in the side of it using 6-mm tubing. After completing two or three T seals of this type, try making a few using two pieces of tubing that have the same diameter. This is slightly more difficult than T seals made from tubing of different diameters because when the seal is fused, the entire joint usually becomes very flexible and hard to control.

o o o o o o o o

Fig. 10.19



10.8 Ring Seals

A ring seal is used when a piece of glass tubing must extend through the wall of a larger-diameter tube. In most cases, this seal is made through the round bottom of a tube similar to a test tube.

Ring seals can be made in two ways. One method, called a triple seal, is to make an internal seal, blow a hole in the wall of the outer tube, and make an external seal. One end of the inside tube is flared, and a blowing hose is attached to the other end. The inside tube is then held so that the flared end rests against the bottom of the outer tube. It can be held in axial alignment by wrapping it with asbestos tape so that it fits snugly inside the outer tube. The seal is made by heating the bottom of the outer tube and fusing the tubes together. A bubble is made in the outer tube by blowing through the hose attached to the inside tube (Fig. 10.20). The bubble is removed, the edges are fire-polished, and a regular end-to-end seal is made, using the same diameter tubing as the inside tube. Straighten the tubes and anneal the joint, and the seal is completed.

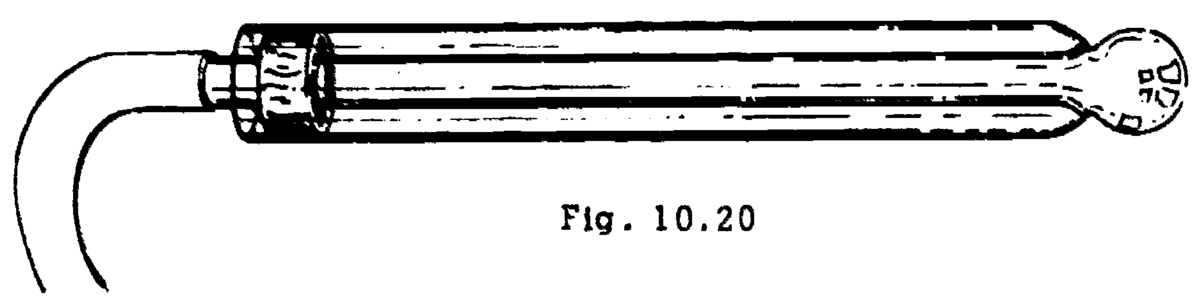
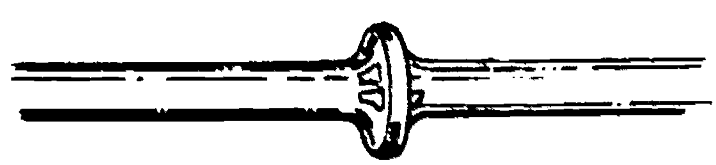


Fig. 10.20

Another type of ring seal is made by blowing a hole in the outer tube. This hole should be slightly larger than the outer diamete. of the inside tube. A ring is formed on the inner tube at the point where the seal is to be made to the outer tube (Fig. 10.21). This can be done by closing one end with a

Fig. 10.21



stopper and attaching a blow hose. A narrow band is heated where the ring should be. When hot, the tube is removed from the flame, blown into so that a small bulge is formed, and pushed together to form the ring. The diameter of the ring should be slightly larger than the hole in the outer tube.

The two pieces of tubing are put together so that the ring is on the outside. The two surfaces to be joined are heated, pushed together, sealed, and straightened. For this seal, the blowing hose is attached to the smaller tube and the larger tube is closed by a stopper.

o o o o o o o o

Practice both procedures by making ring seals out of medium-diameter tubes. The ratio of the diameters of the tubing should be about 2 : 1.

o o o o o o o o

Project 11: A DISTILLING COLUMN

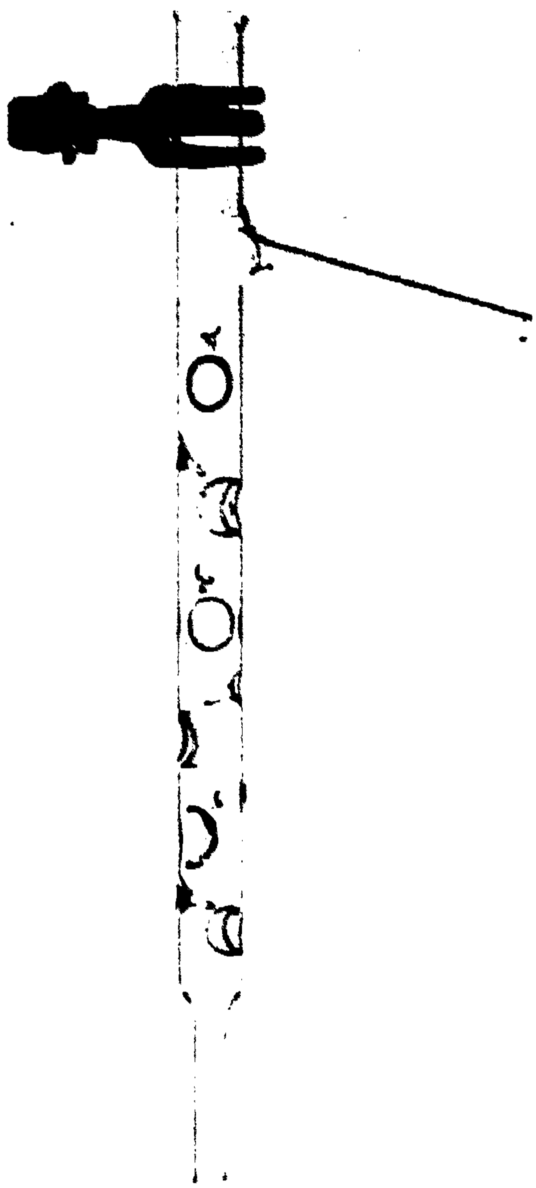


Fig. 11.1

The apparatus shown in Fig. 11.1 is called a Vigreaux distilling column. The combination of bubbles and drip-off points makes this type of column very useful for fractional distillations. Because the column does not flood as easily as one of the glass-bead type, it is particularly effective with organic solvents.

The procedure for constructing the distilling column is simply a combination of two types of seals that you have practiced and two other very simple operations. Since large tubing makes up the main section of the column, it must be fire-cut and sealed. In the process of fire-cutting larger diameters, the tube must be shrunk quite a bit before it is pulled so that the wall thickness at the bottom will not be too thin to work with. The torch will "burn" through the thin glass, and the result will be a large hole.

If it is necessary to fire-cut and seal a piece of tubing that is too short to hold with both hands, attach a piece of glass rod as shown in Fig. 11.2. This will provide an easy means of holding the tubing while fire-cutting. Be sure that the rod is straight and in axial alignment before you begin fire-cutting.

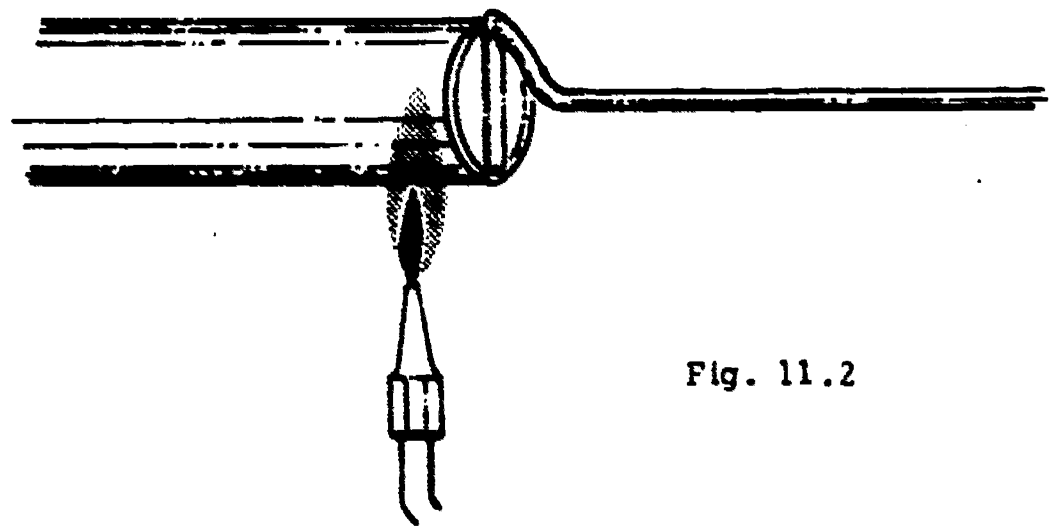


Fig. 11.2

An end-to-end seal is then made between the 25-mm and 12-mm pieces of tubing. Do not forget to anneal the seal and the surrounding area after the joint is completed.

Occasionally, while making a seal a hole will develop. An easy technique for closing the hole is to fill it with molten glass. This must be done before the hole becomes too large. The seal can then be fused to form a relatively smooth surface.

The next step is to make the bubbles on the inside of the column. The column is held so that the point of the flame heats up the spot where the bubble is desired. Once the tubing begins to shrink and the wall starts to thicken, remove the column from the flame and suck on the blow tube until the bubble is the proper diameter. Make sure that the wall is allowed to thicken before the bubble is formed; otherwise, the wall of the bubble will be thin and much too delicate. After the first bubble is made, rotate the column 90 degrees and proceed to make the next bubble. No dimensions are given for the distance between the bubbles. If dimensions were given, they would be only approximations. Much of glassblowing is done by "eyeball"; and so just make the next bubble where it "looks like" it should be.

The drip-off points are made by heating small spots until they soften, by removing the column from the flame, and then by placing a small-diameter carbon rod into the center of the hot spots and pushing until the point is just above the bubble on the opposite wall. A piece of lead from a pencil can also be used for this operation. The column is then annealed.

The side arm is a simple T seal that is bent to the proper angle in the process of fusing the seal itself. When making the T seal, do not forget that two other corks as well as the blow hose are needed to close the system before blowing can be done.

At the bottom of the distilling column there is another drip-off point so that fluid can easily drip back into the boiling flask. This drip-off point is made by sealing a piece of small-diameter rod to the edge of the tube and then by fire-cutting the rod. The point should turn in so that a rubber stopper can slide easily over the tube. This must be done rapidly and with a small flame so that the edge of the tube is not distorted.

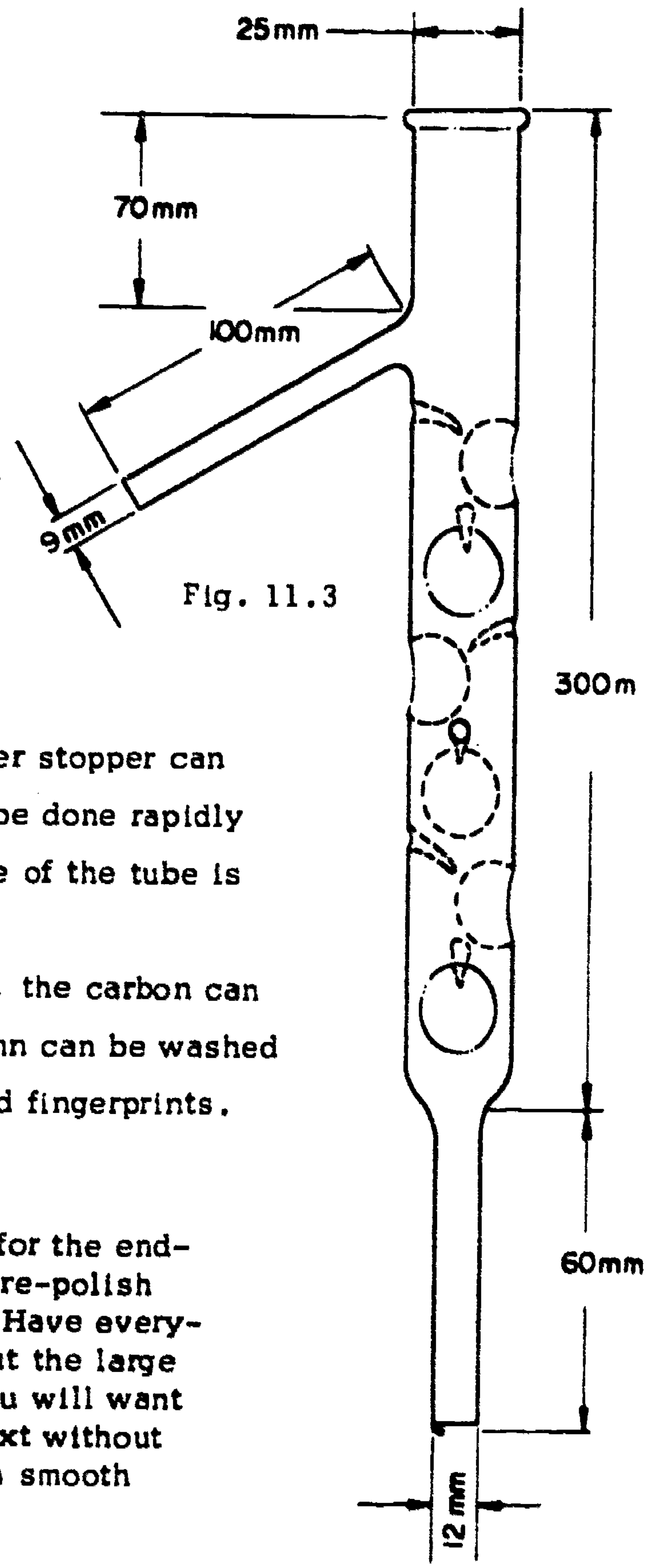


Fig. 11.3

When the whole column is cool, the carbon can be wiped off with a cloth and the column can be washed and rinsed in alcohol to remove dirt and fingerprints.

o o o o o o o o

Make the side arm and 12-mm tube for the end-to-end seal as shown in Fig. 11.3. Fire-polish all ends and put corks where needed. Have everything you need ready before you fire-cut the large tube. Once the glass is heated up, you will want to proceed from one operation to the next without any delays. Try to make all seals with smooth and uniform walls.

o o o o o o o o

Project 12: A COLD TRAP

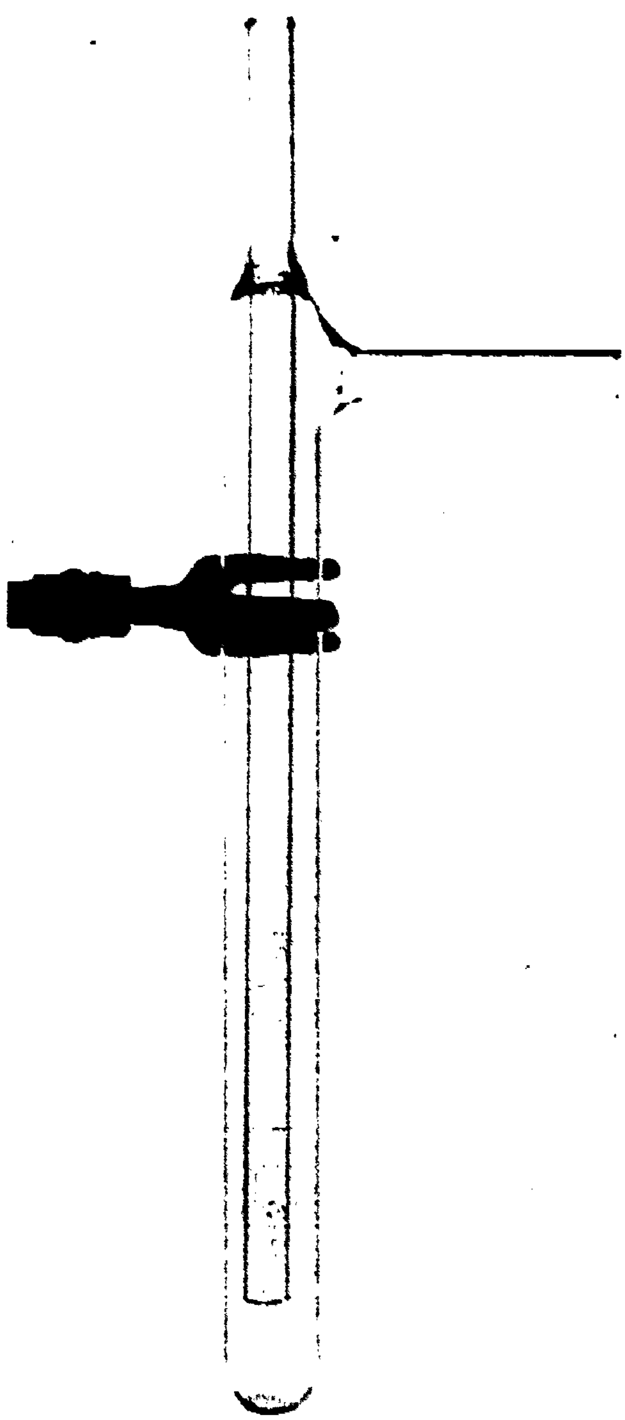


Figure 12.1 shows a cold trap that can be placed in a Dewar filled with Dry Ice or liquid nitrogen to freeze out undesirable gases during an experiment.

The construction of the cold trap involves making a ring seal and a T seal, followed by fire-cutting and sealing off the outside tube. The inner tube and the side arm are prepared before any work is done on the main chamber. It is suggested that the second type of ring seal be used rather than the triple seal.

Immediately after the ring seal is completed, the side arm is attached. The glass should not be allowed to cool completely because it may crack while being reheated for the T seal, even if it has been annealed.

Fig. 12.1

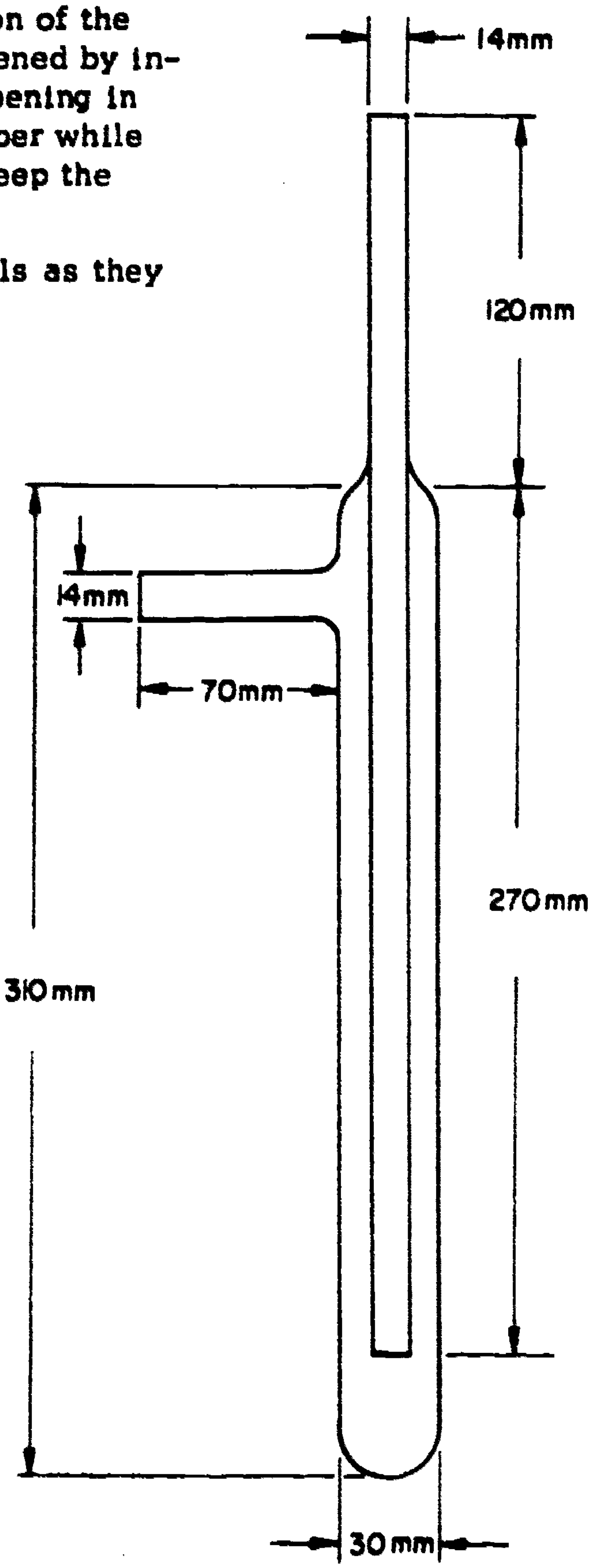
o o o o o o o o

Figure 12.2 is a dimensional drawing of a cold trap. Make the separate pieces and then assemble the entire trap. If the inner tube is not in alignment following the completion of the ring seal, it can be straightened by inserting a tube through the opening in the bottom of the main chamber while applying a gentle flame to keep the ring seal soft.

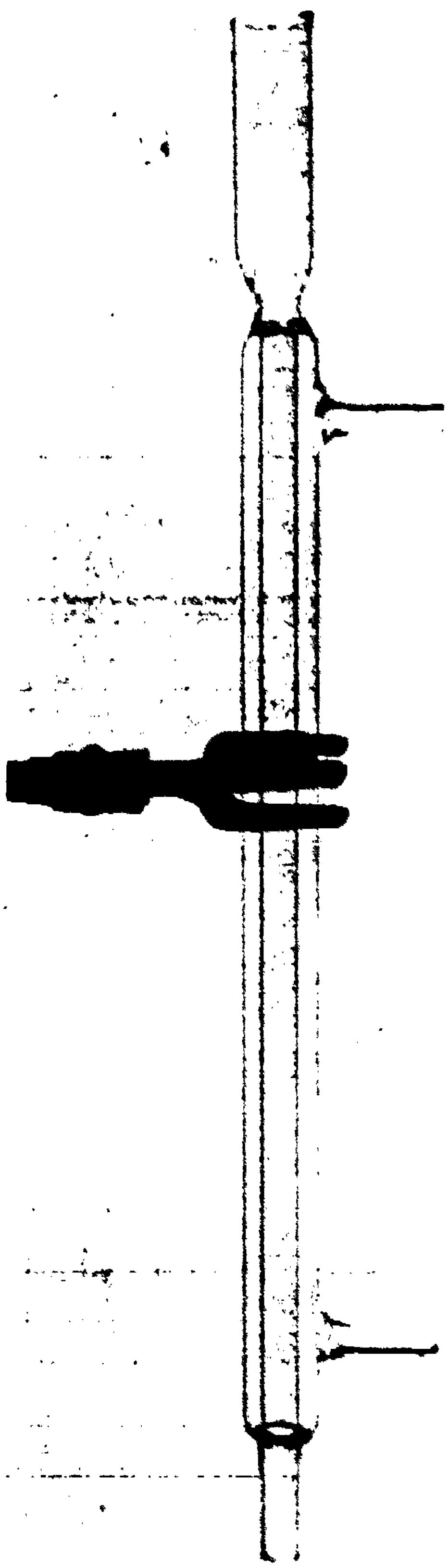
Be sure to anneal the seals as they are completed.

o o o o o o o o

Fig. 12.2



Project 13: A CONDENSER



The apparatus shown in Fig. 13.1 is a water-cooled condenser. It is often used in conjunction with a distillation column to cool and condense vapors in the course of a distillation.

Again, the piece that you will build is just a series of seals and other operations that have been done before. The condenser consists of a ring seal, two T seals, and a variation of the ring seal. This variation, called a shrink ring seal, is the only operation that is new. You start by assembling the first ring seal and the nearby side arm. It is very important that the inner tube be aligned properly.

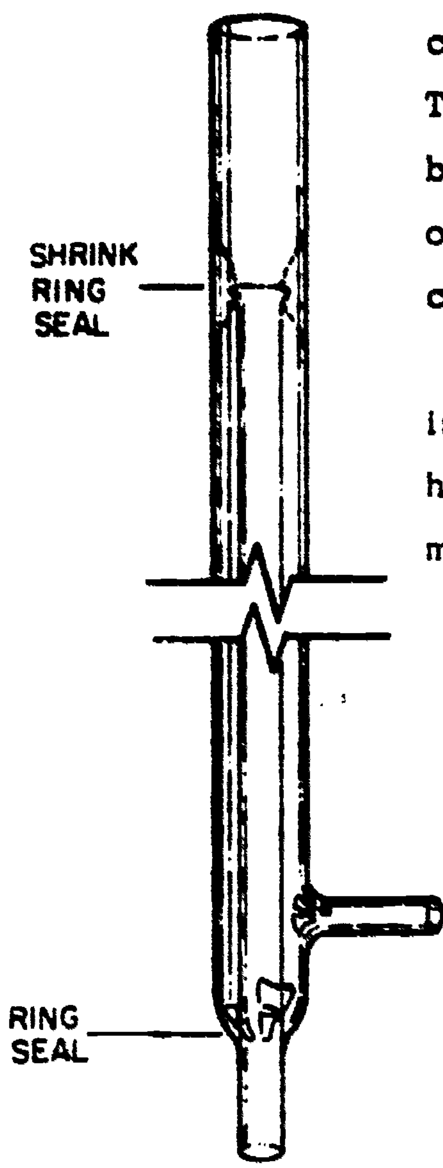
For the shrink ring seal, you must blow into both the cooling chamber and the inner tube. A hose is connected from the side arm to the protruding end of the inner tube, and the blowing hose is connected to the open end of the large tube.

The shrink ring seal is made as if the tube were to be fire-cut. The only difference is that the outside tube is

Fig. 13.1

shrunk until it 's fused with the flare on the end of the inside tube (Fig. 13.2). Care must be taken so that when the tubing is sealed the wall thickness is not too thin or too thick.

Fig. 13.2



After the seal is fused, the end of the cooling chamber can be shaped by blowing. The inner tube should not be constricted at the point of the seal. Blowing takes care of this, too.

Again, the side arm is attached before the glass has a chance to cool too much.

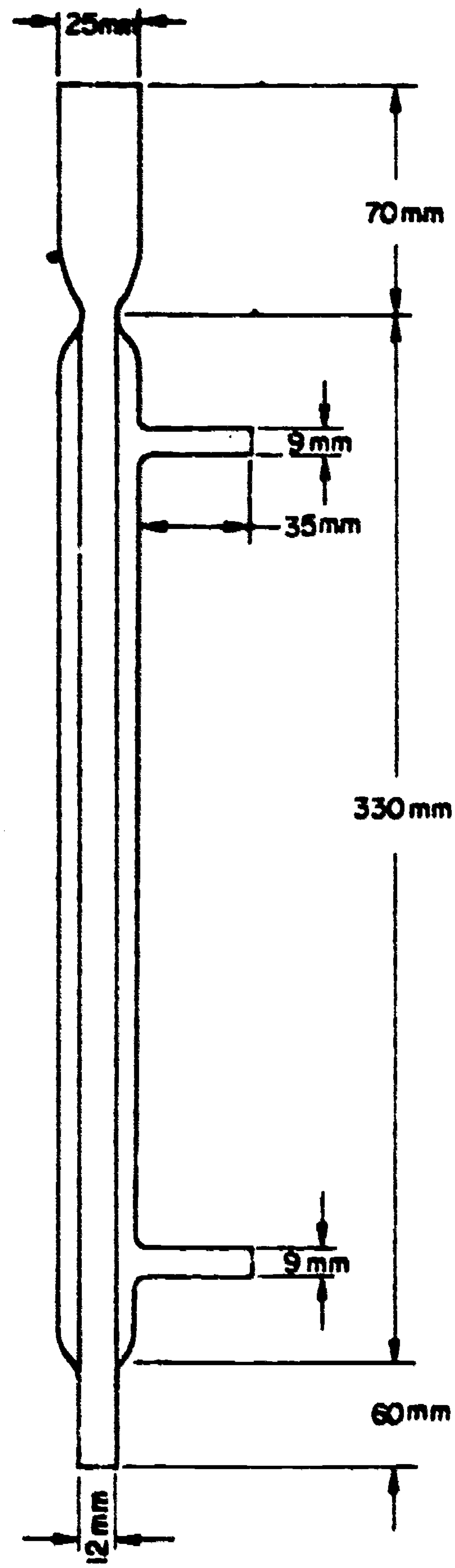


Fig. 13.3

o o o o o o o o o

A dimensional drawing of the condenser is shown in Fig. 13.3. Prepare all the parts beforehand and then proceed with the complete assembly. Do not forget to anneal all seals.

o o o o o o o o o

Appendix 1: SHARPENING TOOLS

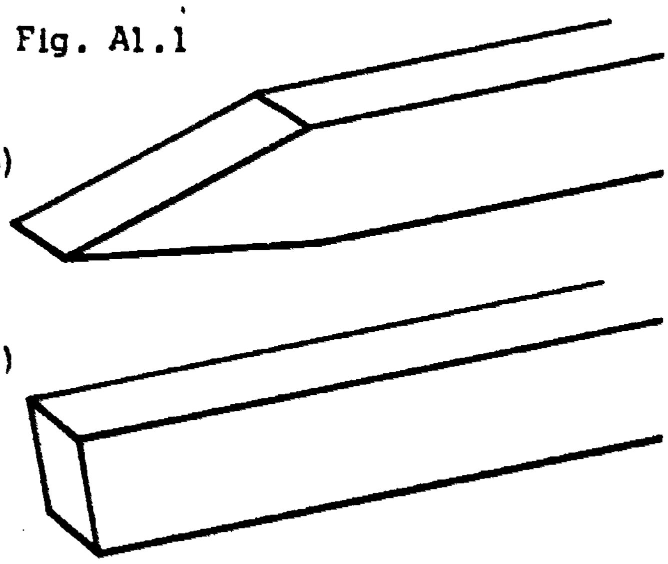
The sharpness of a tool is directly reflected in the quality of the work that it can do. A sharp tool cuts easily, smoothly, quickly, and accurately. A dull tool requires more force to do the same amount of work, lengthens the time for an operation because it cuts slower, produces a rough finish since the tool is likely to chatter, and makes it difficult to cut within the specified tolerance. In addition, a dull tool is more dangerous to use than a sharp tool. Consequently, it is important for you to be able to recognize when tools are dull and to know what to do when they need to be sharpened.

It is important to remember that in the context of tools "sharp" describes the condition of the cutting edge rather than the shape of the cutting tool. The cutting tools shown in Fig. A1.1(a) and (b) are considered sharp as long as the cutting edges are not rounded and not nicked. This is easily determined by looking at the cutting edge. Nicks and a rounded cutting edge can be seen because of the light that reflects from them.

Fig. A1.1

(a)

(b)



The shape of the tool is determined by the job for which it is designed. The angle of the surfaces that form the cutting edge is more acute (see Fig. A1.1(a)) when the material being cut is soft. For example, the tip of a razor blade used to cut hair has an angle of about 7 degrees, whereas the tip of a chisel used for cutting steel has an angle of about 65 degrees. There are two reasons for this. The first is the strength required of the tool: A broader angle is needed for tougher jobs. The second is that the more pointed a tool, the faster it becomes dull. Therefore, as we discuss sharpening cutting tools, you will see that the angles of the cutting point change as the applications change.

In making the density kit you cut and filed a piece of steel with tools that were also made of steel. For this to be possible the tools must have been much harder than the steel being worked or the tools would have dulled rapidly. All steel is made by adding carbon to iron. When the carbon content is greater than 0.3 percent the steel can be made much harder than lower-carbon steel. The amount of carbon does not make the steel much harder or softer in itself, but allows it to be hardened by a process called <u>heat treatment</u>. The high-carbon steel (called <u>tool steel</u>) is made harder by heating it until it is red (about 1400°F) and by cooling it quickly (quenching it) in a bath of oil or salt water. In this state the steel is extremely hard but very brittle. To reduce the chance of cracking, the steel is reheated to a temperature between 300° and 1000°F, depending on how the steel will be used, and quenched as before.

A1.1 The Bench Grinder

A tool that is hardened and tempered cannot be sharpened with a file because the tool and the file are of equal hardness. Therefore, a grinder (see Fig. A1.2) is used that consists of a motor with a grinding wheel at-

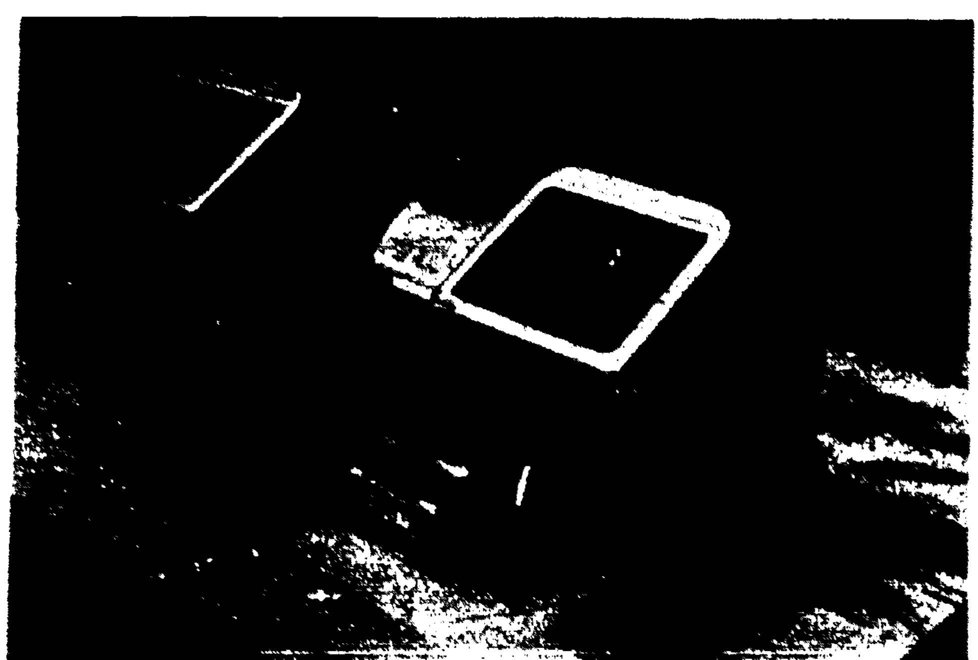


Fig. A1.2

tached to each end of the shaft. The adjustable rests on the front of the grinder serve to support the workpiece. A safety shield is also attached, as shown in the figure.

Grinding wheels are made of small pieces of stone that are bonded together with a glasslike substance. For grinding different materials different types of stone are used. The size and the spacing of the stone chips determine the coarseness of the grinding wheel. A complicated numbering system is used to describe the characteristics of each wheel, but to simplify our discussion we will classify wheels as coarse, medium, fine, and extra fine. Most grinders are equipped with a coarse wheel for rough work and a fine wheel for finish work. Grinding wheels are available in various sizes (diameter and width) and shapes for specialized applications.

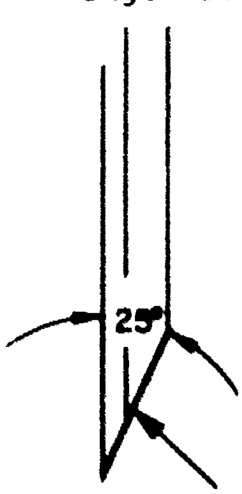
With use, a grinding wheel becomes clogged with metal and the edges of the stone become dull. Sometimes the face of the wheel becomes irregular and must be smoothed before the grinder can be used. The process of reconditioning the wheel is called <u>dressing</u> the wheel, and a tool called a <u>wheel dresser</u> is used. For specifics on wheel dressers and how they are used, ask your instructor or refer to a machinist's text.

ALWAYS WEAR SAFETY GOGGLES whenever you use a grinder. The many pieces of stone and metal thrown by the wheel could go into your eyes. These pieces are very sharp and can cause severe eye damage.

A1.2 <u>Sharpening a Wood Chisel</u>

The wood chisel is one of the most maligned hand tools, and unjustifiably so. The problem is that dull wood chisels are poor tools. However, when sharpened correctly and not abused, they are one of the most useful hand tools you will use. In Fig. A1.3 the blade of the chisel is drawn from a side view. The angle of the two surfaces forming the cutting edge is about 25 degrees.

Fig. A1.3



SURFACE A

The first step when sharpening a wood chisel is to remove the nicks and any rounding of the cutting edge. Begin by adjusting the tool rest so that surface <u>A</u> in Fig. A1.3 will be ground at 25 degrees. Because the tool rest is not calibrated and there is no room for a protractor, this must be done by eye. After loosening the bolts on the tool rest, hold the chisel on the tool rest and tilt the tool rest until all of surface A is in contact with the face of the grinding wheel. Make sure there is about 1/16-inch clearance between the tool rest and the grinding wheel and retighten the bolts. With the grinder switched on, lightly touch the chisel to the grinding wheel. Look at the grinding marks on the surface of the chisel to determine if the rest angle is set correctly, and make readjustments if necessary. Then grind the entire surface of the chisel by moving it laterally across the face of the grinding wheel. Be sure that the blade of the chisel is perpendicular to the face of the wheel; otherwise the end of the chisel will not be square.

When any metal is being ground, heat is produced by the friction between the metal and the wheel. If too much heat is developed, the metal turns blue, loosing its hardness quickly. Therefore, after every few seconds of grinding, the tool should be dipped into a cup of water and left there until it is cool. This procedure is very important. Many cutting tools have been ruined because this precaution has not been taken.

After grinding a wood chisel, the cutting edge is still not sharp enough. The grinding wheel leaves burrs and a rough surface on the cutting edge. Remove the burrs and smooth the edge by hand rubbing the cutting edge on a very fine stone called an oilstone. Oil is used while sharpening the chisel to help maintain the flat surface of the oilstone and to prevent metal buildup in the pores of the stone. Hold the chisel as shown in Fig. A1.4 and move it back and forth as indicated. To ensure that the surface will be flat, be certain not to rock the chisel as you move it. Turn the chisel over and repeat the procedure holding the entire

Fig. A1.4

surface of the blade against the stone. For the cutting edge to be sharp, the adjoining surfaces must be very smooth. When they are smooth, the surfaces will appear shiny but no light will reflect from the cutting edge itself.

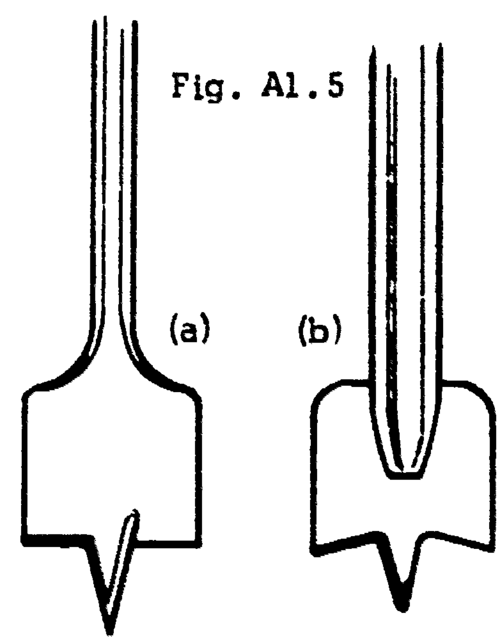
The procedure for sharpening the cutting blade of a plane is the same as for a wood chisel. Because the blade of the plane is simply a wider version of a chisel, even the angle of the cutting tip is the same.

A1.3 Sharpening Power Bits

Enlarged views of the cutting end of two types of power bits are depicted in Fig. A1.5(a) and (b). Both bits are used the same way, but because of their shape, one of the sharpening steps is different.

To reduce friction, all cutting tools are designed so that the minimum surface area is in contact with the workpiece. The surfaces that form the cutting edge are always made so that the angle between them is less than 90 degrees, providing clearance. In the case of the wood chisel and the plane cutter, the clearance is provided by the angle at which each was held. With power bits and most other cutting tools, the clearance must be ground into the tool as it is sharpened. The angle between the edge that is ground and the workpiece is called the clearance angle or relief angle (see Fig. A1.6).

Fig. A1.5

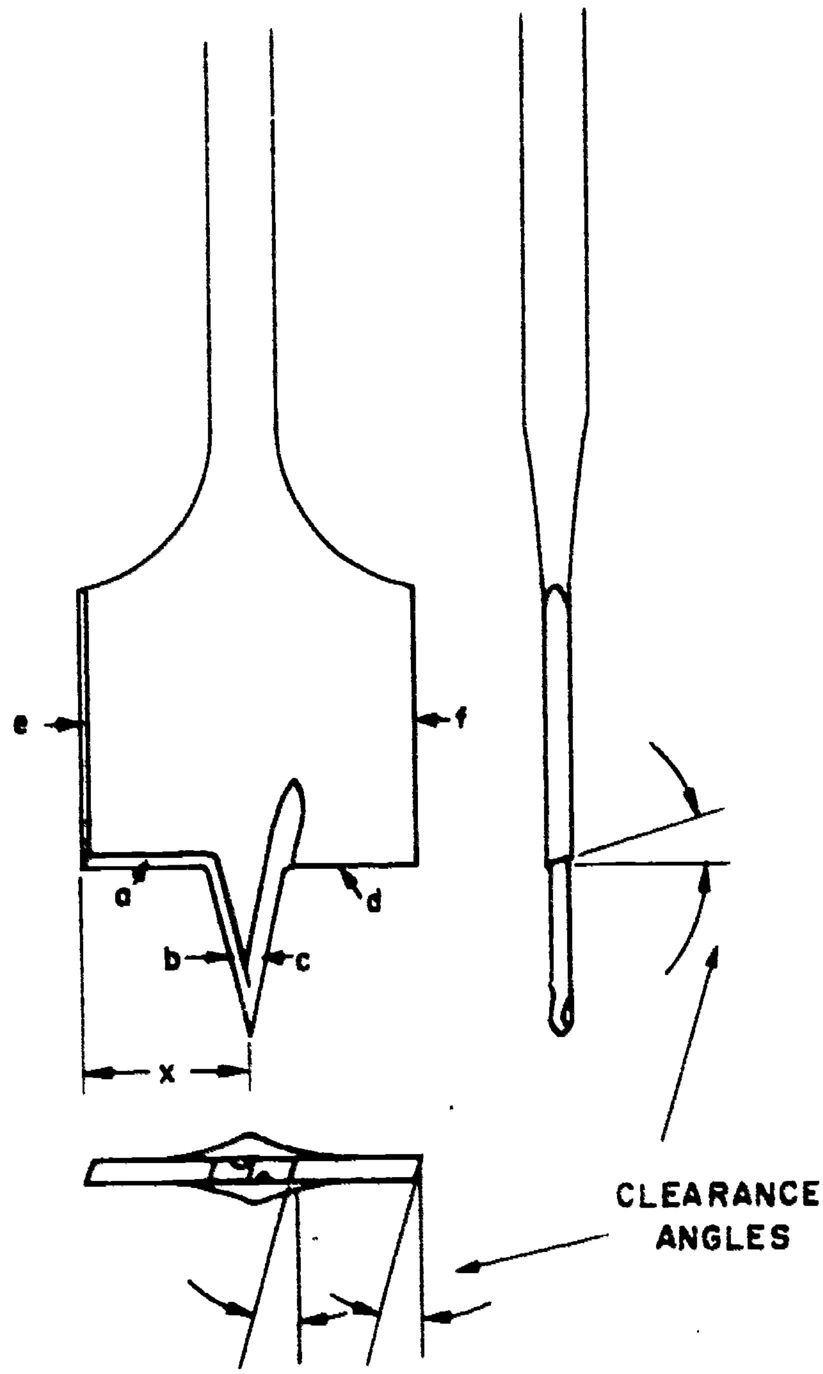


Each cutting edge of a power bit must be sharpened to give clearance. To sharpen the bit, you must grind edges a, b, c, and d. However, you should not grind edges e and f because this will cause the size of the drill to be reduced.

When a wood chisel is sharpened, the tool rest is tilted and the chisel is held against it to grind the angled surface. But because there are so many cutting edges on a power bit, it is easier to hold the bit by hand. By looking at Fig. A1.7 you can see that the surface being ground is not at a right angle to the power bit. By raising or lowering the tool rest, you can achieve the desired angle.

When sharpening any cutting tool that rotates, you will find that the greatest problem is to grind the tool symmetrically. If a drill is not symmetrical, the hole it drills will be too large. For the power bit, both the length of the cutting edges a and d and the distance from the point of the drill to cutting edges a and d must be the same. If cutting edge a is longer than cutting edge d the point of the drill (used to make a pilot hole and to act as a guide) will be off center, and the diameter of the hole will be twice the distance from the point to the edge of the drill (dimension x). If more material is removed from edge a than from edge d only edge d will cut the wood. The result of this is that more side pressure would be applied to the drill, causing the hole to be oversized.

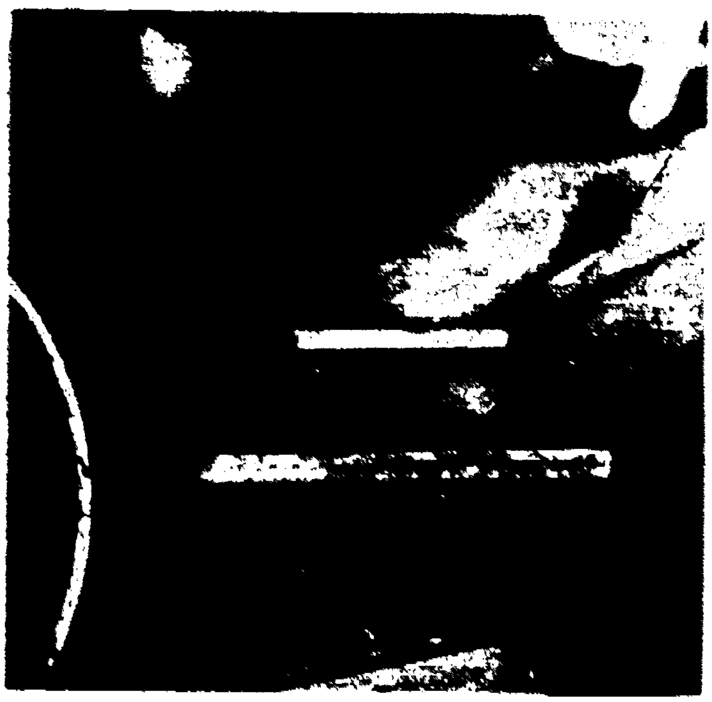
Fig. A1.6



Because of its contour, a power bit is difficult to sharpen symmetrically. It is difficult to take meaningful measurements of the length of cutting edges. Therefore, power bits must be sharpened by eye and with an acquired "feel."

To sharpen a power bit, grind away the rounded cutting edge a, removing as little material as possible. Be careful that the side of the grinding wheel does not touch surface b. Now turn the drill over and repeat the process on edge d. Try to use the same amount of pressure for the same period of time so that you remove the same amount of material from edge d as you did when sharpening edge a. Use the side of the grinding wheel to sharpen edges b and c in turn, again using the same pressure for the same time period. Be sure to rotate the drill slightly to produce the proper clearance. Use a steel rule to see if edges a and d lie in a straight line, and visually check that the rule is at right angles to the axis of the power bit. To determine if the point of the drill is centered, measure the distance from the point to the end of cutting edges a and d.

Fig. A1.7



The power bit shown in Fig. A1.5(b) is easier to sharpen because edges a and b are sharpened simultaneously, as are edges c and d. Simply hold the drill at an angle to use the side of the wheel to sharpen the point (and provide clearance) while the face of the wheel sharpens the cutting surface. As before, take the same precautions to ensure that the drill is sharpened symmetrically.

When using a power bit for drilling holes in wood, it is not necessary to use an oilstone to further sharpen the cutting edges. For use in drilling plastic, however, it is essential to make the drill as sharp as possible. Therefore, you should use an oilstone as you did when sharpening the chisel or plane cutter.

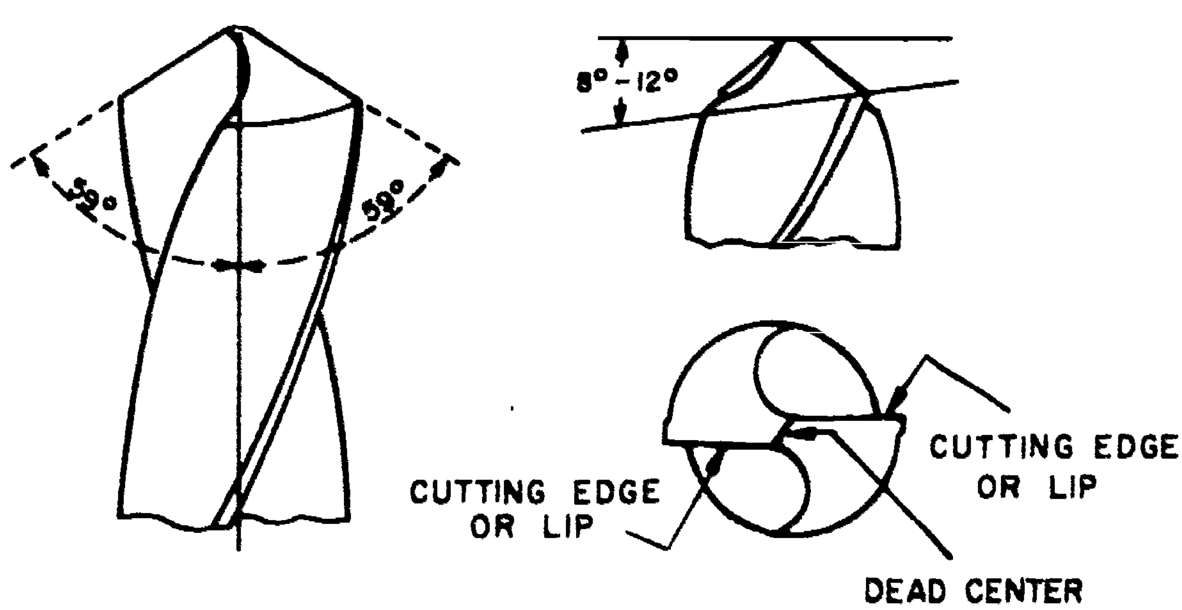
As you can see after reading this explanation, power bits are not meant for precision drilling. However, with a little experience and care you will be able to sharpen them well enough for most uses.

A1.4 Sharpening Twist Drills

Because twist drills are designed to drill holes to very close tolerances they must be sharpened precisely. Some shops have special tools for grinding drills, but if they are not available you can sharpen them by hand.

There are three important points to consider when sharpening a twist drill (see Fig. A1.8). First, both cutting edges must be the same length and must be sharpened at the same angle or the resulting hole will be oversized. Second, clearance must be provided for both cutting edges. (The reasons for the first two points should be obvious from our earlier discussions.) The third point involves the dead center of the twist drill. Because the dead center does not remove material, it must be pushed into the workpiece by the downward force exerted on the spindle of a drill press. To minimize this force, the dead centers should be as small as possible.

Fig. A1.8



While sharpening a twist drill, hold it as shown in Fig. A1.9 with the drill at a 60 degree angle to the face of the grinding wheel. After a little experience you will be able to judge this angle accurately. Now touch the cutting edge to the face of the grinding wheel and pivot the drill over your right forefinger by moving your left hand downward, as indicated by the arrows. Never allow the shaft of the drill to be higher than the cutting end

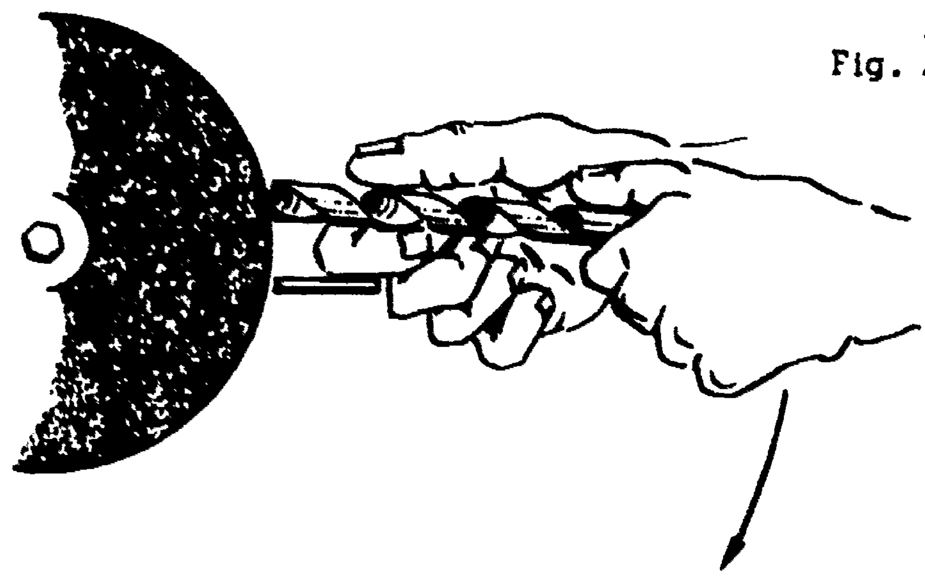


Fig. A1.9

because the drill will not cut. By keeping the drill in contact with the grinding wheel as you pivot it, clearance will be ground for the cutting edge. If the angle is too small, the drill will not cut. If the clearance angle is too big, the drill will dull more rapidly. See Fig. A1.8 for the proper angle.

To prevent the drill from overheating, always keep it moving when it is in contact with the grinding wheel. If the drill is dipped in water after every few passes on the grinding wheel, it will not overheat.

After two or three passes over the grinding wheel, check the angle of the cutting edge with a drill-point gauge, as shown in Fig. A1.10. (A protractor head for a combination square can be used as a substitute for a drill-point gauge.) Make corrections if necessary, and then check the cutting edge to make certain it is sharp. Repeat the procedure to sharpen the second cutting edge. At this point you must check the length of both edges as well as

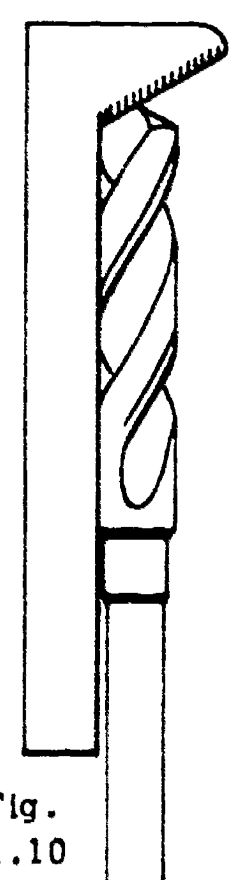


Fig. A1.10

the angle of both edges. On some drill-point gauges a scale is conveniently provided for measuring the length of the edge while measuring its angle. However, a steel rule or caliper can also be used. The length of the cutting edge is measured from the circumference of the drill to the point at which the dead center joins the cutting edge. Be sure everything is correct because any error in the measurement of the length of the cutting edge will be reflected in the size of the hole the drill will make. If you follow the steps correctly the drill will make the correct size hole and the dead center will be sufficiently small.

All cutting tools become dull with use. However, because twist drills are used with power drills to drill hard materials, they receive more abuse than the other tools discussed here. If a twist drill is used after it becomes dull, more force is required to make the drill cut. Excessive force creates more friction, which causes the drill to heat up and lose its hardness or to chip or crack. If any of these problems should occur the drill must be ground down far enough to remove the soft steel or until the chip does not interfere with the cutting edge. (Use a coarse wheel at first and then switch to a fine wheel.)

Always remember to check the drill that you will be using because it will save time if you sharpen the drill before it is damaged and because properly sharpened tools produce much better work.

A1.5 Sharpening Various Tools

So far we have discussed only a few tools and how they are sharpened. Some tools require only a brief description of the sharpening procedures. Several tools require special machinery to ensure the accuracy of the cutter or take so much time that it is less expensive to send them to a professional tool grinder. Others cannot be resharpened and must be replaced once they become dull. In this section we will mention some of the tools you have used in the course and describe what to do when they become dull.

Auger bits are not made of hardened tool steel. Therefore, they can be sharpened with a file. Clamp the shaft of the auger bit in a machinist's vise with the cutting end facing upward. File the cutters (refer to Fig. 1.25) just as you would grind the cutting edges of a power bit, making sure that the file is angled correctly to provide the proper clearance. The edges of the spurs are sharpened by filing the inside of the spurs. Remove as little material as possible to prolong the life of the bit. Be careful to avoid filing the screw. Smaller auger bits will require the use of small delicate files; so go slowly and be careful.

A center punch is made of hardened tool steel and must be sharpened on a grinder. Although the center punch is not a cutting tool, the point must be sharp to function properly. To sharpen a center punch, simply hold it at a 45 degree angle to the face of the grinding wheel and spin the punch as you grind it. Make sure that the end comes to a point.

Circular saw blades should be sharpened by a professional. Because the circumference of the blade must be true to the shaft of the table saw, circular saw blades must be sharpened on a special machine. A good hardware store usually provides this service.

A die for cutting threads cannot be resharpened. Once it becomes dull, a die should be discarded and a new one purchased.

Files fit into the same category as dies; there is no way to resharpen them. However, a dull file should not be thrown away because it can be used in many other ways around a shop. Files are made of very good tool steel, and when they are dull they can be ground to make knives or cutting tools for a wood lathe.

Hacksaw blades cannot be resharpened; but again they are made of good steel and can be used for other purposes.

Handsaws can be sharpened by hand. A special tool can be purchased to set the teeth of the saw. However, to do a good job takes experience. Hardware stores generally provide this service, and the cost is not prohibitive.

Scribers and other layout tools can be sharpened on an oilstone. Simply spin the tool while rubbing it against the oilstone.

Screwdrivers are not often thought of as being dull or sharp. However, sometimes the end becomes so rounded that it continually slips out of the slot of a screw. Other times the end of the screwdriver has been chipped. To sharpen a screwdriver, grind the end on the face of the grinding wheel. Be sure that the end is square to the axis of the screwdriver. If the end has been ground many times, you will have to grind the sides of the screwdriver as well.

Taps cannot be resharpened. Because so much force is required when using a worn tap, the tap often breaks off in the hole. Therefore, make sure a tap is sharp before using it; otherwise you may ruin the piece you are making.

There are many other tools that require sharpening but have not been mentioned in this appendix. Most of them require professional sharpening, whereas others do not. After your exposure to this appendix you should be able to make informed judgments concerning dull tools you may come across.

The most important things to remember about the general maintainance of tools are to keep them sharp, to use them only for the operation for which they were designed, and to keep a light coating of oil on them, which will prevent them from rusting.

Appendix 2: OPERATIONS ON A METALWORKING LATHE

This appendix is an introduction to the metalworking lathe and some of the simpler operations that are possible with it. All the information about a lathe itself and descriptions of all the operations that can be performed cannot be included here. However, where possible, explanations are expanded to provide information beyond that needed to make the projects. If you have any additional questions, ask your instructor or refer to a machine-shop textbook.

The dry calorimeter in Fig. A2.1 (the first of two projects you will make) is used in an experiment to determine the relationship between electrical energy and thermal energy. The second project is the joule cylinder (Fig. A2.2), which is used to determine the relationship between thermal energy and gravitational potential energy.

Fig. A2.1

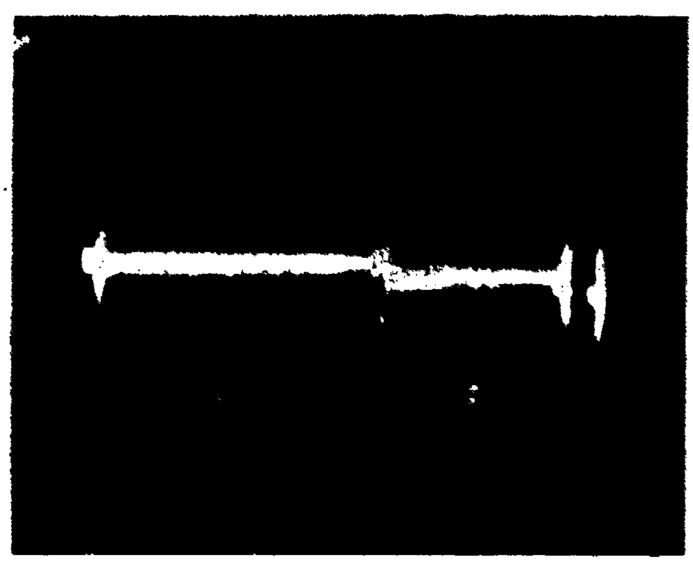


Fig. A2.2

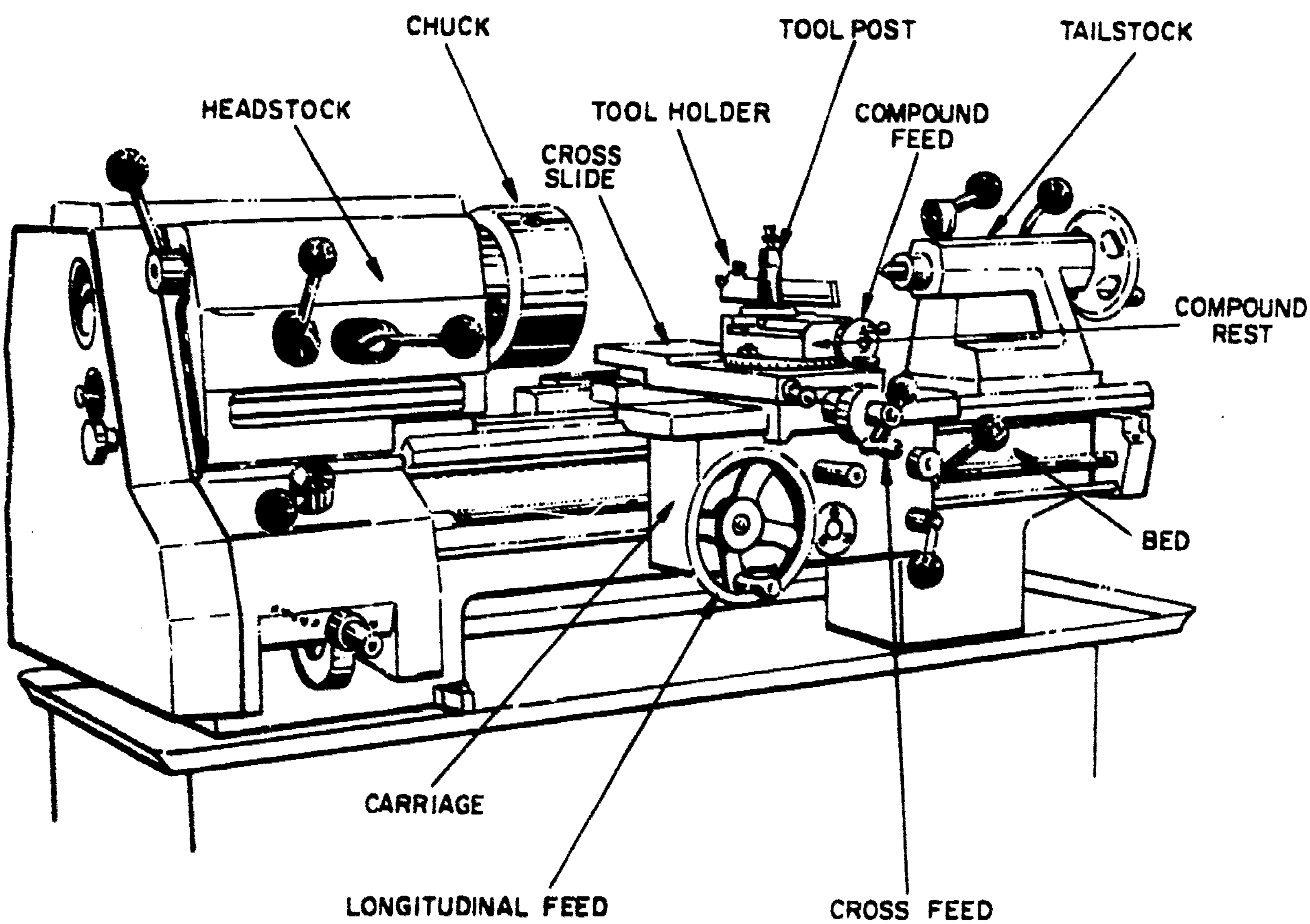
A2.1 The Lathe

The <u>lathe</u> is one of the most versatile power tools ever invented, and its main function is to produce pieces that are cylindrically symmetric. (Other operations can be performed with the proper attachments.) Most power tools are designed so that material is removed by forcing the workpiece into contact with a spinning cutter, as in the drill press, table saw, and so on.

The lathe removes material by forcing the cutting tool into a rotating workpiece, thereby producing the desired shape. The movement of the tool can be precisely controlled, making it relatively easy to produce pieces to a tolerance of ±0.001 inch. Even greater degrees of accuracy are obtained with high-precision lathes.

The drawing in Fig. A2.3 has the most important parts of a lathe labeled. Because lathes come in many different sizes and types, the location and the kinds of controls may differ from one lathe to another. Consequently, it is important to know the function of each knob or lever before turning on the power.

Fig. A2.3



The basic concept behind the design of all lathes is that a workpiece (the stock being machined) is attached to a shaft rotated by a motor. The rotating shaft and its drive system are located in a casing called the headstock. The drive system, which in turn is connected to the motor, consists of a series of pulleys and belts or gears whose ratio can be changed to vary the speed of the shaft. Other than the tailstock, the remaining parts of the lathe are designed to move the cutting tool in a precise manner.

A2.2 Holding Stock in a Lathe

Of the different methods for holding stock in a lathe the use of a chuck is the most common. Although designs may differ, all chucks operate on the same basic principle. Each has movable jaws that can be adjusted to hold stock firmly.

The most common type, and the easiest to use, is a three-jaw universal chuck (Fig. A2.4). Because the three jaws move in unison, this type of chuck is self-centering (within 0.003 inch) and can hold circular-, triangular-, or hexagonal-shaped stock. It is equipped with one set of jaws that can hold small pieces from the outside and larger pieces from the inside, as in Fig. A2.5(a) and (b). Another set of jaws, illustrated in Fig. A2.5(c), is used to hold large-diameter stock externally.

Fig. A2.4

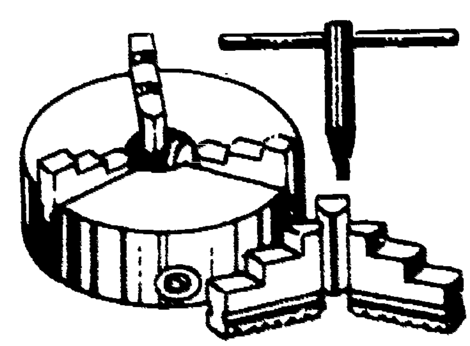
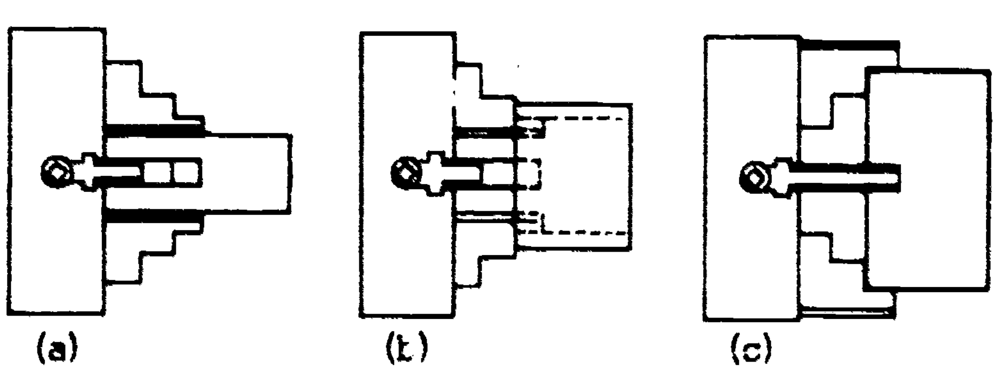


Fig. A2.5



Each jaw of the chuck is marked with a number corresponding to the slot into which it fits. To change the jaws, open them as wide as possible by rotating the chuck wrench counterclockwise and remove one jaw at a time. If you look into one of the slots after the jaw is removed, you will see a spiral gear that rotates as the chuck wrench is turned and meshes with the teeth on the back of the jaw. The jaws must be engaged in the proper order to maintain the axial alignment. This is done by first rotating the spiral gear until the leading tooth is just behind the edge of slot No. 1. The jaw is then slid into the slot and the chuck wrench is turned clockwise just enough to engage the jaw. Then jaw No. 2 is placed in its slot and engaged in the same way, and then No. 3.

Another type of chuck, called a <u>collet</u>, is illustrated in Fig. A2.6. The diameter of the hole through the axis of the collet determines the size of the stock that can be held. The conical end has three or four slots that form the jaws. The other end is threaded and screws into the <u>drawbar</u>. Figure A2.7 is a drawing of the necessary parts, and Fig. A2.8 is a cutaway of the headstock that shows how these parts are assembled in a lathe. As the drawbar (<u>a</u>) is rotated clockwise by hand, the collet is pulled into the headstock, and because of the matching taper in the collet sleeve (<u>c</u>), the jaws are tightened onto the stock.

Fig. A2.6

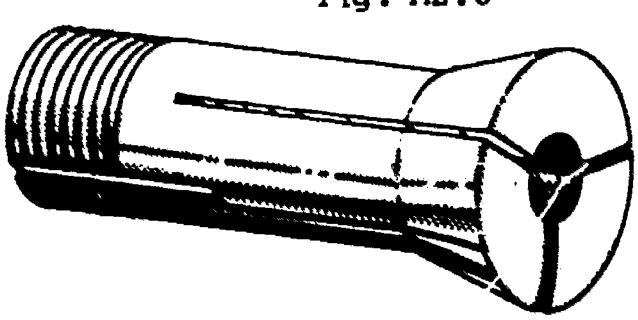
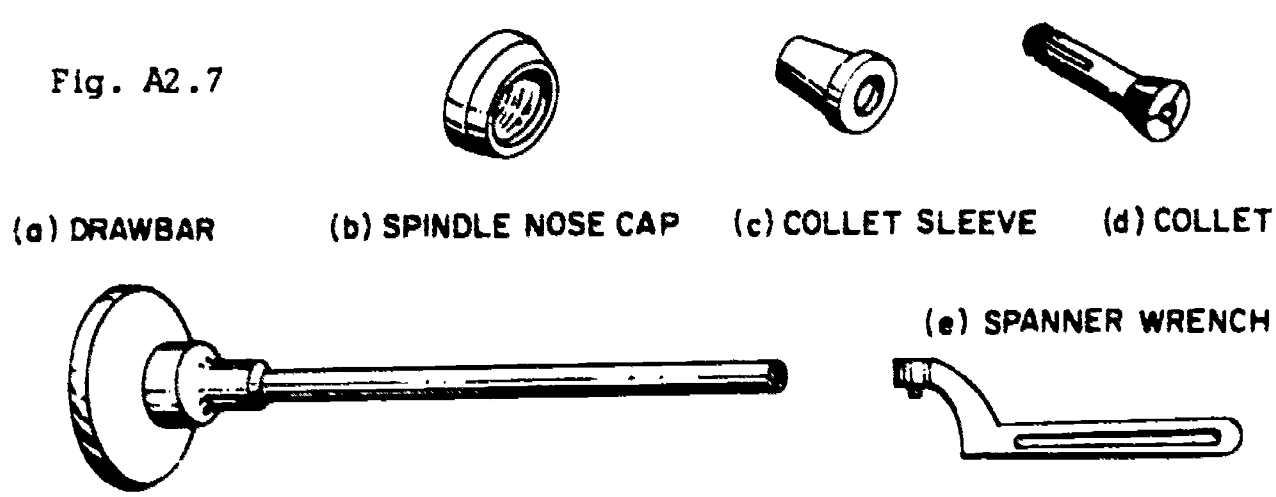


Fig. A2.7



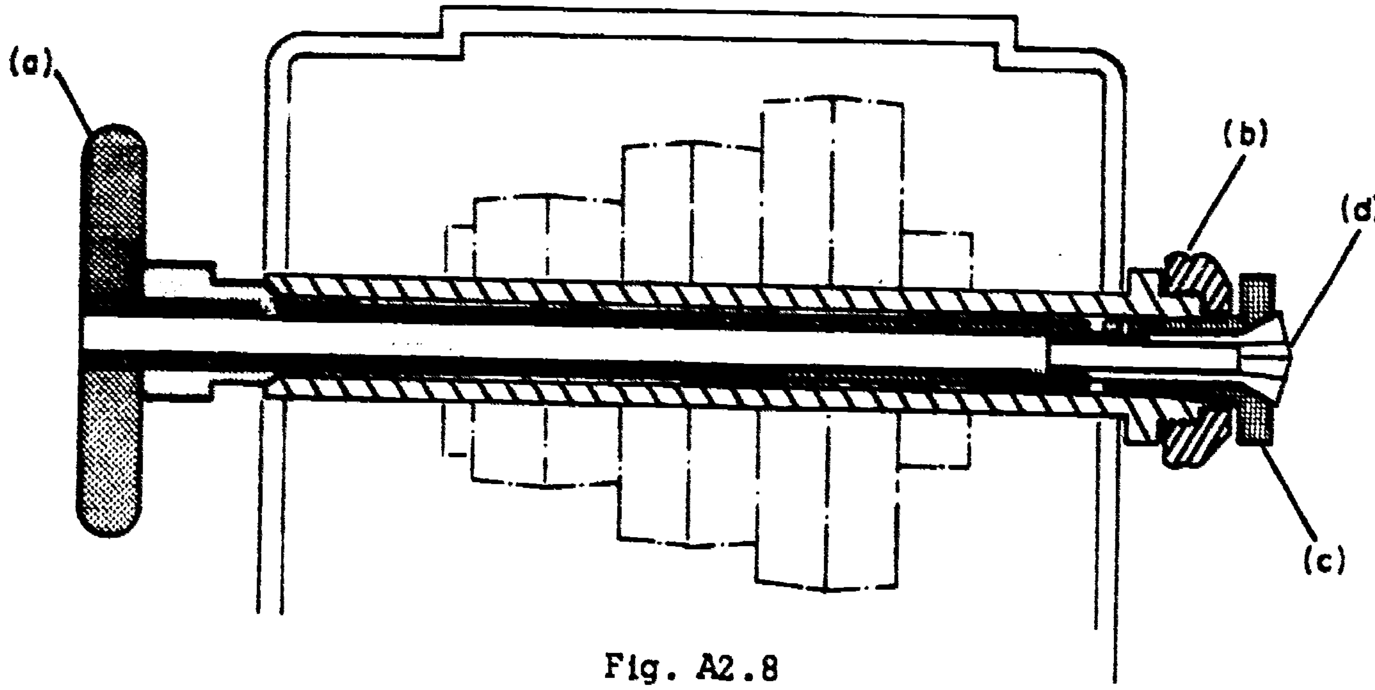


Fig. A2.8

The advantages of collets are that they center the stock accurately and are convenient for repeated operations. Because of their small size, they are less likely to interfere with the compound rest when a piece is machined close to the chuck. The main disadvantage is that the diameter of the workpiece must be within ±0.001 inch of the size marked on the collet. Since collets come in steps of 1/32 or 1/64 inch, they can hold only standard-diameter stock.

The three-jaw and collet chucks have two disadvantages in common. First, they can hold only symmetrically shaped stock (cylindrical, triangular, hexagonal). Second, the center of the stock must always lie along the axis of the chuck, and the tolerances within which the stock can be centered deteriorate as the jaws wear. The four-jaw independent chuck (Fig. A2.9) overcomes both of these difficulties. Each jaw can be moved independently by means of its own adjusting screw, which enables the stock to be adjusted off-center. Furthermore, the accuracy of the four-jaw independent chuck is not limited by the wear of a gear or a jaw because any wear can be compensated for in the process of setting up the piece in the chuck.

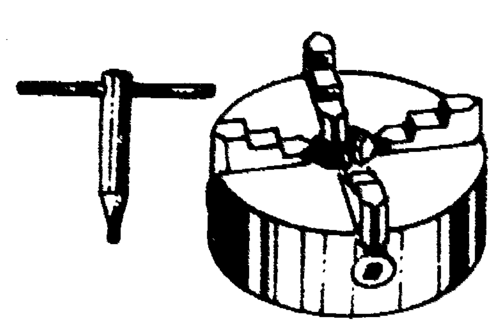
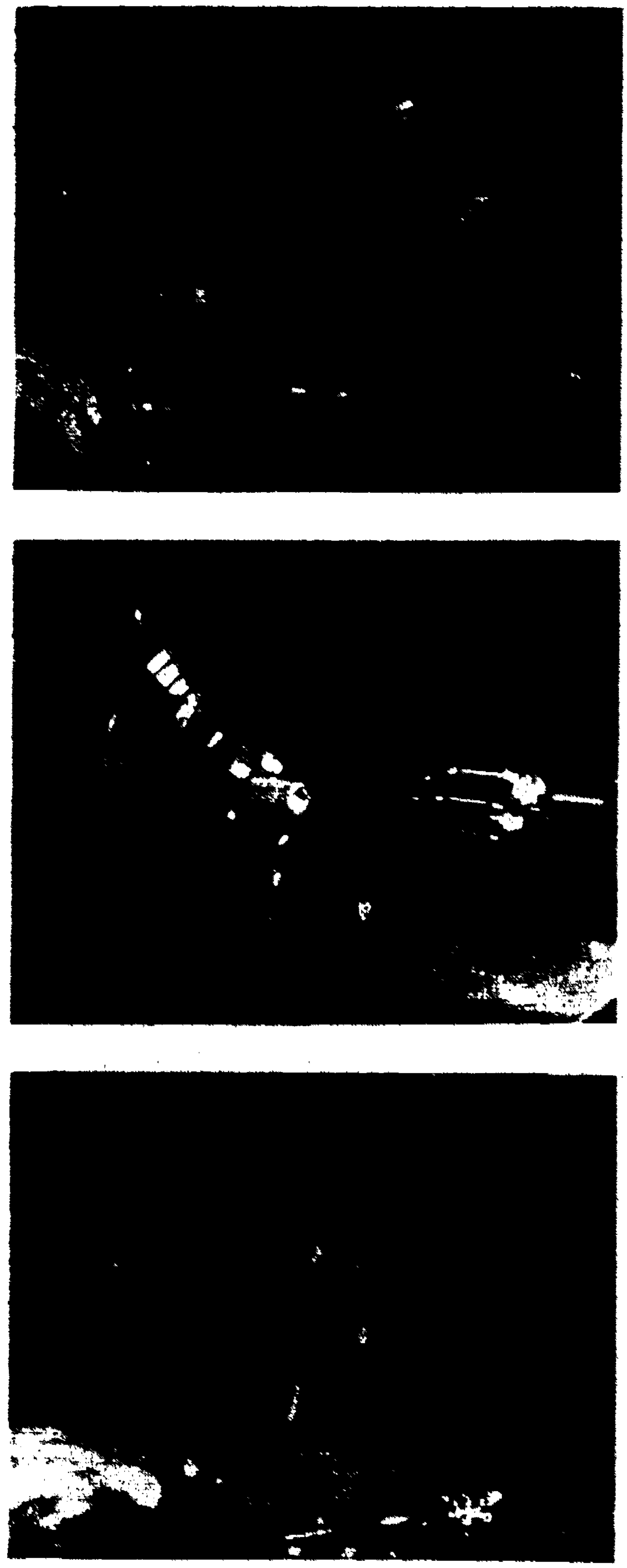


Fig. A2.9

Figure A2.10 shows three examples of operations that can be performed with a four-jaw chuck: (a) ordinary machining to fine tolerances, (b) drilling a hole off-axis, and (c) machining a plumbing elbow.

Fig. A2.10



(a)

(b)

(c)

The main disadvantage of a four-jaw chuck is in the amount of time needed to set up an operation. Because a three-jaw chuck is suggested for the projects in this section, the setup procedure for a four-jaw chuck will not be described. However, it is adequately described in most machine-shop texts.

When using any chuck, be sure that the workpiece is held tightly but not so that its surface is marred by the jaws. Never leave a chuck wrench in a chuck at any time. If the lathe is turned on, the wrench will be thrown and someone could be seriously injured.

A2.3 Cutting Tools

There are different shapes, sizes, and qualities of cutting tools used with a lathe. Usually the operator grinds the tool for a specific operation. As with other cutting tools, lathe tools (see Fig. A2.11) are ground with clearance for the cutting edge. Because the angles of the surfaces on a lathe tool vary depending on the use of the tool, it is impractical to go into a full discussion of lathe tools. However, you should be able to recognize what operation each shape is designed for. Figure A2.12 shows some of the tools you are likely to see and their uses.

Fig. A2.11

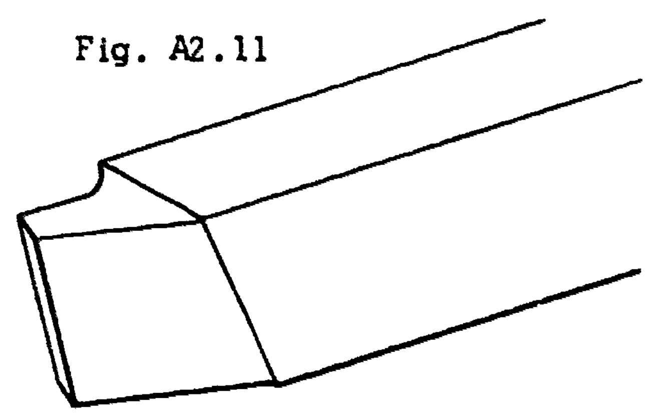
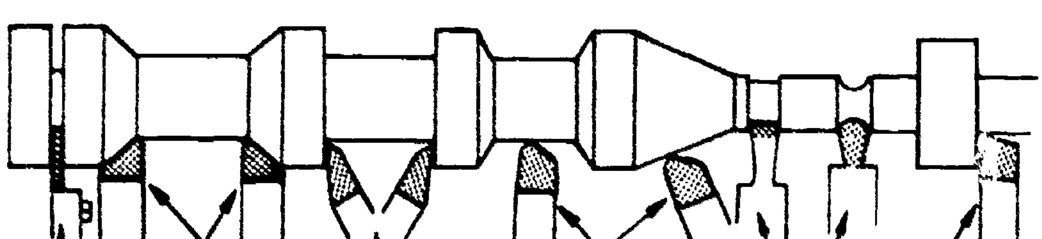
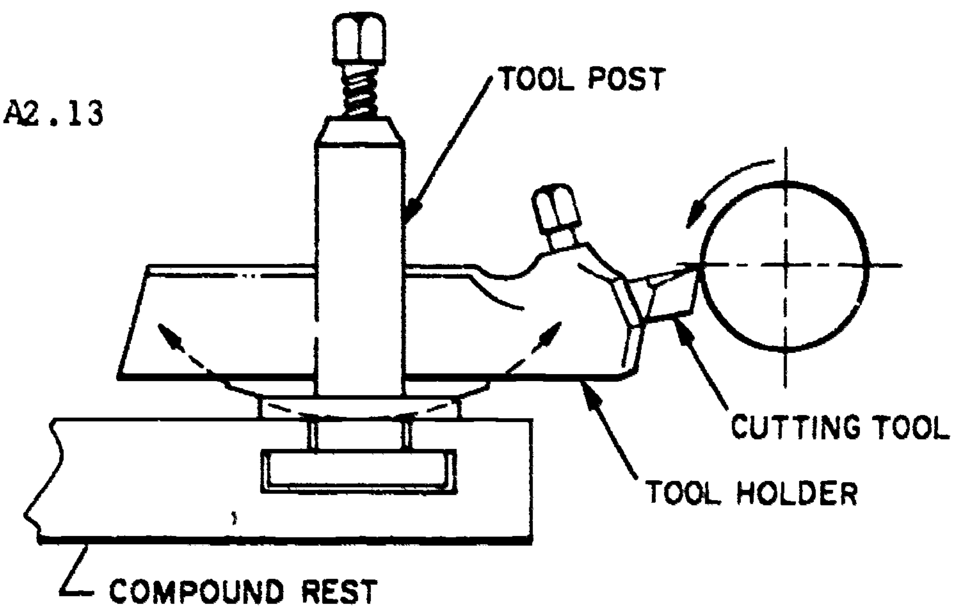


Fig. A2.12



The cutting tool is held in a tool holder and is fastened by means of a bolt (Fig. A2.13). The tool holder, in turn, is held in the tool post. By loosening the bolt at the top of the tool post, the holder can be pivoted up and down, slid in and out, and rotated sideways. This versatility makes it possible to adjust the position of the holder for any tool or operation.

Fig. A2.13



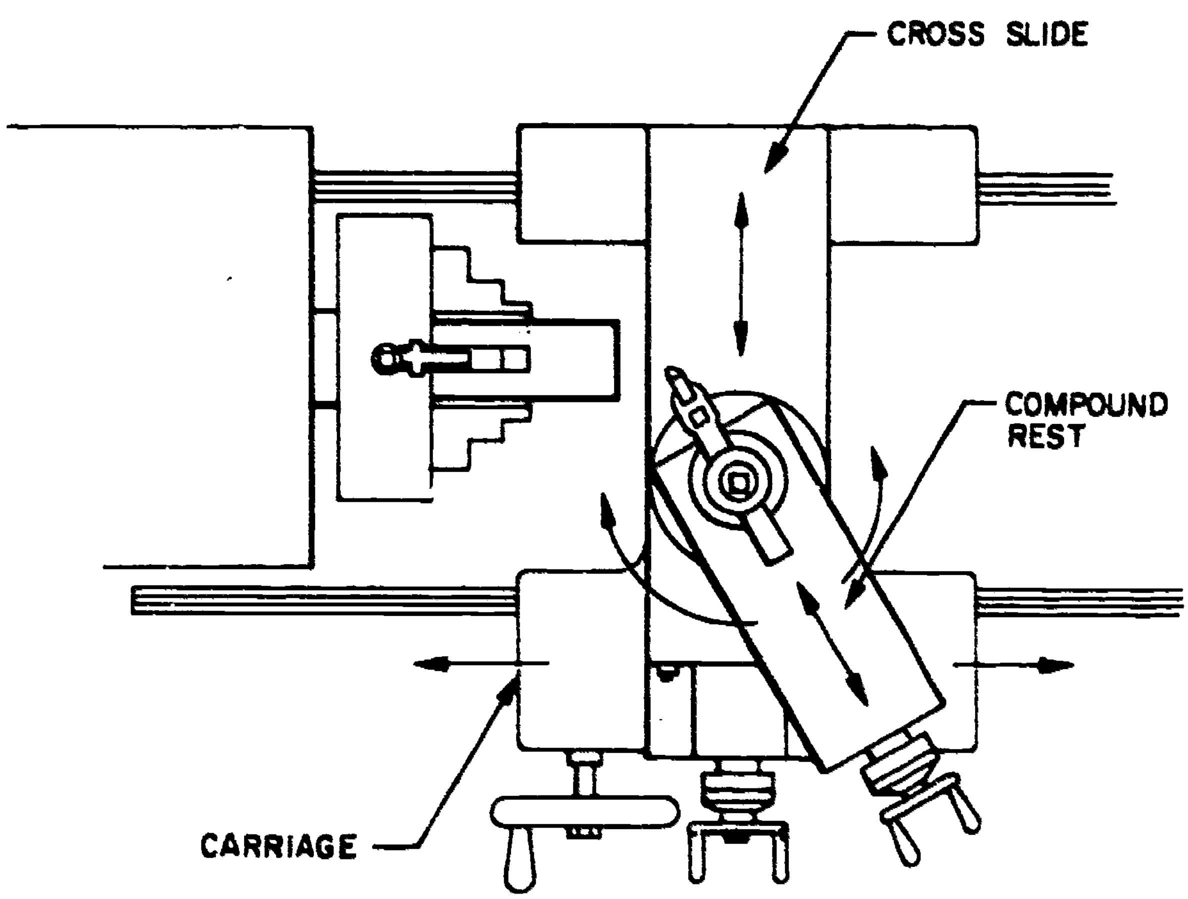
A2.4 Moving the Tool

Looking back at Fig. A2.3, you will notice that there are three different feed controls: the longitudinal feed, the cross feed, and the compound feed. They are all part of a mechanism called a carriage. Machined into the bed of the lathe are a series of tracks, called ways, that run parallel to the axis of the main rotating shaft of the lathe. They act as guides and bearings along which the carriage can slide. The motion of the carriage, and therefore of the tool, is controlled by the longitudinal-feed wheel. By rotating the wheel clockwise the carriage moves away from the headstock. A counterclockwise rotation produces the opposite movement.

Mounted on the carriage are two other feed controls. Machined into the top of the carriage is a guiding track perpendicular to the axis of the lathe. The cross slide is moved along this track by rotating the cross-feed knob (Fig. A2.3). On top of the cross slide is the compound rest, which can be pivoted through 360 degrees and locked at any angle. The base of the compound rest is calibrated in degrees for convenient adjustment. When the compound-feed knob is rotated, the tool moves at the angle at which the rest is set. On top of the compound rest is a "T" slot into which the tool post can be slid and fastened.

In order to move the tool a precise distance, both the compound feed and the cross feed are equipped with dials calibrated in thousandths of an inch. A clockwise rotation of either feed knob will move the tool away from the operator. Figure A2.14 will enable you to understand the possible movements of the cutting tool.

Fig. A2.14



o o o o o o o o

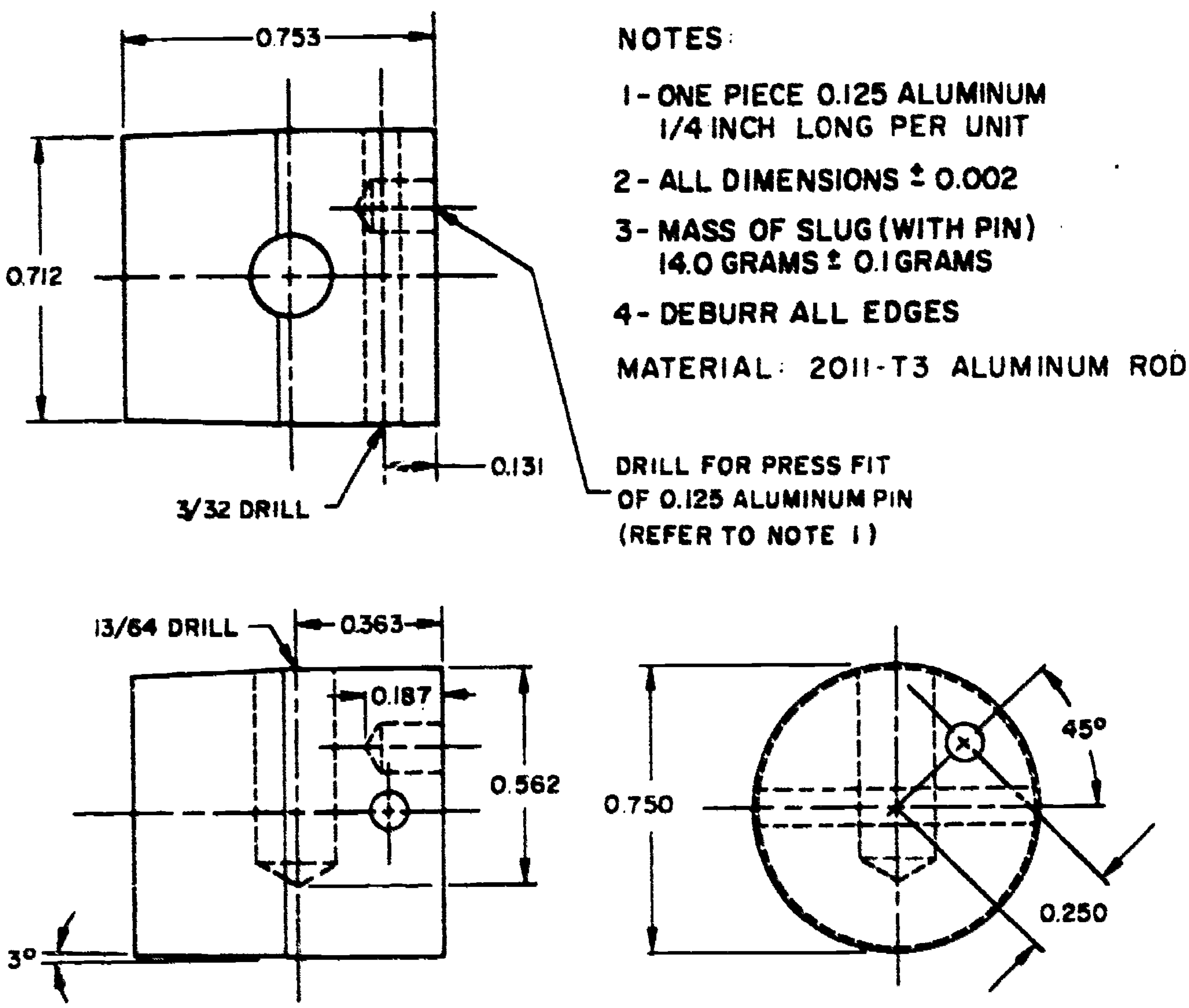
With the lathe turned off, move all the feed controls. Use your left hand on the longitudinal feed and your right hand for the others. Try to get the "feel" and coordination of the different feeds.

o o o o o o o o

A2.5 Facing

Figure A2.15 is a dimensional drawing of the dry calorimeter. Figure A2.16 is provided to assist in the discussion of the operations and the order in which they will be performed. As in every project you have made,

Fig. A2.15



the first step is to prepare one or more surfaces that can be used as references for future operations. In this apparatus the reference end, labeled (1) in Fig. A2.16, should be machined smooth and at right angles to the workpiece. The operation that does this is called facing. You will use the facing operation again to finish the workpiece to the proper length.

Before facing the piece, there are three things to be considered in the proper placement of the cutting tool. First, the tool must protrude far enough

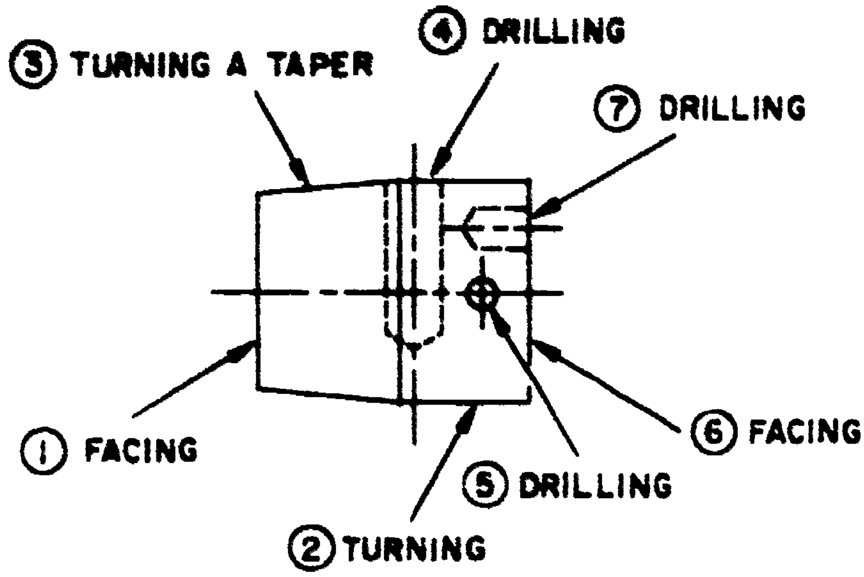
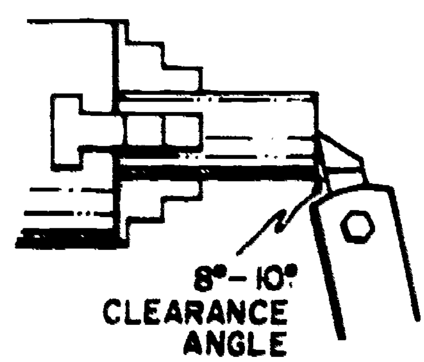


Fig. A2.16

to prevent the tool holder from touching the surface of the piece to be machined. This distance is determined by the shape of the tool and is checked visually. If the tool extends too far, it is likely to vibrate (chatter), producing a rough finish. Second, because chatter is also caused when too much of the cutting edge is in contact with the machined surface, it is necessary to have a small clearance angle between the cutting tool and the surface being faced (Fig. A2.17). The third factor to consider when positioning the tool is the height. The tool must be adjusted so that its point will intercept the axis of the workpiece. If the tool is adjusted too low or too high, it will be impossible for it to remove material at the center of the stock. The angle and the height of the tool are adjusted at the same time because the tool-post bolt must be loosened for both.

Fig. A2.17



The clearance angle is set by loosening the bolt and by rotating the tool post until the proper angle is set. The angle is not very critical and can be set by eye. Adjusting the height of the tool is more difficult, however, because it is done by trial and error. The tool holder is pivoted up or down in the tool post until the tool is approximately at the correct height, and the tool-post bolt is then tightened. A trial cut is taken, and the height of the tool is readjusted if necessary.

Another method for approximate positioning is shown in Fig. A2.18. A small ruler or a straightedge is placed between the point of the cutting tool and the circumference of the stock. If the straightedge is vertical, the point of the tool is at the correct height. If the top of the straightedge tilts toward the operator, the tool is too low. If the straightedge tilts in the other direction, the opposite is true. A trial cut is taken and, if necessary, a fine adjustment is made.

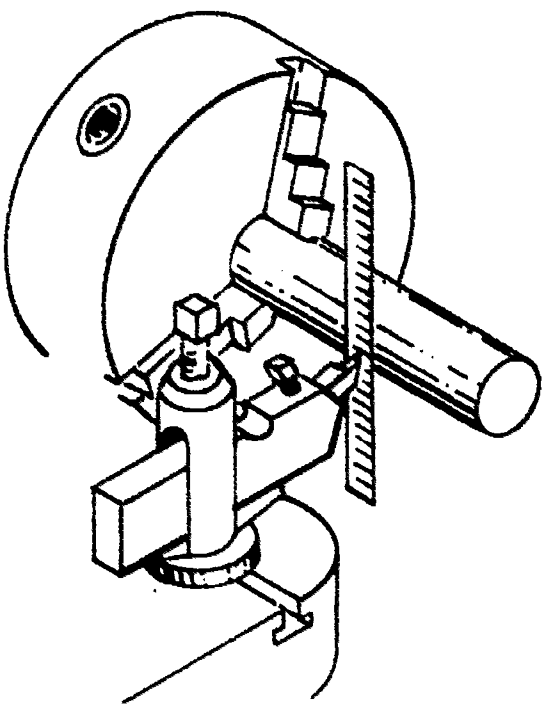


Fig. A2.18

WARNING: Never adjust the cutting tool while the lathe is running.

Facing tools are designed to be moved from the circumference to the center of the stock when making rough cuts and from the center to the circumference when making finish cuts. However, until you have gained experience with the lathe, it is safer to perform all facing operations from the center to the circumference.

To face the workpiece the lathe is turned on and the cutting tool is moved so that it barely touches the surface at the center. This is done by rotating the carriage wheel (longitudinal-feed wheel) with the left hand and adjusting the cross feed with the right hand. Apply a slight pressure with the longitudinal feed until a chip begins to form on the cutting tool. Remove your left hand from the longitudinal-feed wheel and begin rotating the cross-feed knob in a counterclockwise direction. The motion of the tool will be smooth if you alternate hands while rotating the knob. Go slowly until you get the "feel" for what can be done on a lathe. In general, a slower feed gives finish cuts a smoother surface. The process is repeated until the desired finish is produced.

As with the drill press, the diameter of the stock determines the speed at which the lathe can be run. For diameters below 1.000 inch, refer to Fig. 3.8. For larger diameters, use the formula

$$RPM = \frac{\text{cutting speed} \times 4}{\text{diameter}}$$

where the cutting speed is 40 FPM (feet per minute) for stainless steel; 65 FPM for copper; 95 FPM for steel; 130 FPM for brass; and 230 FPM for aluminum. Most lathes do not have continuously variable speed controls; therefore, you should select the closest speed below the one specified.

A2.6 A Word on Safety

When using a lathe always wear safety goggles or glasses and never wear a necktie, a scarf, or any loose-sleeved clothing. Wear long-sleeved clothing with tight cuffs or roll the sleeves above the elbows. Any loose clothing can be a hazard because it might get caught on a control. Long hair should be tied back away from the face.

Always allow the lathe to come to a complete halt before you touch the chuck or workpiece and before making a measurement of any kind. When cleaning the lathe remove the cutting tool and use a brush or rag. Never handle metal chips. They are very sharp!

Be sure to remove the chuck key and make certain that nothing is in the way of the chuck before starting the lathe. Above all, plan ahead and think before you do anything. Most operations on a lathe can be done slowly, and so there is no reason to rush things.

o o o o o o o o

Take a piece of aluminum stock 4 to 6 inches long and 7/8 inch in diameter. Fasten it in the chuck with about two inches extending beyond the jaws. Set the lathe at the correct speed and adjust the cutting tool. Before starting the lathe, check to see that there is enough clearance between the chuck and the cross slide and the tool holder. Start the lathe and make a light cut. Vary the rate at which you turn the cross feed and note the results on the surface of the aluminum. Continue making cuts until the surface is smooth. The last cut should be made with a very slow but steady feed.

o o o o o o o o

A2.7 Turning

It is not always possible to purchase stock with the exact diameter specified in a drawing. Even if it is available, the specifications for the smoothness of the finish may prevent the operator from using standard diameter stock. For these reasons, it is often necessary to remove material from the perimeter of the stock until the desired diameter and/or smoothness is achieved. The process, illustrated in Fig. A2.19, is called turning. There are basically two types: rough turning and finish turning. As its name implies, rough turning removes large amounts of material with no consideration given to the smoothness or accuracy of the surface. In finish turning, the stock is machined to the dimension specified. The basic procedure is the same for both types: By means of the longitudinal-feed wheel the tool is moved parallel to the axis of the rotating stock. The main differences between rough and finish turning exist in the shape of the tool that is used and the angle at which it is held.

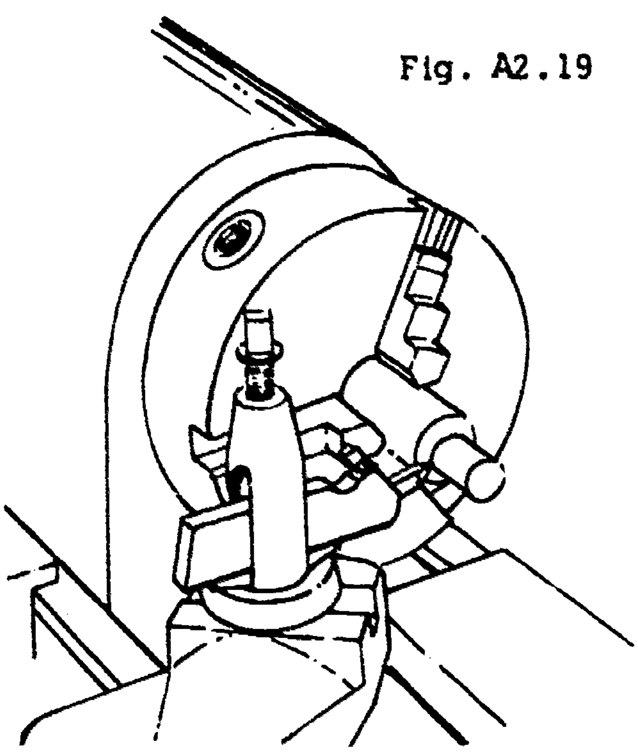


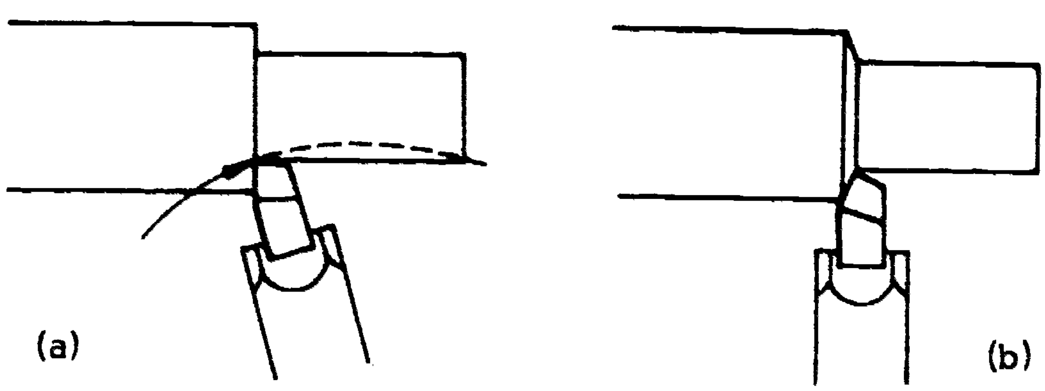
Fig. A2.19

If you look back at Fig. A2.12 you will note that the rough-turning tool has a relatively sharp point and that the cutting surface is perpendicular to the axis of the stock. The smooth-finish tool has a round nose and can be held at a variety of angles.

A sharp-pointed tool produces a series of V-shaped grooves similar to the threads on a machine screw. The round-nose tool produces a smoother finish because more of its cutting surface is in contact with the workpiece and the cuts overlap. If the roughing tool has a round nose, it would tend to chatter because too much of the cutting edge would be in contact with the stock.

As you might imagine, there is a tremendous amount of force exerted on the cutting tool when large amounts of material are removed. This force is exerted downward because of the rotation of the stock and also laterally because of the movement of the carriage and tool. Because the tool post and tool holder are designed to be versatile, they are not as rigid as they might be. Therefore, the lateral force exerted on the tool may cause the holder and post to pivot when heavy cuts are made. If this should happen with the tool holder positioned as shown in Fig. A2.20(a), the surface would be gouged or machined to an undersized diameter. However, with the holder positioned as shown in Fig. A2.20(b), the pivoting of the tool post does not result in damage to the workpiece. To help minimize this problem, be sure the tool post is as tight as possible.

Fig. A2.20



To turn down a piece of stock, place it in the chuck with enough material extending to allow the cutting tool to be moved the desired distance without any part of the carriage being hit by the chuck. If the stock extends too far, it may bend or vibrate while being machined. (The tailstock and a dead or floating center can be used to eliminate these problems.)

The carriage is then moved to the right so that the tool is beyond the end of the stock. Move the cross feed to the desired setting, and then move the carriage toward the headstock by rotating the longitudinal-feed wheel counterclockwise with a slow, smooth motion. When the proper length is machined, the tool is moved away from the surface it has just cut by turning the cross feed counterclockwise, and the carriage is moved toward the tailstock to reposition the tool for the next cut. The maximum depth of the cut is determined by the material being machined, the diameter of the material, the type of cutting tool, and the size of the lathe. Experience is the only way to learn the capacity of the lathe and the size of the cut that can be taken. However, it is not unreasonable to take 0.040- or 0.050-inch cuts. Rough turn to about 0.035 inch over the final diameter before switching to the finishing tool.

As you can see by looking at Fig. A2.15 and Fig. A2.16, the second operation of the project requires you to turn down the diameter of the dry calorimeter to 0.750 ±0.002 inch. The stock used is 7/8-inch-diameter aluminum; therefore, approximately 1/8 inch of aluminum must be removed from the diameter of the stock. The distance the tool is moved is indicated by the dial on the cross slide. If the dial is moved from 25 to 75 the tool has been moved 0.050 inch. However, the diameter of the stock will have been reduced by twice that amount, or 0.100 inch.* Therefore, in the process of turning down the diameter of the stock for the dry calorimeter from 7/8 inch to 0.750 inch, the micrometer dial — and therefore the tool — will be moved by only 0.062 inch.

You have learned that it is always necessary to have a surface that can be used as a reference. Because the stock used in this project may be slightly bent or out of round, the circumference should not be used as a reference. The first step in turning is to make a cut that can then be used as a reference for future cuts. After the first cut is made, the dial reading is noted, the diameter of the stock is measured with a micrometer, and the next movement is calculated from these two numbers.

*This is true for most lathes. However, a few lathes are designed so that the dial reading represents the total amount of material removed. Check the lathe you are using to determine which method is used.

o o o o o o o o

If after the first cut has been made on a 1.000-inch-diameter aluminum bar, the dial reads 13, and the diameter measures 0.896 inch, what will the final dial reading be to reduce the diameter to 0.784 inch?

Take the piece of stock you have faced for the dry calorimeter and set it up in the chuck so that you can turn down the stock for a length of 1-1/2 to 2 inches. Position the cutting tool properly, and check to make sure that nothing will hit the chuck during the operation. Then proceed with the operation.

o o o o o o o o

A2.8 Turning a Taper

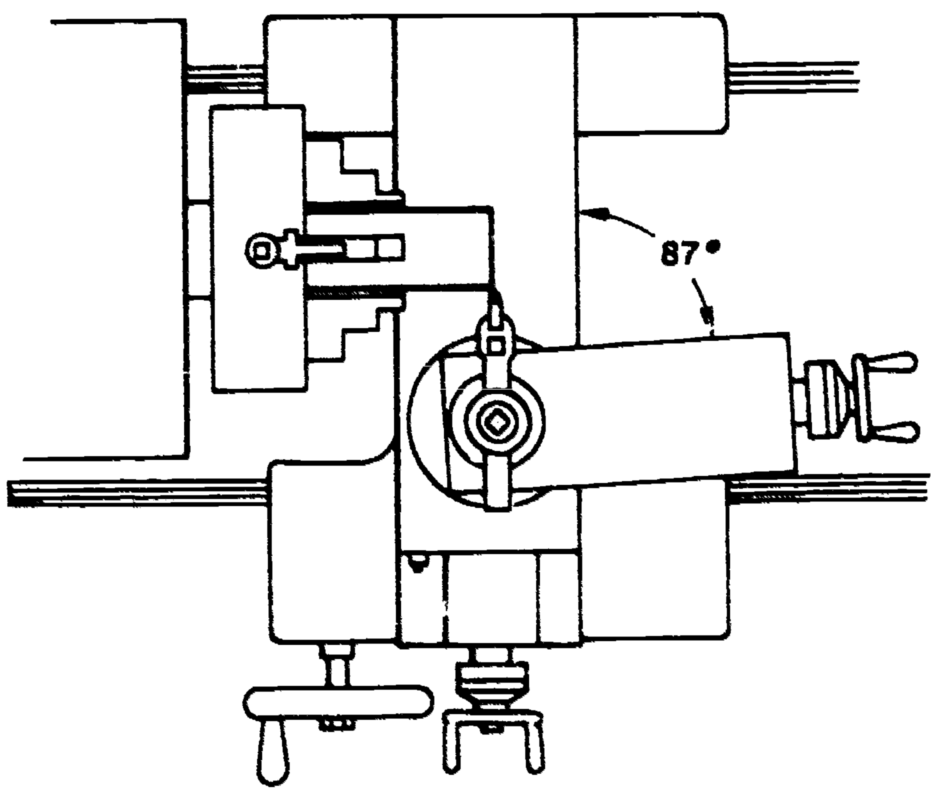
In making the dry calorimeter, the third step is to taper one end. This taper must match a mating taper that is in the end of a hard rubber rod. The rod, in turn, is attached to the center of a weighted bicycle wheel that is used with the dry calorimeter to investigate the relationship of thermal and kinetic energies.

Because the compound rest can be rotated through 360 degrees (Fig. A2.14), it can be used to turn tapers. The desired angle is set according to the scale on the base of the compound rest; and by rotating the feed knob, a cut is made at this angle.

To set the compound rest at the required angle, loosen the two bolts, nuts, or screws that hold it secure. The exact position of these fasteners will vary from lathe to lathe. Rotate the compound rest to the proper angle and retighten. The tool holder is then set in the proper position for turning.

The taper in Fig. A2.15 is given as 3 degrees. To make a cut at this angle, the compound rest is rotated counterclockwise so that the angle between the cross slide and the compound rest is 87 degrees (Fig. A2.21). Depending on the lathe, the scale on the compound rest will read 93 degrees, 3 degrees, or 87 degrees. The procedure from this point on is the same as for the previous operation with one exception: The tool is moved by rotating the feed knob on the compound rest rather than on the longitudinal feed. First, however, it is wise to lock the carriage in place to prevent any errors caused by accidental movement. This is accomplished by tightening a nut or a bolt that is usually located on the front, top right-hand section of the carriage.

Fig. A2.21



The one limitation of using the compound rest to turn tapers is in the degree of accuracy that can be attained. Most tapers are described in terms of inches per feet where the accuracy required is generally ±0.002 inch per foot. This degree of accuracy is attained by using a taper attachment or by offsetting the tailstock. Since the setup procedures are complicated for both, their explanation is left to other texts. The compound rest, however, will be accurate enough for the short length of taper needed in this project.

o o o o o o o o

What instrument and method of measuring would you use to check the diameter of the taper as given in Fig. A2.15?

Which tool should you use, the roughing tool or the finishing tool?

Turn the taper on the dry calorimeter.

The fourth and fifth steps in making the dry calorimeter consist of drilling the holes. Before cutting the stock, lay out the holes and use the drill press to drill them. This will make it easier to hold the piece in the V blocks.

After the holes are drilled, cut the stock with a hacksaw, leaving an extra 1/16 inch for final machining.

o o o o o o o o

A2.9 Facing to Length

After the workpiece has been cut from the piece of rod stock, you must face the end of the calorimeter and machine it to the length specified in the drawing. Several difficulties make this facing operation different from that described previously. Because the longitudinal-feed wheel is not provided with a micrometer dial, it is impossible to determine by exactly how much the carriage moves when the wheel is rotated. Therefore, the depth of a facing cut is unknown, making it very difficult to machine a piece of stock to the proper length. Micrometer attachments can be fastened to the bed of the lathe and used as references; but many lathes are not so equipped.

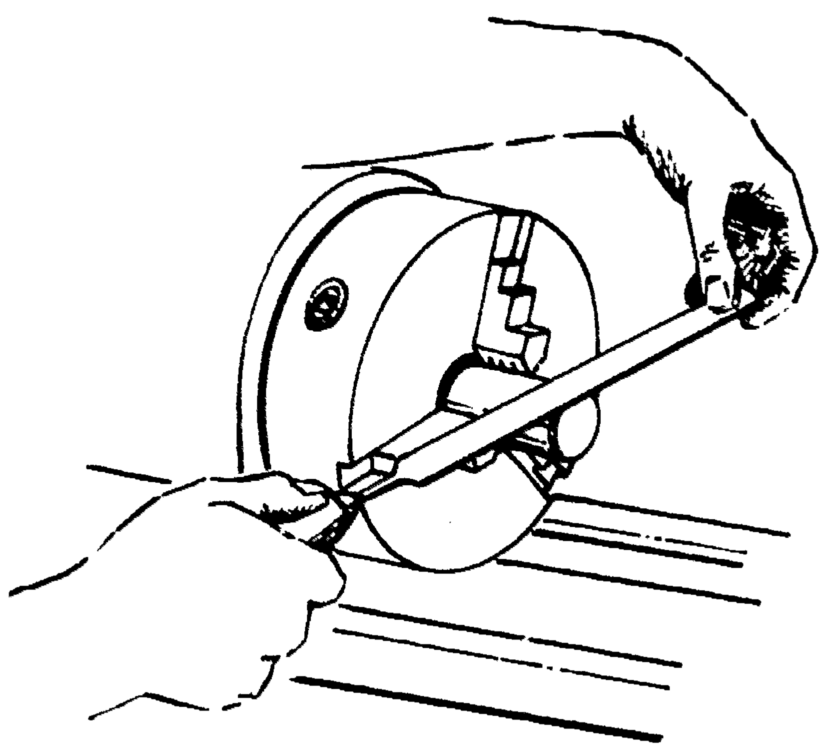
Since the compound rest can be set at 90 degrees to the cross feed, it can be used as the mechanism for laterally moving the tool a known distance. A cut is made as a reference, the length is measured, and the compound feed is moved until the proper amount of material is removed. This procedure is correct in theory, but it is not quite so simple in practice. Normally it is not possible to measure the length of a piece of stock when it is clamped in the chuck, and so it is necessary to remove the workpiece to measure it. Because it is extremely difficult to reposition the workpiece exactly, the dial reading on the compound rest is meaningless. To reestablish the faced surface as a reference, the tool is moved carefully into contact with the surface, removing as little material as possible. This operation is often referred to as "picking up the edge" and requires a certain amount of experience. Through close observation and/or sensitive hearing it is possible to "pick up an edge" and to remove less than 0.001 inch. Always perform this operation near the circumference of the stock rather than the center, which is nearly motionless. Move the tool slowly until the smallest chip or particle is removed by the tool. It is sometimes possible to hear the sound of the tool rubbing against the stock even before a chip appears. Once the tool has been set, note the dial reading on the compound-feed dial and determine the amount of feed needed to remove the desired amount of material. The procedure from this point on is the same as that described in Section A2.5 with one exception: Instead of the longitudinal feed being used to mov ...e tool, the compound feed is used.

Because it is more difficult to make measurements when facing the workpiece, the operator is often tempted to leave a space between the reference end of the workpiece and the face of the chuck and use a caliper or micrometer to measure the piece without removing it from the chuck. This practice can be unsafe or be the source of error. Always try to position the workpiece so that the length of material that extends beyond the face of the jaws is as short as possible. This method is safe and will result in greater accuracy.

Each machining operation produces a burr on the corner of the machined surface. In Project 2, to remove burrs you used a file held at a 45 degree angle to the surface. A similar procedure is used on the lathe. The sharp corner is filed off by moving the file perpendicular to the stock with a light, steady stroke while the workpiece is spun by the lathe. The file shou'd be held so that the surface that it produces is at 45 degrees to the machined surfaces. As you can see in Fig. A2.22, care must be taken when deburring with a file. Any loose sleeves or clothing could easily be caught in the chuck because the left arm passes over the chuck and the headstock. If the stroke of the file is too long, the right hand could be hit by the spinning jaws. Deburring is one of the most dangerous operations performed on a lathe, and so be very careful, think ahead, and proceed slowly.

To deburr the holes, a countersink can be used, either by hand or with a drill press.

Fig. A2.22



o o o o o o o o

Face the dry calorimeter to the length shown in Fig. A2.15. Deburr all corners and holes.

Lay out and drill the hole in the back of the dry calorimeter. Deburr the hole to make it easier to press fit the aluminum pin.

Cut a 1/8-inch-diameter aluminum rod to a length of 3/16 inch. Face it to length (0.250), bevel (taper with a file) both ends, and press it into the hole in the back of the dry calorimeter. To protect the surface, an <u>arbor press</u> or a machinist vise equipped with soft aluminum jaws may be used.

o o o o o o o o

A2.10 Turning a Shoulder

Figure A2.23 is a dimensional drawing of the joule cylinder you will make as the second project in this appendix. By looking at Fig. A2.24, you will notice that the first operation is to face the workpiece. The second is to turn down a section of the workpiece to a smaller diameter. The surface that connects the large diameter section of the stock to the smaller diameter section is called a shoulder, which can be beveled or curved depending on the design of the piece.

Fig. A2.23

NOTES:
1- ALL DIMENSIONS ± 0.002 INCH
2- MASS OF CYLINDER 21 GRAMS ± 0.1 GRAMS
3- DEBURR ALL EDGES

MATERIAL: 2011-T3 ALUMINUM ROD

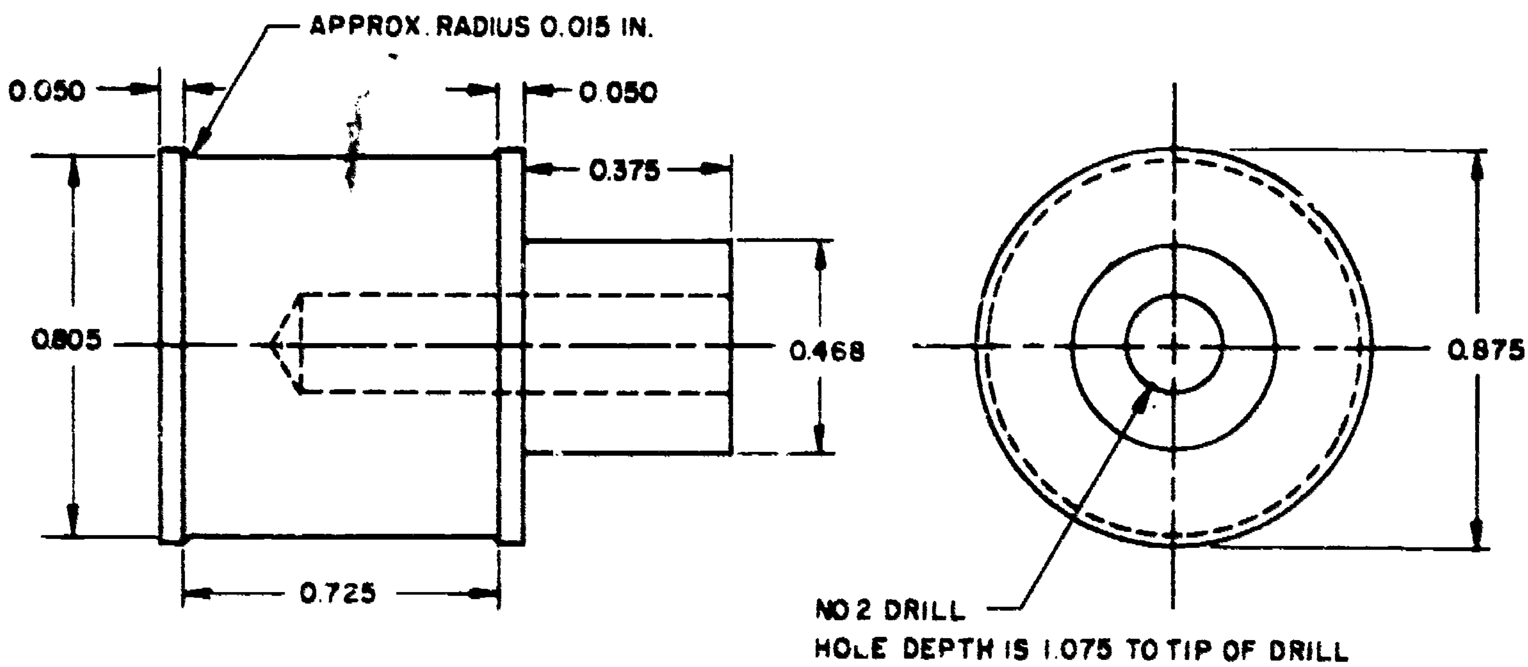
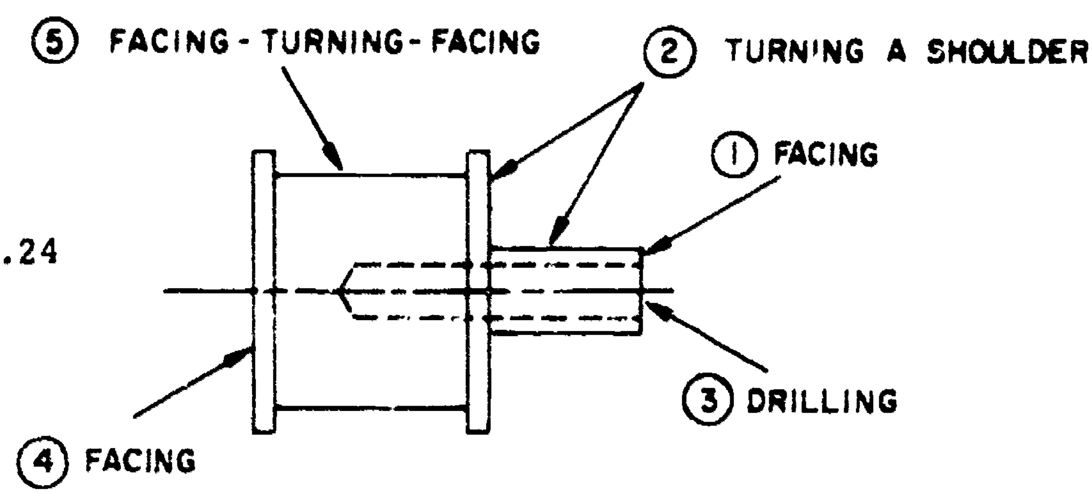


Fig. A2.24



There are two methods of producing the shoulder on the joule cylinder. The first involves the use of the longitudinal feed and the cross feed, and the second substitutes the compound-rest feed for the longitudinal feed.

After facing the end, a mark is made on the stock at the position of the shoulder. As the lathe is turning, a line can be drawn around the circumference of the stock by holding a pencil or a scriber at the mark. The procedure from this point on is similar to the standard turning operation. Material is removed by moving the tool longitudinally until it reaches the line on the stock. A smooth finish is produced on the shoulder by moving the tool outward with the cross feed. The process is repeated until the desired diameter is reached. A vernier caliper or a depth micrometer can be used to measure the length of the smaller diameter portion and the shoulder can be machined more if necessary. As you can see, this operation is a combination of two operations you have already used: turning — to reduce the diameter, and facing — to produce a smooth shoulder. If the transition from turning to facing is not immediate the tool will chatter, leaving a rough finish.

The second method is more convenient and faster; however, it is limited for two reasons. First, the compound rest must be set at right angles to the cross feed. Since this setting cannot be exact, this method is not as precise as the first. Second, the length of the screw in the compound rest limits the length of the stock that can be turned down.

After the compound rest is set at right angles to the cross feed, set the dial on the compound rest to zero. Face the stock as you normally would, clamping the carriage on the final cut. Turn down the workpiece by using the compound-rest feed rather than the longitudinal feed. Because the compound-rest feed is calibrated, the tool can be fed the distance specified in the drawing and the shoulder faced using the cross feed as before. When using this procedure, allow 0.002 or 0.003 inch for a finish cut. Although the compound-rest feed is quite precise, you shoul' measure the distance to the shoulder to be sure it is correct.

o o o o o o o o

Face the end and turn the shoulder on the joule cylinder. Deburr the edges with a file.

o o o o o o o o

A2.11 Uses of the Tailstock

Figure A2.25 is a drawing of a tailstock with the most important parts labeled. The main purpose of the tailstock is to hold various tools in axial alignment with the headstock spindle. Because operations must be performed on workpieces of different lengths, the tailstock is constructed so that it can slide along the ways while maintaining axial alignment and be fastened at

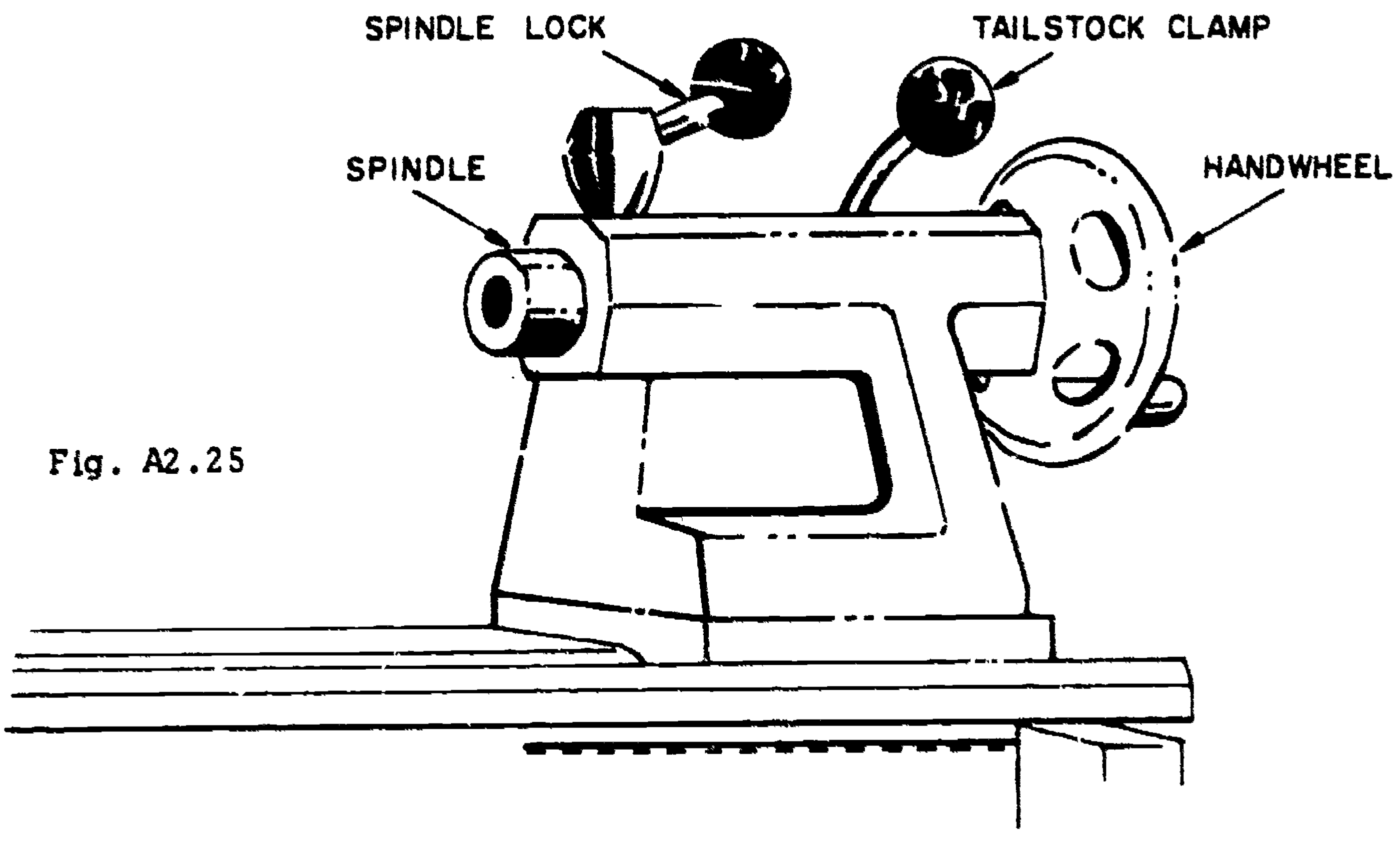


Fig. A2.25

the appropriate position by turning a clamping bolt or lever. The tailstock spindle can be moved in or out by rotating the handwheel, making it possible to make fine adjustments or to move a tool into a spinning workpiece. A clockwise movement of the handwheel results in a movement toward the headstock. A counterclockwise rotation produces the opposite motion. Tools with matching tapers are held in the tapered hole of the tailstock spindle.

A scale inscribed on the spindle is used to measure its movement. Since the tailstock can be used to support spinning workpieces, the spindle may be locked against accidental movement by turning the lock lever.

The third operation on the joule cylinder is to drill a hole into which a thermometer can be inserted. A drill press may be used to drill the hole as in Project 3, but it is faster and more accurate to drill it on a lathe. No layout is necessary because the tailstock ensures that the hole will be properly aligned if care is taken while drilling.

A drill chuck is needed to hold the drill in the tailstock. It is similar to the chuck in the drill press but has a tapered shank that is inserted into the tailstock spindle. The chuck is fastened to the spindle by inserting the shank into the hole and forcing the tapers together. However, before this is done both tapers must be wiped clean to remove oil and grit to ensure proper fit and maximum friction between the two surfaces. The chuck is removed by rotating the handwheel counterclockwise until the chuck is automatically released.

When you drilled a hole in metal, it was necessary to mark its location with a center punch to make sure that the drill started correctly. The same is true when drilling with a lathe except that a different tool is used. Figure A2.26 is a drawing of a combination center drill and countersink. Because of its short length and lack of long flutes it will not bend, ensuring that the starting hole is aligned with the headstock spindle. The smaller diameter section is the center drill, and the beveled part is the countersink. These tools are supplied in an assortment of sizes ranging from a drill diameter of 0.025 to 0.250 inch. Two factors determine the size of the center

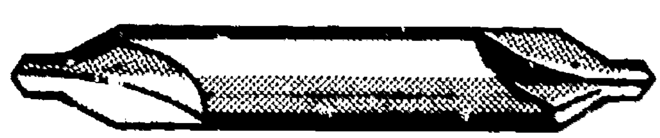


Fig. A2.26

drill — the diameter of the hole to be drilled and the size of the <u>dead center</u>* of the drill. The center drill should be smaller than the diameter of the drill but larger than the dead center of the drill.

Once you determine the proper size, insert the combination center drill and countersink into the chuck of the tailstock and tighten the chuck with a chuck key. Then release the tailstock clamp and slide the tailstock toward the headstock until there is between 1/4 and 1/2 inch clearance between the center drill and the workpiece. Tighten the tailstock clamp and, after selecting the proper speed, start the lathe. Feed the center drill into the stock by turning the handwheel clockwise, but do not drill deeper than the flutes of the countersink.

When drilling blind holes in a workpiece (as in the joule cylinder) use the scale on the tailstock spindle to determine the depth of feed. With the spindle set at a major division on the scale (0, 1/2, or 1 inch) slide the tailstock until the point of the drill is flush with the end of the workpiece. Tighten the tailstock and feed the drill into the stock the specified amount. Because the smallest division on the scale of the spindle is 1/16 inch, you cannot drill a blind hole with the accuracy that other lathe operations have. To subdivide the 1/16 inch divisions, turn the handwheel a calculated fraction of a turn to provide a more precise feed.

o o o o o o o o

Drill the thermometer hole in the joule cylinder. Deburr the hole with a countersink held in the tailstock chuck.

o o o o o o o o

A2.12 <u>Turning Two Shoulders</u>

In the joule experiment, a long piece of nylon line is wrapped around the cylinder. To keep the line from slipping off, two shoulders are machined on the cylinder (Step 5). This can be done with either of the grooving tools shown in Fig. A2.12. One tool has a square nose that produces flat shoulders,

*Refer to Fig. A1.6.

and the other has a round nose to produce curved shoulders. Since both tools cut on the side as well as the end, they can be moved laterally so that the width of the groove is not restricted to the width of the tool. The drawing calls for a radius in the corners; so therefore a round-nose tool with the proper curve is used.

The only difference between this operation and turning one shoulder is that the cut must begin at a specified position rather than at the end of the stock. The cylinder is held in the chuck by the end that has the small diameter, which makes it difficult to perform the operation without the tool holder hitting the chuck. Therefore a special cutting tool is used (Fig. A2.27) that is really the same as the other grooving tools but it is ground at an angle to make the cut easier.

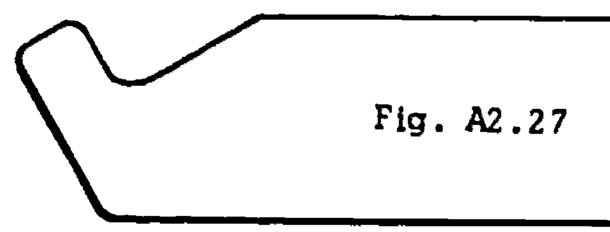


Fig. A2.27

Although you will later measure the shoulders precisely, mark the position of the shoulders to act as guides for the early cuts. Position the tool as shown in Fig. A2.28. Use the cross feed to move the tool into the work. Allowing a little space for a finish cut, move the tool laterally until its left edge reaches the line for the second shoulder. Move the tool toward you using the cross feed and start the procedure from the beginning. Continue turning down the stock until the diameter is 0.002 or 0.003 inch oversize. Then measure both shoulders and face them until they are oversize by about 0.002 inch. Now make all three finish cuts at one time by facing the right shoulder to the proper width, making the finish turning cut, and facing the second shoulder to the proper width. When facing the shoulders, be careful to remove only the 0.002 or 0.003 inch you have allowed.

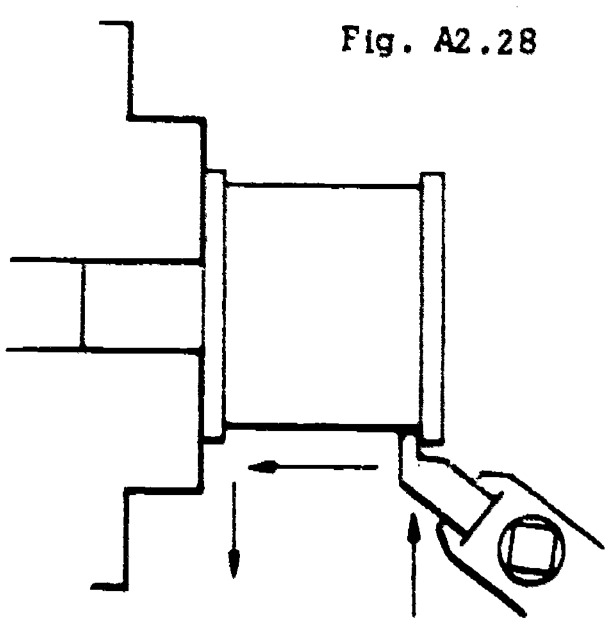


Fig. A2.28

o o o o o o o o

Face the end of the stock to length.

Turn the double shoulders. Since the nylon line slides on the surface between the shoulders, it must be smooth.

Deburr all edges with a file.

o o o o o o o o

Appendix 3: THE CATHODE-RAY OSCILLOSCOPE

The most useful piece of electronic test equipment is the cathode-ray oscilloscope — "scope" for short. Whenever a voltage changes too rapidly to be observed with a DC voltmeter, a scope can show you what is going on.

The principles of its operation are very simple:

1. A beam of electrons is fired at a screen that produces a flash of light whenever an electron strikes it.
2. The beam begins at the left side of the screen and produces a trace as it moves across at a constant rate — a rate that can be set over a wide range of values. Therefore, if the beam takes 0.1 sec to cross the screen, the length of the trace represents 0.1 sec. If the sweep time is 1 millisecond, the trace represents 1 msec, and so on. (The sweep rates are usually given in time per division because the screen is scribed with a grid.)
3. The voltage being measured causes the beam to be deflected vertically. Thus the final scope trace gives a picture of the voltage (vertical deflection) as a function of time (horizontal deflection).
4. Except for special oscilloscopes that can store and display a single trace of the electron beam, what you actually observe on the screen is the result of repeated traces of the same signal. Thus the voltage to be studied must be periodic and be synchronized to the sweep of the beam so that each trace will coincide with the previous one.

Knowing how an oscilloscope functions is hardly sufficient when the time comes to use one. What you need to know then is which knob controls which function, and so we will look at the oscilloscope from this point of view.

1. The Beam

The only external controls over the electron beam itself are the knob that changes the beam's intensity and the one used to adjust the focus.

2. The Time Base

The sweep of the beam is controlled by a group of circuits that are referred to as the time base. For some scopes the knob that sets the sweep speed is calibrated and reads directly in time per division (roughly from 1 sec/div to 1 μsec/div). For other scopes two knobs are used: One sets the general range of the sweep, and the other is used to make fine, uncalibrated adjustments. To shift the entire pattern to the right or the left a horizontal positioning knob is provided.

3. The Vertical Input

You connect the scope to an external circuit by means of the vertical input terminals. The ground connection should be clearly indicated. A range switch is used to match the incoming signal to the input circuitry. On some scopes the range switch is calibrated in volts per division; on others the range is set by a continuous, uncalibrated control.

Another knob, in addition to the range selector, is adjusted to position the trace up or down.

4. Synchronization and Triggering

Basically there are two ways to synchronize the sweep of the electron beam with the input signal. A trigger circuit is the easiest to adjust but is expensive to produce. The scope waits for a signal of a certain size and a certain polarity before the sweep is initiated, and so you must adjust the trigger level, the voltage necessary to start the sweep, and the slope, which makes the sweep begin on either positive or negative signals. There may be other adjustments but these are the basic ones.

The sweep speed of the beam is determined by the time base selector. You can decide whether you want to observe one cycle of the signal, or a fraction of a cycle, or several cycles.

For scopes that do not have a trigger circuit, the beam continually sweeps at a constant rate. Thus the sweep speed must be adjusted until the pattern appears stationary on the screen. The time base is not calibrated, and so an external signal of known frequency is required when quantitative time measurements are made.

For both types of scopes, there is another set of terminals marked "External Sync" or "External Trigger." Using this input the beam sweep is synchronized to the external signal.

o o o o o o o o

Use your oscilloscope to look at the output of a sine-wave signal generator. Set the generator for 1000 Hz, and adjust the oscilloscope controls to display approximately five sine-wave cycles. What is the period of each cycle?

If the signal generator has a square-wave output look at it at 1000 Hz. How can you tell where zero volts is?

If your scope accepts DC input voltages, you can use a flashlight battery to check the calibrations of the vertical deflection. With zero input a straight line appears across the scope face. Now apply a DC voltage — either positive or negative — to the input terminals and observe the deflection. How good is the scope's calibration? What is your estimate of the accuracy of a voltage measurement?

o o o o o o o o

NOTES TO THE INSTRUCTOR

The text is divided into three sections: woodworking and metalworking, electronic circuits, and glassblowing. Each consists of a series of projects that teaches the students to develop the skills needed to perform operations with a variety of tools. Every tool is described as it is used to perform an operation. After a tool and the operation are discussed, a series of instructions – set off from the text by circles (o o o o o o o o) – are provided to tell the students how to apply the information to build the project. These sections often include questions that encourage them to proceed thoughtfully.

The students' backgrounds will differ enormously depending on their previous experience with the materials being discussed. Therefore, the format of the text is designed so that a student can be somewhat independent of the instructor. This allows the instructor to spend more time with the less experienced students while the others continue at their own pace.

The entire course can be taught in approximately 90 hours, with each class period being at least two hours long. About half the time is needed for woodworking and metalworking, with the remainder divided equally between electronic circuits and glassblowing.

To assist you in preparations for the course, a brief explanation and lists of materials and tools are provided for each project. The sizes of the tools are intended as guidelines. Other sizes can be substituted if the tools are already available.

WOODWORKING AND METALWORKING

Because many of the techniques used in working metal and wood are similar, woodworking and metalworking have been combined into one section. Although some of the projects use only wood or only metal, others require that both materials be used.

Most woodworking and metalworking hand tools are used in making the projects in this part of the text. Because of cost factors, the power tools that are used (drill press, belt sander, and table saw) are oriented more for working wood than for metal.

The facilities should be as spacious as possible with plenty of room around the power tools, especially the table saw. Workbenches equipped with machinist's and woodworking vises should have durable hardwood tops. Because it is easier to cut a board with a handsaw when the board is below waist level, be sure to have sawhorses or low stools available.

The quantities of tools needed to teach the course depend on the size of the class and the number of students that perform the same operation at the same time. Therefore, as projects continue, fewer multiples of tools are required. Each student should have access to a handsaw, a plane, and a square because the operations that use them are very time-consuming. The drilling operation, however, takes a very short time, and so only a few brace and bit sets are needed.

Project 1

By constructing the laboratory stand the students are introduced to more than the hand tools used to build it. They acquire a feeling of how to approach a project and the correct sequence of operations from the way the text and the instructions are presented.

As a substitute for the plane, the belt sander is used in the first project to finish end grain of boards. In the past, we found that students became discouraged because of the amount of time needed to do a good job with a plane.

To help the students better understand shop sketches, make some blocks of wood with two holes drilled in it. (One of the holes can be counterbored.) Give one to each student, and have them make a 3-view sketch that gives all the information required to build the block. In this exercise the emphasis should be on the communication of information rather than on the making of precise mechanical drawings.

Materials needed per student

2 × 4 fir or spruce, approximately 8 ft

1 × 4 common pine, approximately 6 ft

General supplies

4d or 6d cement-coated box nails

Sandpaper, medium and fine grit

Wood glue, Elmer's brand or equivalent

Tools needed

Auger bit, 5/16-in. diameter

Belt sander

Brace

Crosscut handsaw, 24 in., 10 or 12 points

Hammer, 16 oz

Plane

Square

Steel rule, 6 in.

Tape measure

Project 2

While working on the density kit the students should make two major observations: Because metal is harder than wood, more time is needed to work it; and metal can be worked to closer tolerances.

To give the students practice in using vernier calipers and micrometers and in making shop sketches, supply students with pieces of scrap metal of various shapes and have them make a shop sketch with the dimensions they have measured. Check each piece and have the students remeasure if necessary.

Materials needed per student

1/2-in. square 2024-T4 aluminum bar stock, 1 in.

1/2-in. square cold-drawn steel bar stock, 1 in.

1/4 × 1-in. rectangular 2024-T4 aluminum bar stock, 1-1/2 in.

<u>General supplies</u>

Dykem blue or equivalent

<u>Tools needed</u>

Combination square

File, assorted sizes

File card

Hacksaw

Micrometer

Scriber

Vernier caliper

<u>Project 3</u>

The elasticity apparatus is the first project in this text that uses wood and metal. The text for this project also includes a greater amount of information than any of the projects in this section.

If a wire-bending brake is not available, the guide arm for Project 1 and the pointer for the elasticity apparatus can be bent by using a machinist's vise and a hammer. After marking the position of the bend, the shorter end of the stock is placed in the vise with the mark at the edge of the jaws. Pressure is applied to the free end of the rod with the left hand and the bend is made by striking the rod, close to the jaws, with a hammer.

If you find it difficult to get the 3/16-inch-diameter brass tubing, <u>tension pins</u> having a 3/16-inch diameter and a 0.022- or 0.028-inch wall thickness can be substituted. Because they can be purchased in 1/2-inch lengths, tension pins require no additional work.

<u>Materials needed per student</u>

2 × 3 spruce or fir, 2 ft

3/4-in.-diameter 6061-T6 aluminum rod, 1/2 in.

1/8-in.-diameter cold-rolled steel rod, 15 in.

3/16-in.-diameter cold-rolled steel rod, 12 in.

8-32 × 1/2-in. R.H. steel machine screw

8-32 × 1/4-in. R.H. steel machine screw

8-32 × 2-1/2-in. R.H. steel machine screw

8-32 wing nut

4 No. 8 brass washers

3/16-in.-diameter, thin-walled brass tubing, approximately 2 in.

General supplies

Dykem blue

Sandpaper

Tools needed

Belt sander

Center head for combination square

Center punch

Combination square

Die, 10-24 N.C.

Die stock

Drill press

Hand drill

Handsaw

Micrometer or vernier caliper

Plane

Scriber

Steel rule, 6 in.

Tap, 8-32 N.F.

Tape measure

Tap handle

Twist drills, number and fraction sizes

V blocks

Wood chisel, 1/4 and 3/4 in.

Project 4

In making the wooden frame the students will use the table saw for the first time. Because of the danger involved, this is one of the few times where it is necessary for you to give a demonstration, followed by each student making a few practice cuts. Be very critical of every student's actions near the table saw. Note such things as (1) the way they hold the board and move their hands, (2) where they stand, (3) the rate at which they feed the stock into the blade, (4) how they switch off the machine, and (5) how they approach the saw when someone else is using it. All of these points are important for safety.

Materials needed per student

1 × 4 select pine, 4 ft

General supplies

Wire nails

Wood glue

Tools needed

C-clamps

Combination square

Hammer

Sandpaper

Steel rule, 6 in.

Table saw, with mitre gauge and rip fence

Tape measure

Project 5

Have each student write a detailed description of the operations used in making the test-tube rack. Insist that they describe everything, including such things as which side of the saw blade is used when setting the rip fence for a sawcut. This description by your students will assure you and them as to whether or not each one understands the use of the table saw and the drill press.

Materials needed per student

2 × 4 fir or spruce, 1 ft

Tools needed

Belt sander

Drill press

Power bit, 13/16-in. diameter

Sandpaper

Steel rule, 6 in.

Table saw

Project 6

The write-up of the lab cart should be as complete as the description for the test-tube rack. Some minor details have been deliberately omitted to encourage some thought by the student.

Materials needed per student

2 × 4 fir or spruce, 1 ft

1/4-in.-diameter wood dowell, 6 in.

1/2-in.-diameter wood dowell, 7 in.

8-32 × 1-3/4-in. F.H. steel machine screw

8-32 steel hex nut

2 1/4-20 × 2-1/2-in. R.H. steel machine screws

2 1/4-20 steel square or hex nuts

3 1/4 × 1-1/4-in. R.H. wood screws

2 No. 6 × 1/2-in. R.H. wood screws

2-in. steel mending plate

3/4-in. O.D. steel tubing (electrical conduit), 9 in.

3 Roller skate wheels

Compression spring

Tools needed

Belt sander

Countersink

Drill press

Drill sets, fraction and number sizes

File

File cards

Hacksaw

Pliers or wrench

Screw driver

Steel rule, 6 in.

Table saw

Tape measure

V blocks

ELECTRONIC CIRCUITS

The projects in this section are designed to teach the student how to assemble a circuit from a list of components and a circuit diagram. Therefore, the descriptions of the components and their uses are intended to help the student recognize the components rather than provide a complete understanding of the functions of each. Circuit explanations are included for those students who are interested.

Along with a signal generator, an oscilloscope is used to investigate some of the components and to check circuits. An appendix is provided to introduce the oscilloscope as a tool for measuring voltage as a function of time.

Project 7

While building the neon blinker, the students will learn five skills that are essential for the construction of any electronic device: (1) to recognize components; (2) to read circuit diagrams; (3) to lay out the components in a practical arrangement; (4) to make good solder joints; and (5) to test the circuit and determine if it works correctly. All of these skills are reinforced by the projects that follow.

The students should use an ohmmeter to determine the correct terminals for connecting the switch and potentiometer (Fig. 7.10).

Because the push-in terminals protrude through the perforated breadboard, feet are needed to suspend the board above the table top. We suggest wooden or metal strips that can be fastened to the board by nails or screws.

The mounting brackets for the potentiometer and the switch can be made from aluminum sheet stock.

Materials needed per student

470 kΩ 10% 1/2-watt carbon resistor

100 kΩ 10% 1/2-watt carbon resistor

1 megohm potentiometer

.01 μf 200 V paper capacitor

.1 μf 200 V paper capacitor

1 μf 200 V paper capacitor

1-pole, 3-position rotary switch

NE-2H 1/4-watt neon bulb

2 Mounting brackets

4 × 5 in. piece #64A18 Vectorboard

General supplies

Assorted lead wire

Nuts and screws for mounting brackets

Push-in terminals, Vector #T9.4

Solder, 60% tin-40% lead

Tools needed

Hammer, small

High-voltage power supply, 100 VDC

Oscilloscope

Pliers, diagonal-cutting and needle-nose

Soldering iron

Wire stripper

Project 8

The construction of the electronic power supply introduces new components and different uses of components from the previous project. The bipolar-power supply is used for the final project in this section of the course.

The design and construction of the case for the power supply, which should be the responsibility of each student, is an opportunity to put into practice some of the skills learned in the course.

Materials needed per student

2 10 kΩ 10% 1/2-watt carbon resistors
100 kΩ 10% 1/2-watt carbon resistor
5 kΩ 1/2-watt potentiometer
2 1000 μf 25 V electrolytic capacitors
4 1N3193 diodes
Filament transformer, 117 V primary, 12.6 V center-tap secondary
NE-2H neon bulb
SPST switch
Line cord
Line plug
Black 3-way binding post
Red 3-way binding post
Blue 3-way binding post
Vectorboard

General supplies

Assorted lead wire
Lumber supplies for the case
Push-in terminals
Solder

Tools needed

Ammeter, 30-50 ma full scale

Drill press

Oscilloscope

Pliers, diagonal-cutting and needle-nose

Screwdriver

Signal generator

Soldering iron

Table saw

Voltmeter, 10 V full scale

Wire stripper

Project 9

Since integrated circuits have become widely used, a new dimension has been added in the field of electronics. No longer must a person be an engineer to design and to use simple electronic circuits. References now exist that include hundreds of circuit diagrams that use an integrated circuit as the core of the device.

Perhaps the most useful integrated circuit for the science teacher is the operational amplifier. Its versatility makes it possible to construct many different devices with only a few additional components.

The first part of the project is to construct a breadboard for the op-amp that will accept a variety of circuit components and configurations. Following the construction of the breadboard, we have included a few circuits as examples of possible uses of the op-amp.

Materials needed per student

150 kΩ 10% 1/2-watt carbon resistor

4 kΩ 10% 1/2-watt carbon resistor

47 kΩ 10% 1/2-watt carbon resistor

5 kΩ 1/2-watt potentiometer

1 megohm 1/2-watt potentiometer

741 operational amplifier

Selenium or silicon photocell, Radio Shack #276-115 or International Rectifier #S0505E10PL

4 Red 3-way binding posts

2 Black 3-way binding posts

Vectorboard

General supplies

Push-in terminals

Solder

Tools needed

Drill press or electric hand drill

Pliers, diagonal-cutting and needle-nose

Soldering iron

Wire stripper

GLASSBLOWING

Projects 10-13

The techniques used in glassblowing are more difficult for the student to master than any of the other techniques taught in this course. The key to glassblowing is learning how to handle a substance whose properties change as it is being worked. Consequently, students make frequent mistakes while acquiring the necessary "feel" for working glass. Because a student's mistake can ruin a project that has been worked on for some time, the glassblowing section begins with a series of practice operations. Students will still make frequent mistakes, but hopefully some of the frustration can be avoided.

By the time the students begin the projects that follow, they should have acquired the necessary "feel" and confidence that will enable them to do a good job.

In this section the students are learning scientific rather than artistic glassblowing, and so we have chosen to teach only the techniques used for working borosilicate glass. Emphasize slow heating and proper annealing of glass joints and mention that much more care must be taken in these steps if the student ever uses soda-lime glass.

The most important exercise in the glassblowing section is the first one — constricting glass tubing. If students understand what is happening and can constrict the tubing properly, they have come a long way in learning how to work glass.

A class of students can work at the same time if you make two manifolds: One for natural gas and the other for oxygen. One oxygen tank and regulator are able to service many stations, but each station should have separate valves to reduce the possibility of accidental leaks.

Quantity of Pyrex glass per student for Projects 10 through 13

6-mm-diameter tubing, 12 ft
7-mm-diameter tubing, 12 ft
8-mm-diameter tubing, 12 ft
9-mm-diameter tubing, 4 ft
10-mm-diameter tubing, 8 ft
12-mm-diameter tubing, 4 ft
14-mm-diameter tubing, 4 ft
25-mm-diameter tubing, 8 ft
30-mm-diameter tubing, 4 ft
6-mm-capillary tubing, 2 ft
3-mm-diameter rod, 2 ft

Equipment needed for each glassblowing station

Asbestos sheet or Transite, for table top
Asbestos tape, 1 in. wide
Carbon block, 1 in. square
Carbon rod, 1/4-in. diameter
Cork borer
Corks, assorted sizes for all glass tubing
File, triangular
Hand torch, with assorted tips
Mouthpiece, for blowing hose
Rubber tubing, assorted sizes

Safety glasses, didymium, regular and clip-on

Swivel, glassblowing

Torch holder

Twin hose, for oxygen-gas torch

APPENDIX 1: Sharpening Tools

The first appendix is meant to be used for student reference. Students should be able to recognize dull tools, know which tools can be sharpened, and know how to sharpen them. The cutting tools that have been used in this course are listed, and brief descriptions of sharpening procedures are included.

APPENDIX 2: Operations on a Metalworking Lathe

The lathe is a very costly piece of equipment and may not be readily available. However, because knowledge of operations that can be performed on a metalworking lathe is invaluable in the construction of any equipment, we have chosen to include a section on the lathe. This appendix can be used as a reference for interested students or, if a lathe is available, as supplementary exercises after students have completed the previous projects.

The methods for the precise layout of the holes in the dry calorimeter have not been described in the text. Therefore, the method the student will use depends on the tools available in your shop.

We have not mentioned power feeds for the lathe. However, if you find it convenient you might mention their existence and their uses.

Materials needed per student

7/8-in.-diameter 2011-T3 aluminum rod, 3 in.

1/8-in.-diameter 2011-T3 aluminum rod, 3 in.

General supplies

Dykem blue

Equipment needed

Arbor press (if available)

Center head

Center punch

Combination center drill and countersink

Combination square

Countersink

Drill press

Drill sets, fractional and number

Facing tool

File

Finish-turning tool

Hacksaw

Lathe with 3-jaw chuck

Machinist's vise

Micrometer

Rough-turning tool

Scriber

Special-turning tool for joule cylinder

Surface gauge

Surface plate

V blocks

Vernier caliper

APPENDIX 3: The Cathode-Ray Oscilloscope

One of the instruments used in the electronic circuits section of the text is the oscilloscope. This appendix is provided as a reference for students who have no previous experience with a scope.

Because brands of scopes differ, the description in the appendix provides the student with a general understanding of the functions of an oscilloscope. Later the student will have to learn the specific capabilities of the instrument that is available in their laboratory.

INDEX