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WAR DEPARTMENT

TECHNICAL MANUAL

THE BLACKSMITH AND THE WELDER

June 16, 1941

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THE BLACKSMITH AND THE WELDER

Prepared under direction of
The Quartermaster General

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SECTION I

GENERAL

1. General.—Every automotive maintenance shop in the Army, stationary or mobile, should be prepared to do simple metalworking on sheet metal or heavier stock. This work unsually involves blacksmithing, welding, or cutting, or all three. The equipment and the procedure for such work are described in this manual.

2. **Glossary.**—For purposes of clarity and ready reference the following terms used in this text are defined:

Acetylene.—A colorless, inflammable, hydrocarbon gas (C_2H_2) with a distinctive odor. Usually formed by the action of water on calcium carbide.

Adhesion.—The molecular attraction exerted between the surfaces of bodies in contact.

Base metal.—The metal being welded—opposed to filler metal added by welding rod or electrode.

Bourdon tube.—A curved metal elastic tube, oval in cross section, open at one end to gas, steam, or other fluid pressure and closed at the other. Changes in pressure cause it to move and this movement is used to indicate the pressure.

Capillary attraction.—The action by which the surface of a liquid where it is in contact with a solid (as in a capillary tube) is elevated or depressed.

Carbon dioxide.—A heavy, colorless gas (CO_2) which extinguishes flame—popularly called carbonic acid gas. It is produced by the action of acids on carbonates, by the fermentation of liquors, by the combustion and decomposition of organic substances, etc. Water will absorb more than its own volume of carbon dioxide under pressure, in which state it becomes soda, or carbonated, water. Compressed to a liquid it is used in some fire extinguishers and when frozen it becomes dry ice.

Carbon monoxide.—A colorless, odorless gas (CO) composed of carbon and oxygen. It is a product of the incomplete combustion of carbon, and burns with a pale blue flame to form carbon dioxide. It is very poisonous when inhaled because it drives oxygen from the blood. Its presence in the exhaust gases of internal-combustion engines has caused many fatalities.

Cohesion.—The molecular attraction exerted between the particles of a body which unites them.

Current density.—Amperes per square inch of surface.

Deposited metal.—Filler metal added from the electrode in arc welding.

Diaphragm.—A thin, flexible partition.

Dies.—A pair of cutting or shaping tools which, when moved toward each other, shape an object or surface between them by pressure or by a blow.

Ductile.—Capable of being drawn out, as a wire.

Elastic.—Capable of being stretched or deformed by outside force, but returning to original form after outside force is removed.

Element.—One of the ninety some basic substances of which all materials are composed.

Extrude.—To shape by forcing through dies by pressure—opposed to draw.

Flux.—Any substance or mixture used to lower the melting point or to clean surfaces to be joined by soldering or welding and free them of oxide, and thus promote their union.

Fusion.—Melting or melting together.

Hydrogen.—An element commonly isolated as an inflammable, colorless, tasteless, odorless gas, which burns with an almost invisible flame to form water. It is the lightest known substance.

Infrared.—Light rays that are outside the red end of the visible spectrum.

Malleable.—Capable of being extended by beating with a hammer or by pressure of rollers.

Mandrel.—An axle, spindle, or arbor, usually tapered or cylindrical, forced into a piece of work having a hole in it, to support it while the work is machined or worked upon.

Nitride.—A compound of nitrogen with another element, as boron, silicon, and many metals, injurious to metal.

Nonferrous.—Not containing iron.

Oxide.—A compound of oxygen with another element or substance.

Oxidize.—To combine with oxygen; to add oxygen to.

Oxyacetylene.—Of, pertaining to, or consisting of a mixture of oxygen and acetylene.

Oxygen.—An element occurring free as a tasteless, colorless, odorless gas which forms about 23 percent by weight and 21 percent by volume of the atmosphere. It is the most abundant of all the elements in the earth's surface.

Plastic.—Capable of being molded in a solid form by outside force, retaining that form after outside force is removed.

Reducing (in the sense of a reducing flame or agent).—Deoxidizing; capable of removing oxygen.

Scarf.—Bevel or chamfer.

Slag.—Superfluous matter, separated from metal in smelting, consisting mostly of silicates, which floats on molten iron.

Stress.—The external forces exerted on a body or the internal forces resisting them.

Tuyère.—A nozzle through which the air blast is delivered to a forge, blast furnace, etc.

Ultraviolet.—Light rays outside the visible spectrum at its violet end.

Volatile.—Readily vaporizable or easily evaporated.

Section II

BLACKSMITHING

3. **General.**—All the tools listed here will not be available in the smaller shops. Some of them are designed to take the place of the blacksmith's helper and are not required when he is available. Given a forge, an anvil, a hammer, a sledge, a few chisels, and a pair of tongs, the blacksmith can make many of the special tools he needs.

4. **Forge.**—A forge is the most important piece of blacksmith shop equipment. Forges are either portable or stationary.

a. Portable.—(1) A portable forge, the type used in mobile shops, is shown in figure 1. Its essential parts are a hearth, a tuyère and

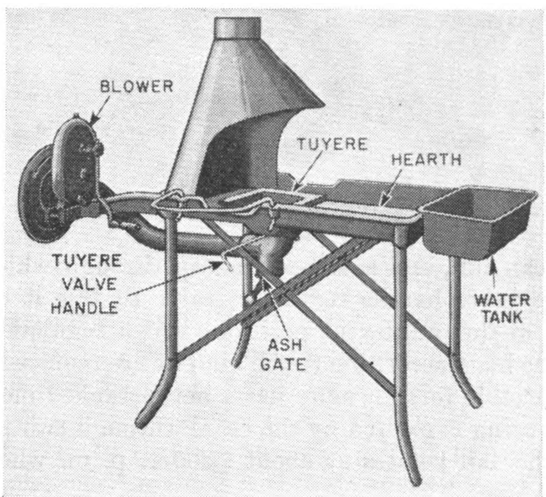

FIGURE 1.—Portable forge.

a blower. The hearth is a pan made from rolled-steel plate in which the fire is laid. The tuyère (fig. 2) directs an air blast into the fire. It is made of cast iron and consists of a fire pot, base, blast valve, and ash gate. The air blast enters the base, as shown in the illustration, and is admitted to the fire through the valve. A popular blast valve is a hollow cylinder having a large opening at the bottom through

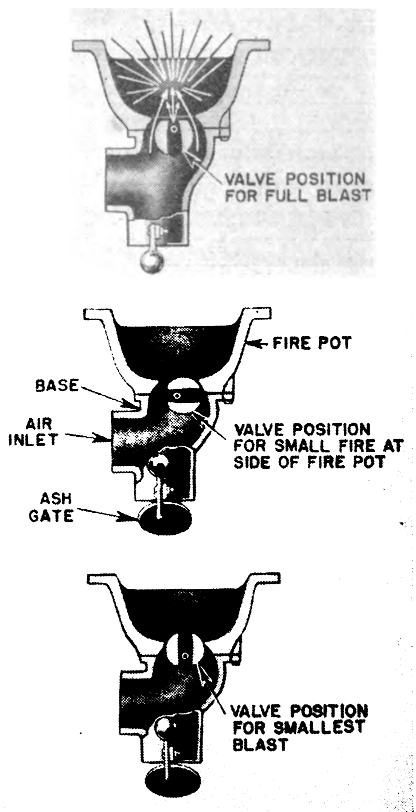

FIGURE 2.—Tuyère.

which ashes can fall, and a slot at the top through which air enters the fire. The valve handle turns the valve to free it of ashes and also places it in three different positions which regulate the size and direction of the blast according to the kind of fire required.

(2) The portable forge usually has a hand-cranked blower (fig. 3). A fan in a housing is rotated by the crank through two pairs of step-up gears. The fan rotates at about 2,200 r. p. m. when the crank

is turned at easy cranking speed, and produces an air-blast pressure of about 2 ounces per square inch.

(3) A hood is provided on the forge (fig. 1) for carrying away smoke and fumes from the fire. A water tank which hangs at the

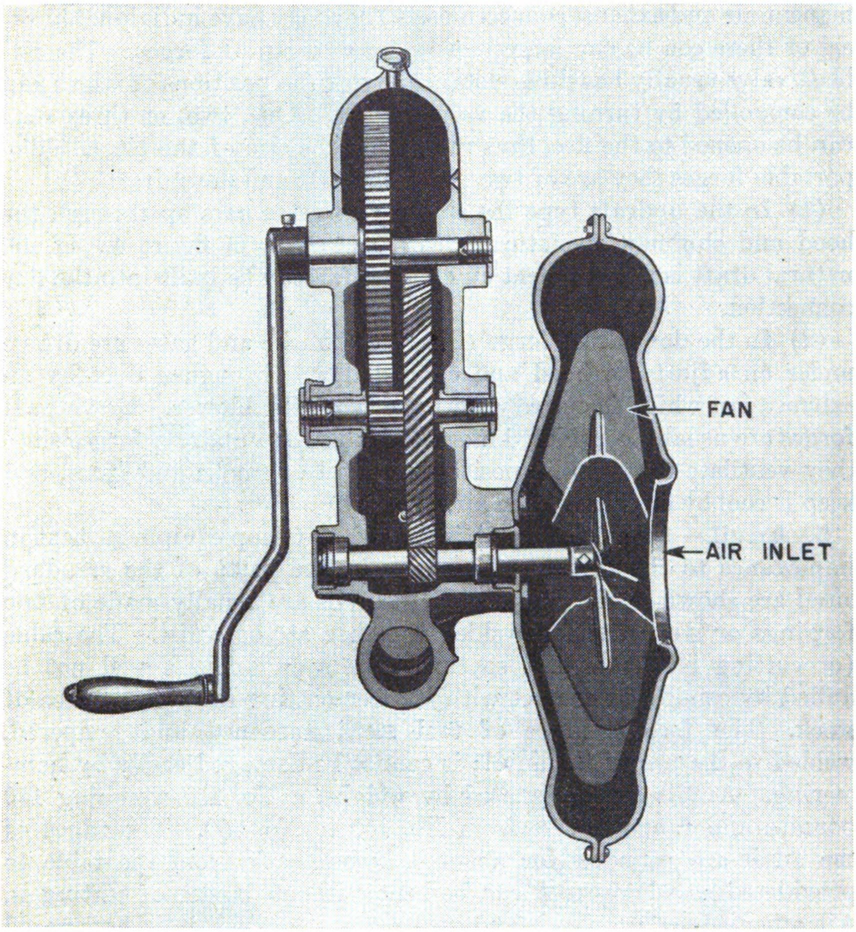

FIGURE 3.—Hand-operated blower.

side of the hearth is also usually furnished. Portable forges are sometimes equipped with electric blowers. These are the same as hand blowers except that the fan is driven by an electric motor. When the fan is power-driven, a blast gate is provided in the pipe between the blower and tuyère to regulate the strength of the blast. Portable forges are sometimes provided with a downdraft hood so the blower intake can remove smoke and gases. Part of the unconsumed gases are returned to the fire for full combustion, which is said to save coal and keep the shop clean and healthful.

b. Stationary.—Stationary forges are essentially the same as the portable forge just described but are usually larger and have permanent air and exhaust connections. They may have individual blowers or there can be one large blower for a group of forges. The air-blast valve usually has three slots at the top, the positions of which can be controlled by turning the valve handle. One, two, or three slots can be opened to the fire, thus regulating the size of the blast. Like portable forges they are of two types, updraft and downdraft.

(1) In the updraft type the smoke and gases pass up through the hood and chimney by natural draft, as shown in figure 4. If the natural draft is not sufficient an exhaust fan can be built into the flue connection.

(2) In the downdraft forge (fig. 5) the smoke and gases are drawn under an adjustable hood and carried down through a duct by an exhaust fan which is entirely separate from the blower. Downdraft forges are usually considered more desirable than updraft forges since they ventilate the shop by positive removal of smoke and gases, and keep it cool by circulating the air.

5. Anvil.—An anvil (fig. 6) is the piece of shop equipment next in importance to the forge. The names of the parts of the standard anvil are shown in the illustration. Anvils are usually made of two forgings or steel castings welded together at the waist. The table (or cutting block) is soft so that cutters and chisels will not be dulled by coming in contact with it after cutting through a piece of stock. The face is made of tool steel, hardened and tempered, welded to the top of the anvil; it cannot be damaged easily by hammering. Anvils are designated by weight, a No. 150 weighing 150 pounds, and range in size from No. 150 to No. 300. The edges of the anvil are rounded for about 4 inches back from the table to provide edges where stock can be bent without danger of cutting it. All other edges are sharp and will cut stock when it is hammered against them. The hardy hole is square and is designed to hold the hardy, bottom swages, and fullers. The pritchel hole is round and permits slugs of metal to drop through it when holes are punched out of stock. The anvil is usually mounted on a heavy block of wood, although steel pedestals or bolsters are sometimes used, and at such a height that the blacksmith's knuckles will just touch its face when he stands erect with his arms hanging naturally.

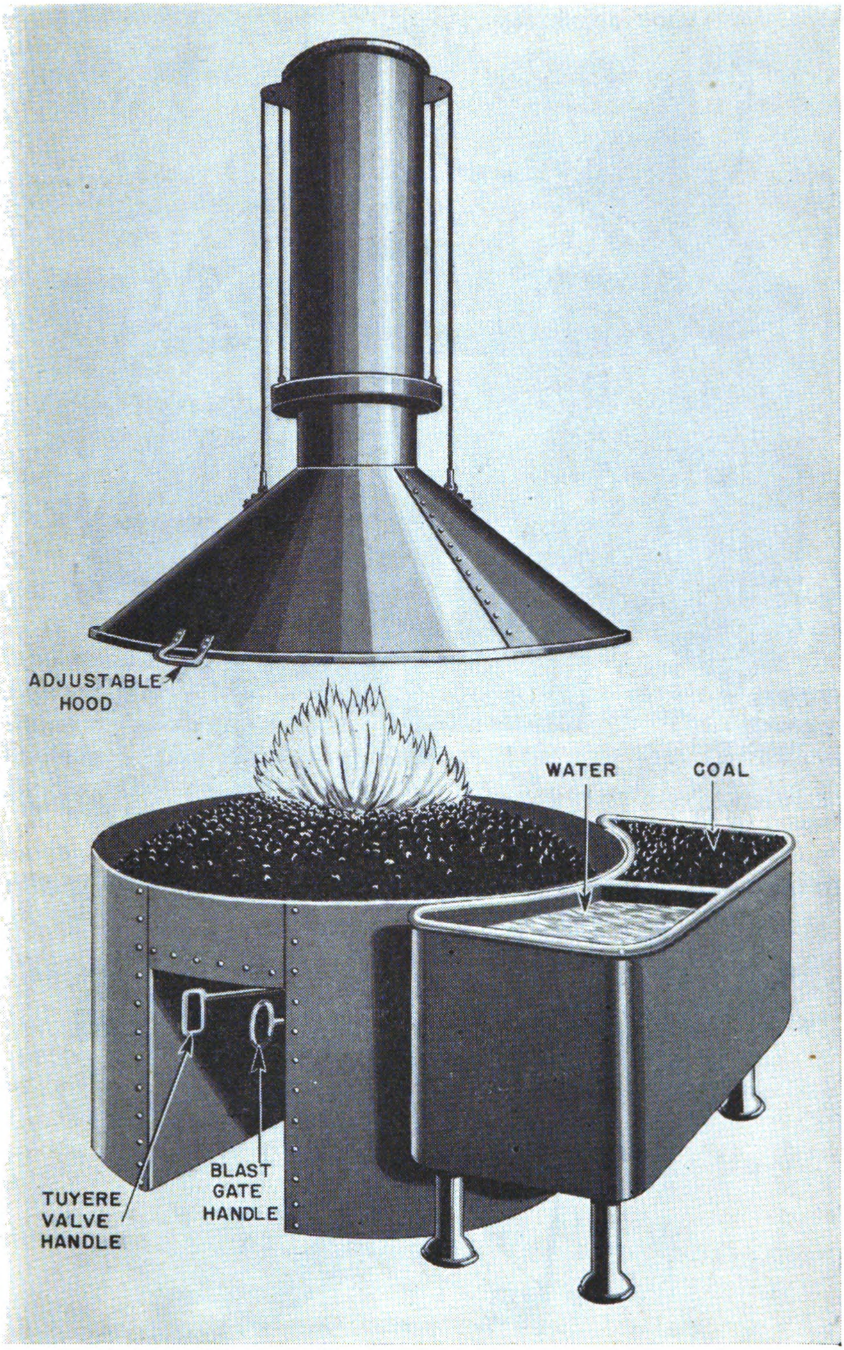

FIGURE 4.—Updraft stationary forge.

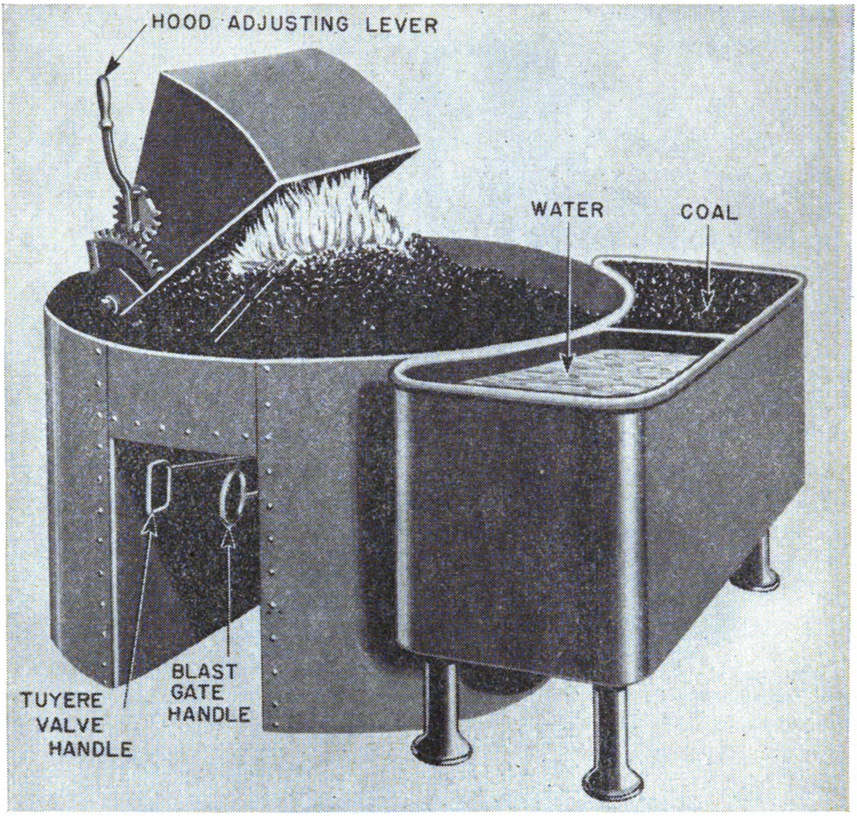

FIGURE 5.—Downdraft stationary forge.

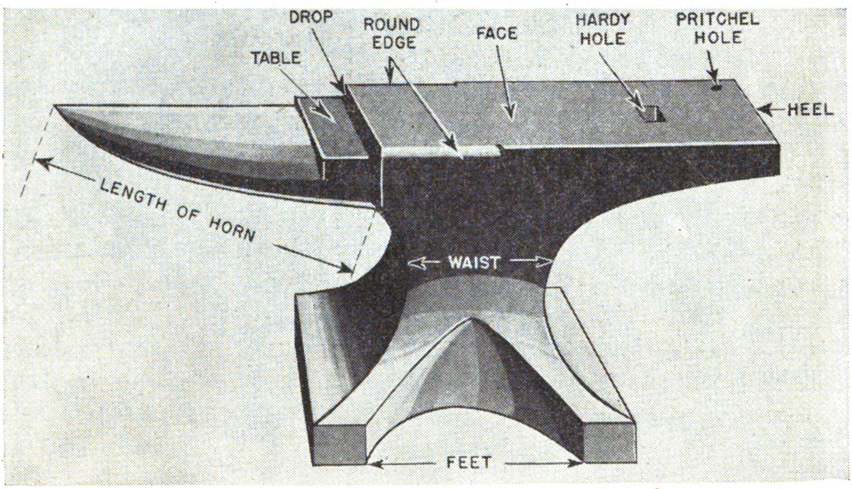

FIGURE 6.—Blacksmith's anvil.

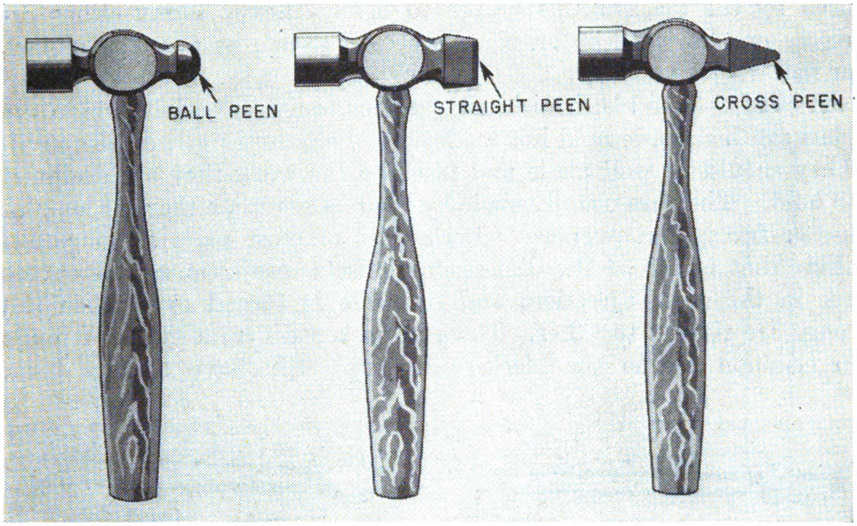

FIGURE 7.—Types of blacksmith's hammers.

6. Tools.—*a. Hammers.*—Three types of hammers (fig. 7) are used by the blacksmith: ball peen, straight peen, and cross peen. The ball peen hammer is the one generally used; the other two are little used. The straight peen hammer is used mainly for spreading or drawing out stock at right angles to the hammer handle. The cross peen hammer is used for drawing out metal in line with the hammer handle. Ball peen is used for ordinary light work.

b. Sledges.—A sledge is a hammer weighing from 5 to 20 pounds, having a handle 30 to 36 inches long. It is usually of the straight peen or cross peen type as shown in figure 8. Sledges are ordinarily

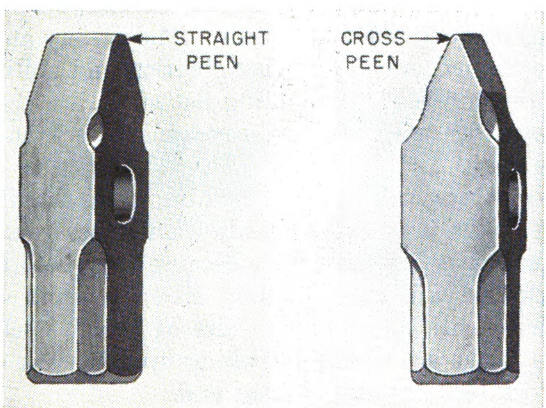

FIGURE 8.—Sledges.

used by the blacksmith's helper to deliver heavy blows either directly on the work or on some other tool such as a swage, fuller, or flatter.

c. Tongs.—The blacksmith uses various tongs, essential tools in the blacksmith shop, to hold hot work while he is forging it on the anvil. They should be well made and fitted to the work they are designed to hold. They are usually made by the blacksmith, either for general use or for special purposes. Both sides of most pairs of tongs are alike, that is, all of the dimensions, offsets, projections, and curves are in the same direction, and one side is turned over when the tongs are riveted together. There are seven different types of tongs in common use in the blacksmith shop. Six have definite form

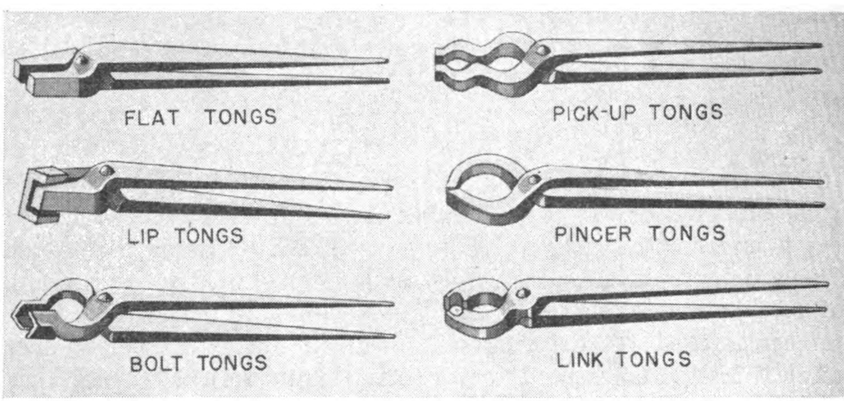

FIGURE 9.—Common tongs.

as shown in figure 9. The seventh type includes all tongs that a blacksmith makes for special purposes. Figure 10 shows a few examples of special tongs made by the blacksmith. The variety and number of such tongs are limited only by his imagination and ability.

(1) Flat tongs are used for holding flat stock.

(2) Lip tongs are used to hold rectagular stock to be bent or worked on its edge.

(3) Bolt tongs are suitable for holding stock having a larger end than body. The jaws can be made with either round or square grooves. Square jaws are preferable because they hold either round or square stock and will hold different sizes or round stock firmly, while round jaws will hold only one size of round stock.

(4) Pick-up tongs are used for picking up hot work or tools and for holding stock being worked on the end.

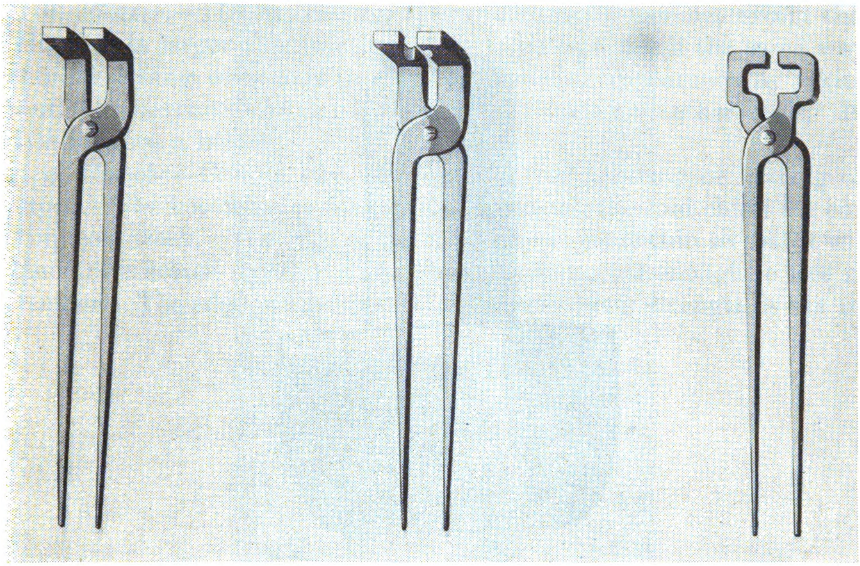

FIGURE 10.—Special purpose tongs.

(5) Pincer tongs, sometimes called barrel tongs, are used mainly to hold round stock while it is worked on the ends.

(6) Link tongs are used for holding chain links or for similar work while they are being forged.

d. Fullers.—(1) The top fuller (fig. 11) is used to make depressions in the upper side of a forging as it lies flat on the anvil or for drawing out or spreading stock. Like the similar tools described below, it has a handle like a hammer and is held on the work by the blacksmith while his helper strikes it with a sledge.

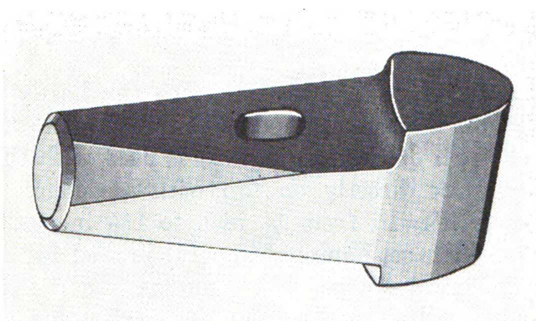

FIGURE 11.—Top fuller.

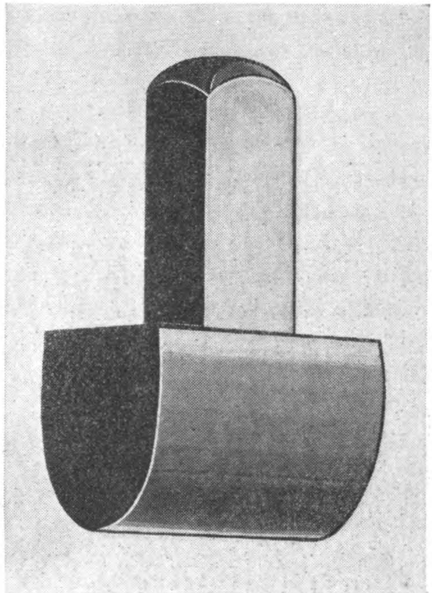

FIGURE 12.—Bottom fuller.

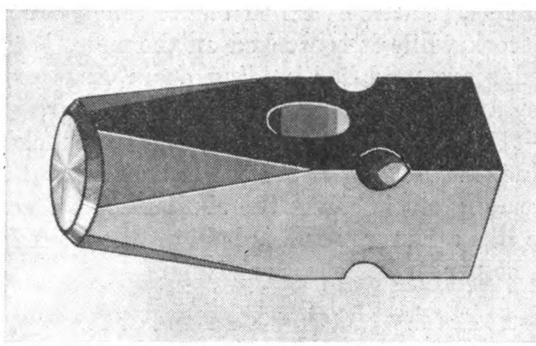

FIGURE 13.—Set hammer.

(2) The bottom fuller (fig. 12) fits into the hardy hole of the anvil. It is used for the same purposes as the top fuller, except that it works on the bottom of the forging. It is used with the top fuller, or the stock is struck directly on top with a sledge. Fullers are ordinarily made with radii from ½ inch to 1½ inches.

e. Set hammer.—The set hammer (fig. 13) is used for setting down work, working in small spaces, or producing sharp inside corners. It is usually made with sharp edges, although some set hammers have rounded edges and are called round edge set hammers. The top fuller and the set hammer are the most useful tools for forge work. Their use, however, requires a helper.

f. Flatter.—The flatter (fig. 14) is like the set hammer except that the face is larger than the body. It is used in much the same way, for smoothing work and producing a finished appearance by taking out the unevenness left on stock by the hammer or other tools. Its use requires a helper.

g. Chisels.—Chisels (fig. 15) are used for splitting or cutting off stock. The hot chisel is for cutting hot metal, the cold chisel for cutting cold stock. The edge of the hot chisel is made thin so that it will penetrate heated metal quickly without getting hot enough to lose its temper. The edge can be made thin because great strength is not required of a tool for cutting hot metal. The cutting edge of the hot chisel is ground to an (included cutting) angle of about 30°. The cold chisel is made blunt and stubby in order to give it great strength. The cutting edge is ground to an (included cutting) angle of about 60°.

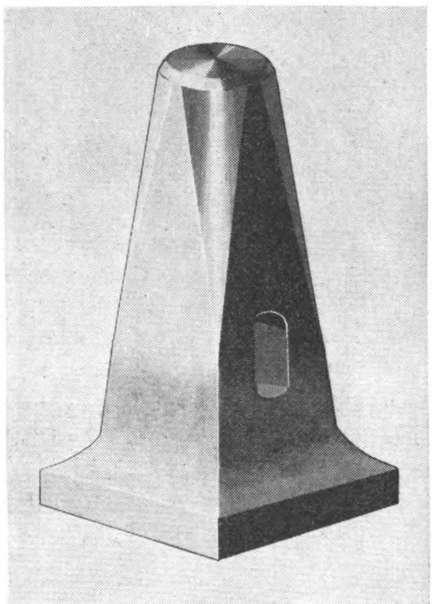

FIGURE 14.—Flatter.

h. Hardy.—The hardy (fig. 16) is a hot or cold chisel made to fit into the hardy hole of the anvil and is used as a bottom cutting tool.

i. Swages.—Swages (fig. 17) are used for smoothing and finishing and are made in all shapes and sizes depending upon the work to be done. They are used in pairs, each pair consisting of a bottom swage and a top swage. The bottom swage is inserted in the hardy hole of

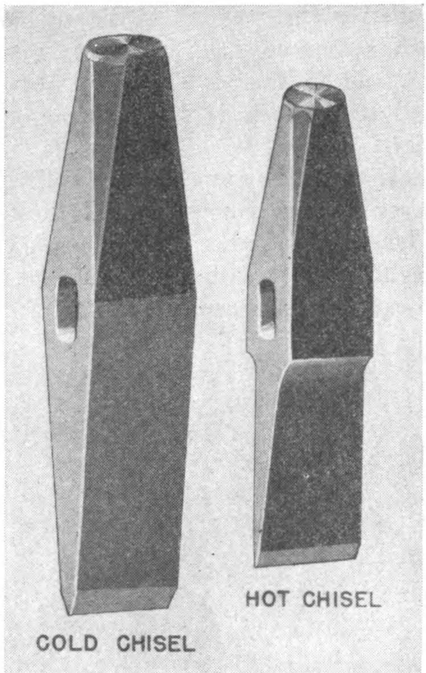

FIGURE 15.—Chisels.

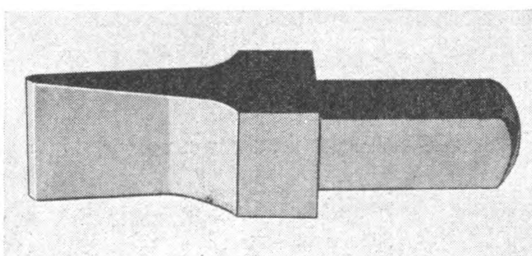

FIGURE 16.—Hardy.

the anvil. The groove in the top swage is the same as that in the bottom swage. The grooves are usually half round, octagonal, and square, although they may be any other shape. The hot forging is placed in the groove of the bottom swage, and the top swage held on top of the work by the smith while his helper strikes it with a sledge.

j. Swage block.—The swage block (fig. 18) is a block commonly made of cast iron weighing about 150 pounds, usually mounted on a stand. It is pierced with a number of round, square, and rectangular holes and provided with grooves of various shapes and sizes around the edge. The holes are mostly used for the insertion of work that is being headed, such as a bolt, for example. The grooves are used principally as bottom swages.

k. Punches, bob, and cupping tool.—Punches (fig. 19) are used for making round, square, or odd-shaped holes in hot stock. Like most of the other forging tools described, they are provided with handles and are held on the work by the blacksmith while being struck with a sledge by his helper. When finishing a hole, the punch is held on the work over the pritchel hole in the anvil, which provides a

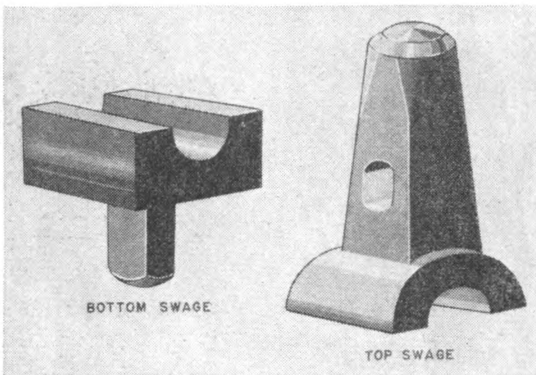

FIGURE 17.—Swages.

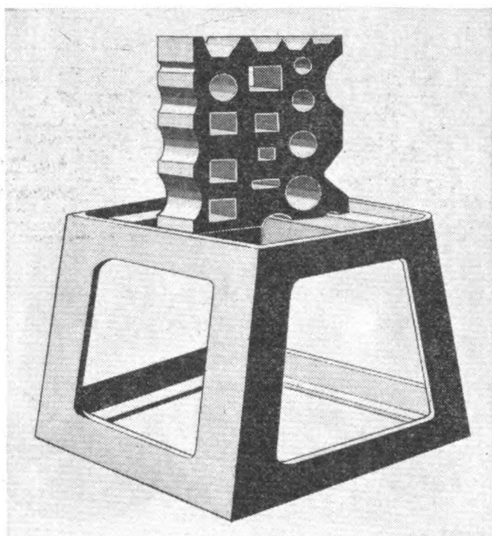

FIGURE 18.—Swage block.

place for the slug of removed stock to go. Two other tools are the bob or counterpunch and the cupping tool (fig. 20). The counterpunch is used mainly for countersinking holes and making depressions for jump welds. The cupping tool is used for rounding off or finishing the heads of rivets.

l. Vise.—A vise has many uses in the blacksmith shop, such as holding work while it is being laid out or being bent, twisted, or filed. A good type of vise for this use is shown in figure 21.

m. Drill press.—A drill press of either the wall or pedestal type is also usually part of the equipment of a blacksmith shop.

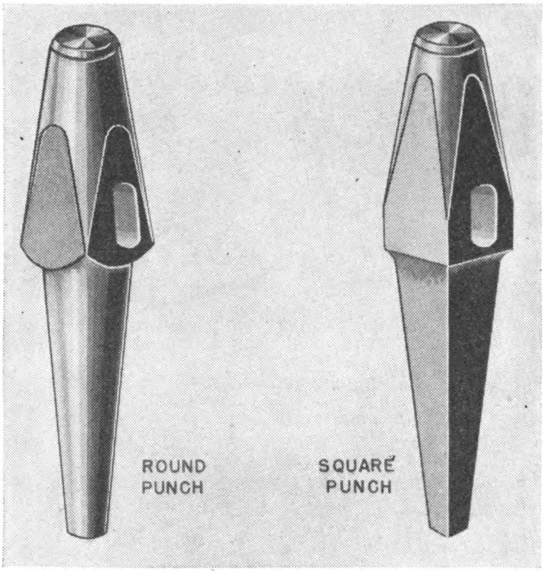

FIGURE 19.—Punches.

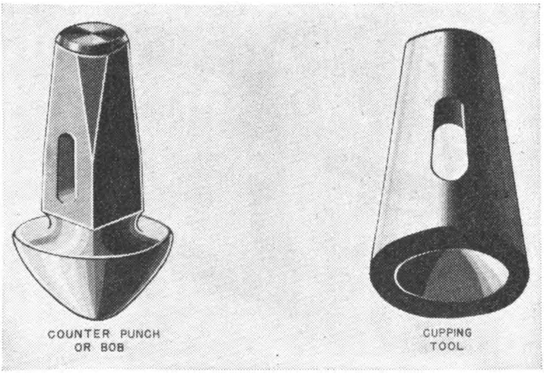

FIGURE 20.—Bob and cupping tool.

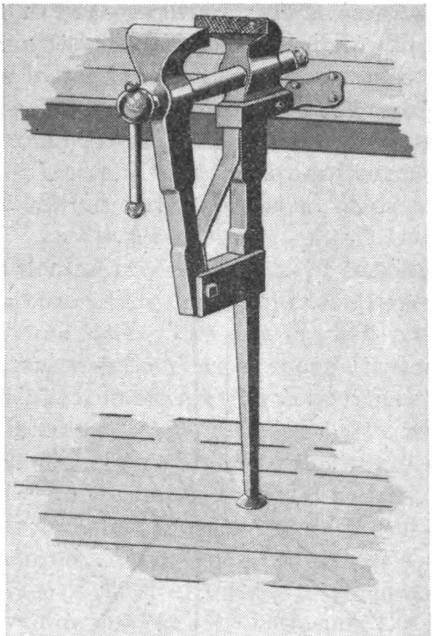

FIGURE 21.—Blacksmith's vise.

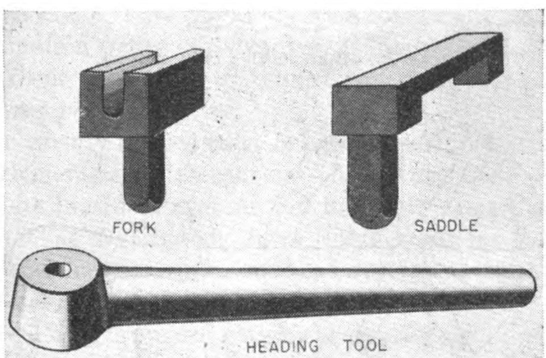

FIGURE 22.—Special tools.

n. Special tools.—Figure 22 shows a few special tools: a fork for bending flat stock; a saddle for drawing out forked stock; and a hand heading tool for making heads on bolts. The swage block takes the place of many such special tools.

o. Measuring tools.—Measuring tools commonly used in the blacksmith shop are a steel rule, a carpenter's 2-foot steel square, calipers, and dividers. A blacksmith usually has a pair of double or twin calipers similar to those shown in figure 23, in addition to the ordinary calipers. Two dimensions may be set on these calipers, such as width and thickness. Another useful tool is the measuring wheel shown in figure 24. Dimensions are obtained by rolling the wheel over the lines to be measured.

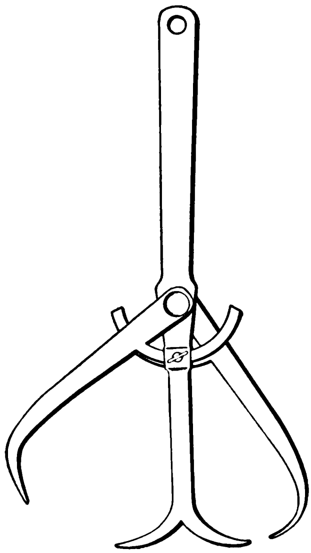

FIGURE 23.—Blacksmith's twin calipers.

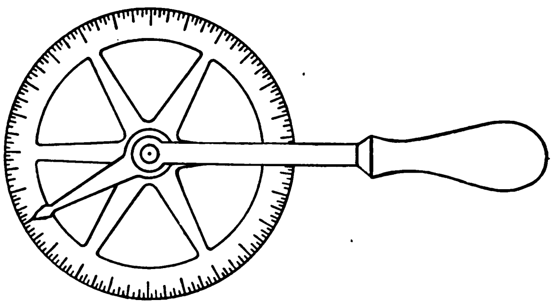

FIGURE 24.—Measuring wheel.

7. Procedure of forging.—*a.* A blacksmith usually works with wrought iron and steel. Wrought iron is fibrous and has stringy streaks of slag running lengthwise of the bar, giving it a decided grain similar to wood. Low-carbon steel is soft steel, sometimes called mild steel or machine steel. It is much the same as wrought iron except that it lacks the fiber and is somewhat stronger. Tool steel differs from these two materials in that sudden cooling from a high heat makes it very hard. Wrought iron or mild steel cannot be hardened by the same treatment. Tool steel is practically the same thing as wrought iron or mild steel with a small percentage of carbon added. In fact, either of the two softer metals can be changed into tool steel by adding carbon to them. This procedure is used in case-hardening.

b. The case-hardening process consists of causing the surface of the piece to absorb carbon. This forms a thin shell upon the piece that has the properties of tool steel. The case or shell can then be hardened by heating and quenching the piece as though it were tool steel. Only the case becomes hard, however; the core remains soft, tough, and ductile. For this reason, case-hardened parts resist shock without breaking better than parts hardened all the way through and are used for many purposes, for example, ball and roller bearings. The case varies in depth from a few thousandths to about 1/16 of an inch, depending upon the process used. Several processes are used for adding carbon to the surface of the steel, but the most common are the packing process and the cyanide process. In the former the parts are packed in bone or leather charcoal in a closed iron container and heated for a considerable length of time in a forge or furnace—the longer the time, the deeper the case. The cyanide process consists of heating the parts in a bath of molten potassium cyanide. This process should never be attempted except under expert supervision. *Cyanide is one of the most dangerous poisons known.*

c. Another variety of tool steel is high-speed steel, which is alloyed with other elements besides carbon—chiefly tungsten. This type of steel retains its hardness even at red heat and is used to make tools for cutting steel at high speeds, from which it derives its name. Such steels require somewhat different heat treatment than do ordinary carbon tool steels, and the manufacturers' recommendations should be observed. There is a third classification of steel, known as medium steel, that has a carbon content between that of mild steel and tool steel. It can be hardened and tempered and is used for parts requiring strength and toughness. Material from which forgings are made usually comes to the shop in the form of round, square, and rectangular bars from 12 to 20 feet in length. Tool steel generally comes in bars 6 or 8 feet long.

d. Metal is forged by heating until it is soft and forming it by striking with a hand or power hammer or by pressure applied in a power press. Drop forgings are formed between the dies of a power hammer and pressure forgings are similarly formed in a power press. These are production processes. The simple forging of light stock, with which the automotive repair or maintenance shop is mainly concerned, is done by striking the red hot metal on an anvil with hand hammers or the other hand tools previously described. Forging breaks up the crystals and refines the grain of the iron or steel, making it stronger and tougher, but if the work is stopped while the steel is still hot the crystals will grow again to some extent. Forging should therefore be continued until the metal cools to a low, red heat.

e. Forgings are used mainly where stronger, tougher, and less brittle metal is required than can be obtained by castings. This is often an important safety consideration. For example, hooks for heavy duty crane, derrick, or winch cables should always be forgings. Otherwise, when heavily loaded, they may break suddenly, causing serious damage by dropping the load or whipping the cable.

TABLE I.—*Melting points of some irons and steels*

Material	Melting point, °F.
Pure iron	2, 800
Wrought iron	2, 700–2, 750
Stainless steels	2, 400–2, 700
Carbon steel	2, 400–2, 750
Cast iron	2, 100–2, 350
Cast steel	2, 600–2, 750

8. Heat treating.—*a. General.*—A blacksmith must have at least an elementary knowledge of heat treating to forge successfully. This subject includes the processes of heating for forging, annealing, hardening, and tempering. One of the most important things for the blacksmith to remember that heat treatment is that steel must never be overheated or "burned." When steel is said to be burned it means that it has been heated to a temperature close to the melting point, which burns out certain elements in it, gives it a very coarse grain structure, and ruins the steel. Table I gives the melting points of some irons and steels. Burned steel cannot be restored to its original quality by subsequent heat treatment. Wrought iron, mild steels, and medium steels can be heated to about 2,000° F. without destroying their desirable properties. Tool steels can be heated only to some lower temperature, depending mainly upon their carbon content. The lower the carbon content the higher the temperature to which steel can be heated without being burned. When available, the manufacturer's recommendations should be followed; otherwise, the temperature to which the material may be heated safely can be determined by experiment with a sample. Table II shows the approximate temperatures of iron alloys indicated by their colors when heated above red heat.

TABLE II.—*Temperature colors (approximate)*

Color	° F.
Faint red, visible in dark	750
Faint red	900
Blood red	1, 050
Dark cherry	1, 175
Medium cherry	1, 250
Cherry or full red	1, 375
Bright red	1, 550
Salmon	1, 650
Orange	1, 725
Lemon	1, 825
Light yellow	1, 975
White heat	2, 200

b. Annealing.—Annealing increases the flexibility, softness, and ductility of metals which have become brittle through the strains of being rolled, drawn, twisted, hammered, forged (work hardened), or which have been hardened by heating and quenching. Steels are annealed by slowly cooling them from a high temperature. When steel is in the annealed condition it can be worked into any shape.

c. Hardening.—Tool steel is hardened by being heated to a high temperature and suddenly cooled, usually by being plunged into water (quenched). This makes it very hard but also very brittle. The temperature to which the steel must be heated for hardening is either within or above what is known as the "critical temperature range." This is the temperature at which the crystalline structure of the steel undergoes a change. Since this temperature varies considerably for different steels, it must be determined for the particular kind being used. Quenching is a fixing process. The grain structure of quenched steel when it becomes cold is the same as it was at the critical temperature. Slow cooling or annealing, on the other hand, allows the grain to grow while the steel is cooling off.

d. Tempering.—The hardened steel is too brittle for ordinary purposes so a portion of its hardness must usually be removed by reheating it to a lower temperature than the critical temperature and quenching it again. This process is known as tempering or drawing. The temperature to which a piece of steel should be heated for drawing depends upon the use to which it is to be put; its final hardness is regulated by varying the reheating temperatures—the higher this temperature, the softer the steel. When a steel tool or other article has been hardened, then polished with emery cloth or a rubbing stone and reheated, the film of oxide (not the metal itself) on its surface becomes a light straw color at 420° F., then varies through intermediate hues to a violet yellow at 509° F., blue at 550° F., while at 725° F. the steel passes to a red heat. These colors guide the smith in his efforts to temper tools as required. Light yellow is the correct temper color for all tools requiring a keen edge, a deeper yellow for fine cutlery, violet for table knives requiring flexibility more than a hard, brittle edge, and blue for all articles required to be very flexible. It is better, however, to be guided by positive temperatures, when known, than by colors, either for tempering or for forging heats, because colors do not appear the same in different lights or to different individuals, most persons being at least a little color-blind.

9. Fires.—*a.* Air is a gas composed mainly of two elements: About four-fifths oxygen and one-fifth nitrogen. It is the oxygen that is active in burning or combustion. Combustion is the rapid uniting of oxygen with a substance. Coal and wood are made up largely of the element carbon. When they burn, the carbon in the wood or coal combines with the oxygen of the air. In a similar manner, hot iron oxidizes when exposed to the oxygen of the air, forming iron oxide, or scale.

b. The fuel used for forge fires should be coking coal, as free as possible from sulphur, slate, and other impurities. Any soft coal that crumbles easily into many-sided small particles with bright, shiny surfaces is good smithing coal. However, the best way to learn a coal's coking properties is to try it and see if it cokes. Many blacksmiths do not bank the fire or make a supply of coke for future use. It is not necessary to do so for light work, because an experienced blacksmith can char coal around the rim of the fire as fast as he needs it. The charred coal that the blacksmith is constantly making and using to replenish the fire and to cover the forging while it is heating is soft coke.

c. Proper selection of fuel and care of the fire are essential to first-class work, especially for forge welding and for working tool steels. The bottom of the tuyère is about 5 inches below the hearth to allow sufficient depth of fire below the piece being heated when it is level with the hearth. The pressure of the air blast should be from 2 to

7 ounces per square inch. This low pressure is not liable to injure the metal that is being heated since destructive oxidation (scaling) will occur but slowly. The hottest part of the fire is from 5 to 7 inches above the tuyère. Three types of fires are used by the blacksmith; the plain open fire, the side-banked fire, and the hollow fire. Each type may be either oxidizing or reducing, according to the depth of the

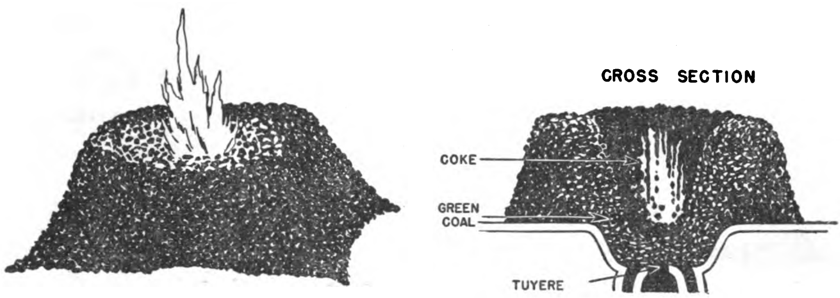

FIGURE 25.—Plain open fire.

fire and the strength of the blast. When the fire is so thin that the blast can pass through it before all the oxygen is consumed, the oxygen will attack the iron and form scale. A fire of this kind is known as an oxidizing fire. A deep fire, in which all the oxygen is consumed by combining with the coal before reaching the metal, is known as a reducing fire. It is slow heating but will not oxidize the metal.

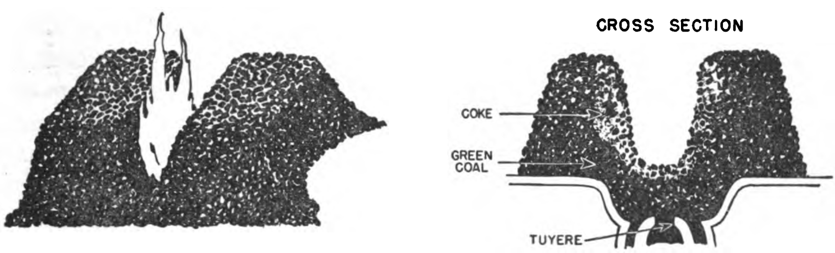

FIGURE 26.—Side-banked fire.

A reasonably thick fire just large enough to surround the piece being heated with glowing coals should always be maintained. Unburned wet coal packed around the fire will keep it from spreading.

(1) The plain open fire (fig. 25) is used for heating flat, wide pieces that cannot be heated in a side-banked fire.

(2) The side-banked fire (fig. 26) is generally used.

(3) The hollow fire (fig. 27) is not used extensively but gives an intense heat. An important use of this fire is for forge welding and

also for heat treating high-speed tool steel which must be heated to a very high temperature (about 2,200° F.).

10. Basic shaping operations.—In general, forging consists of shaping and finishing metals. Five basic operations in shaping are drawing, upsetting, bending, twisting, and welding. When a helper is employed on drawing, upsetting, or welding operations, it is customary for the blacksmith to touch the work with his hammer indi-

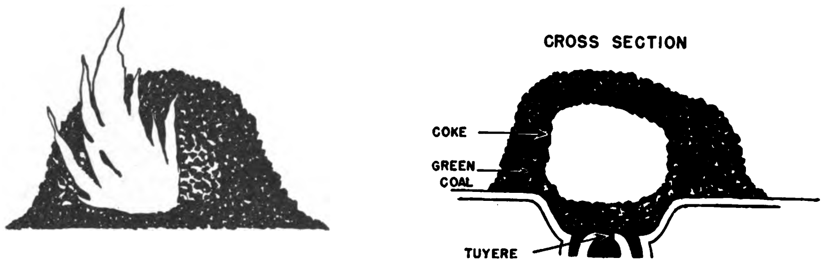

FIGURE 27.—Hollow fire.

cating the spot he wants struck with the sledge by the helper, and to touch the face of the anvil when work is to be stopped. As the hammer usually leaves marks on the work after it is shaped, it is customary to leave the metal a little full, then finish it by means of flatters and swages. This applies to work that has been finished under the sledge. Light work can be dressed smoothly with a hammer.

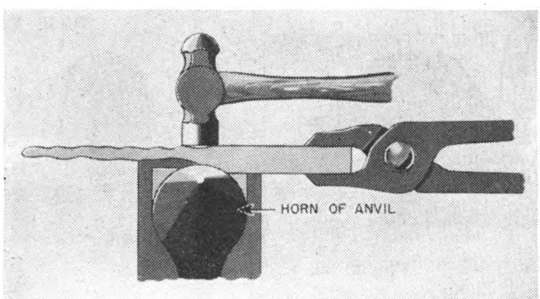

FIGURE 28.—Drawing flat stock.

a. Drawing.—When a piece of metal is worked so that the length is increased and the cross section reduced, it is said to be "drawn out." It is best to heat stock to be drawn out to the highest temperature it will stand without injury. When work is drawn by hammering it on the face of the anvil, the width is increased almost as much as the length. Therefore, to increase the length only and not the width, the forging is worked over the horn of the anvil. The horn acts as a blunt wedge forcing the metal lengthwise, as shown in figure 28. Fullers can be used to advantage for the same purpose. When a piece of iron is to be drawn out both in length and width the flat face of the hammer is used, but when it is to be stretched in one way only, the peen of the hammer is used with the peen at a right angle to the direction the stock is to be drawn.

When a piece of round stock is being drawn out or pointed, it should be forged down square to a little less than the required diameter first. Then, with as few blows as possible it is made octagonal, then round. If an attempt is made to hammer it round directly from the square shape, there is great danger of splitting it. The steps in this process are illustrated in figure 29.

b. Upsetting.—When a piece of metal is worked in such a way that its length is decreased and its cross section increased, it is said to be upset and the process is called "upsetting." Upsetting is the reverse of drawing out. These two processes are fundamental in

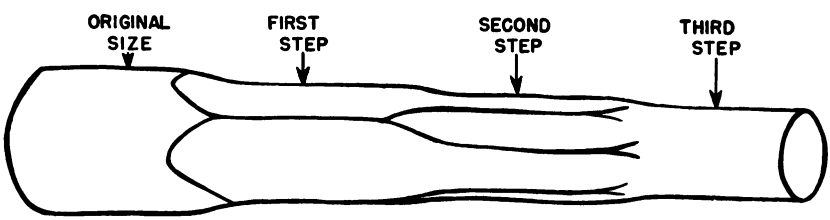

FIGURE 29.—Drawing round stock.

forging, and there are few forgings that do not involve one or both of them. In upsetting a short piece, it is best to stand it on end on the anvil and strike the upper end with a hammer. A piece that is long but of small cross section should be held flat on the anvil, by hand or with a pair of tongs, with the part to be upset extending over the edge. Thus the tendency to bend is lessened. Larger pieces are upset by bumping them repeatedly on the face of the anvil or on an iron plate set on the floor. Since upsetting tends to separate the fibers of the metal, it should be done at a welding heat so that these fibers may be joined. Long pieces will bend while being upset. The bends should be straightened as soon as they start, because if they are not, additional blows will increase the bend without upsetting the stock. Light blows upset the metal for a short distance only; heavier blows upset the piece more uniformly throughout its length. Sometimes the ends of a short piece may become upset while the middle does not. When this occurs it may be necessary to heat the piece uniformly and then quench the ends in water before hammering it.

c. Bending.—Bending is a very common and comparatively simple forging operation. Curves and rings of small cross section can easily be bent over the horn or round edge of the anvil or over a suitable mandrel. The bending of a ring or curve should be started at the end, as shown in figure 30. In bending angles it is usually necessary to make the bend at a particular point on the stock. The point at which the bend is to be made should be marked on the cold stock by a center punch. A cold chisel should not be used because a cut may start a crack when the stock is bent. The easiest way to bend flat work is to heat it, place it in the vise, and hammer it over.

d. Twisting.—Twisting is an operation that looks easy but is difficult to do properly. Each end of the twist is marked on the stock with a center punch. If the stock is light it can be twisted cold.

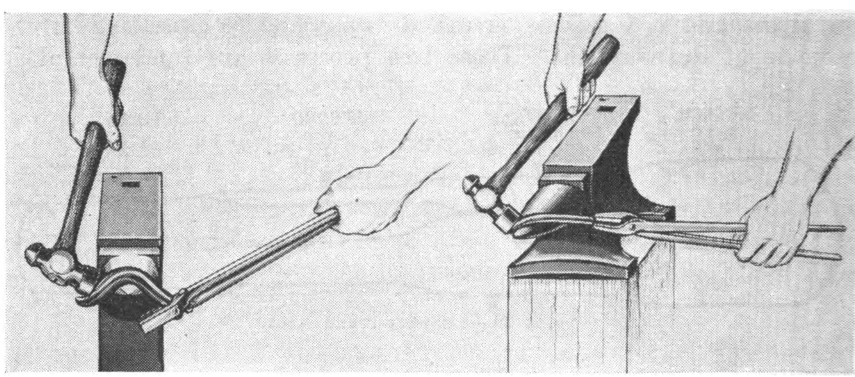

FIGURE 30.—Bending.

The stock is held in a vise with one center punch mark even with the top of the jaws. A wrench or bending fork is placed just above the other mark and given the required number of turns. The wrench or fork must fit tightly. The same method is used for heavier stock except that it must be heated before twisting. The heat must be uniform and the job done quickly.

e. Forge welding.—Forge welding consists of heating two or more pieces of stock to a very plastic state, or nearly to the melting point, at the place where the joint is to be made, and uniting them with quick hammer blows. It is very important to guard against scale on the iron when a weld is to be made, because the scale will lie between the surfaces to be welded and prevent their coming in contact. A flux, usually sand or borax, is sprinkled on the surfaces to be joined just before the metal reaches the welding temperature. The flux spreads over the hot metal and forms a protective coating which prevents further oxidation by keeping out the air. It also lowers the melting point of the scale, making it fluid so it can be squeezed out of the weld when it is hammered. Forge welding is not used as much as formerly because of the great development of gas and electric welding. Several common forge welds are illustrated in figure 31.

11. Calculation of stock for bent shapes.—*a.* It has been found by experiment that if a line is drawn through the center of a piece of stock and the stock is then bent, and the lengths of the inside, center, and outside lines measured, that the outside line will lengthen, the inside line will shorten, and the center line will remain the same. Therefore, the length of stock required for making any bent shape can

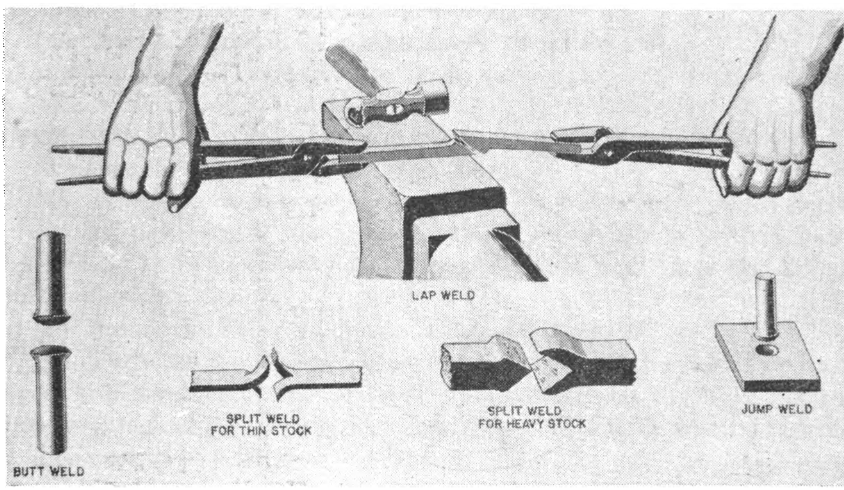

FIGURE 31.—Forge welds.

always be determined by measuring the center line of the curve or bend. Three examples of bent stock are the angle, ring, and link shown in figure 32. In the case of the angle, the outside line is 16 inches, the inside line 14 inches, and the center line 15 inches, which is the length of stock required to make it.

b. The circumference or distance around a circle is found by multiplying the diameter by $3\frac{1}{7}$ or, more accurately, 3.1416. Tables giving the circumferences of circles are available. The inside diameter of the ring shown in figure 32 is 6 inches and the stock is 1 inch. Therefore the diameter of the circle made by the center line would be 7 inches, and the length of stock required would be $7 \times 3\frac{1}{7}$ or 22 inches.

c. Other shapes can usually be divided into straight lines and parts of circles. Thus, in the link shown in figure 32, the center line consists

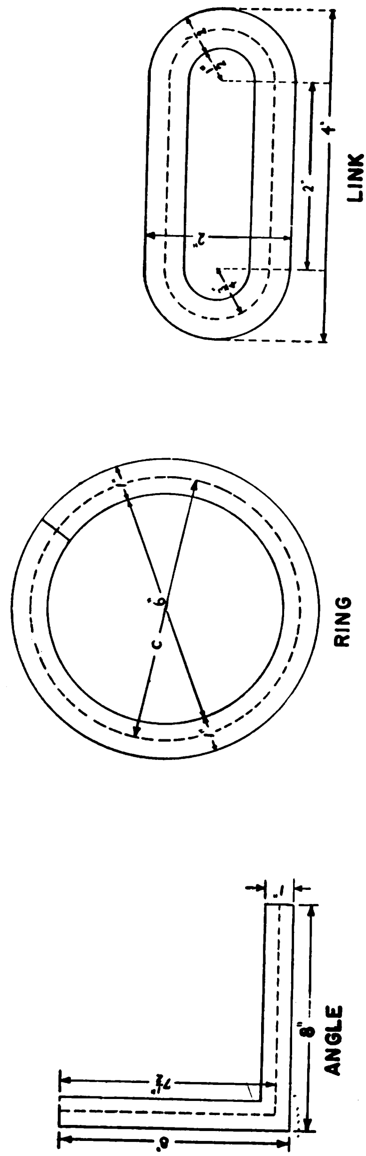

FIGURE 32.—Measuring stock for bending.

of two semicircles, or one circle, 1½ inches in diameter and two 2-inch straight lines. The length of the center line is, therefore, $1\frac{1}{2} \times 3\frac{1}{7} + 2 + 2 = 8.72$ inches. With a slight allowance for welding the link, the amount of stock cut should be 8¾ inches.

12. Unit forging operations.—A few examples of comparatively simple, step-by-step forging operations follow:

a. Bending a ring.—(1) Cut off the proper amount of stock.

(2) Heat about half its length to bright red heat.

(3) Place the stock on the horn of an anvil with one end projecting over it to permit striking a little beyond the horn. Feed the piece across the horn and continue to strike until about one-half of the circle is bent. The piece should not be struck directly over the horn as this will draw it out instead of bending it.

(4) Heat and repeat the operation on the other end.

b. Punching.—(1) Mark the place to be punched with a center punch.

(2) Bring the metal to good working heat.

(3) Lay the piece flat on the anvil face.

(4) Select the desired punch and place it on the center punch mark.

(5) If light work, use a hand punch and strike it with a hand hammer. If heavy work, use a handle punch and have the helper strike it with a sledge.

(6) Punch the hole two-thirds through the work.

(7) Turn the metal over, place the punch over the raised or dark spot, holding it over the pritchel hole, and punch through. If the hole is punched all the way through from one side, it will be tapered and there will be a bulge at the bottom.

(8) Cool the punch from time to time to prevent it from becoming annealed.

(9) In punching holes through thick stock, after the hole is started, remove the punch and place dry coal in the hole to keep the punch from sticking.

(10) Place the punch in the hole and hammer it to the desired depth.

c. Making a cold chisel.—(1) Cut off a piece of ⅝-inch, octagon tool-steel stock 6½ to 7 inches long, heat one end, forge the bevel, and square up to form a head.

(2) Reverse. Heat the other end slowly and uniformly to full red (about 1,450° F.) Draw out first to a short square taper (½ inch square) then flatten to ¾ inch wide and 1/16 inch thick at point. Be careful not to overheat the point.

(3) Heat about 2½ inches of the chisel carefully to full cherry red (about 1,375° F.). Plunge about 1½ inches of the heated end into

water, moving it up and down and around slightly in the bath, leaving about 1 inch of the chisel red hot.

(4) Polish the end quickly with a rub stone or emery cloth wrapped around a piece of bar stock or a file and watch the temper colors run down to the point. When the end becomes purple, quench the entire chisel.

(5) Grind the point to an included angle of 60°.

SECTION III

GAS WELDING AND CUTTING

13. General.—Fusion welding is the process of joining metals by melting or fusing together adjacent surfaces or edges without applying pressure. The heat for fusing the metal may be provided either by gases or electricity. Fusion welding is an important function of every military automotive maintenance shop. By use of the oxyacetylene process, iron and steel can be severed, shaped, or joined, and other metals can be joined. Permanent repairs can usually be made by welding, even in the field, avoiding the necessity for temporary or "stop-gap" repairs.

a. The gases commonly used for welding or cutting are oxygen and and acetylene, although oxygen with some other fuel gas is sometimes used. This section describes the oxyacetylene process. Electric welding will be described in section IV. Almost the same results can be accomplished by either process. The oxyacetylene outfit is somewhat more portable than the electric and is usually available even in mobile shops. The oxyacetylene process cuts steel and iron very efficiently.

b. An important use of the oxyacetylene process, especially in the small shop or in the field, is for heating. When forges and other blacksmithing equipment are not available, simple bending and forming operations can be performed easily by using the welding torch to heat the metal to forging temperature, or for annealing, hardening, and tempering operations, if necessary.

14. Safety precautions.—Acetylene is an inflammable gas that is explosive when mixed with air. Oxygen is a chemically active gas. Both are compressed into cylinders under high pressures for industrial uses, and both are extremely dangerous unless the safety precautions mentioned throughout this section and in the manufacturers' literature are strictly observed. One of the most important of these is *never* to oil regulators, torches, or any part of welding or cutting apparatus and never let oil or grease come in contact with or be near oxygen. Oil or grease coming in contact with pure oxygen under pressure will ignite violently or explode.

15. Equipment.—In its simplest form an oxyacetylene welding and cutting outfit consists of a cylinder of oxygen, a cylinder of acetylene, two regulators, two lengths of hose with fittings, and a welding torch supplemented by a cutting attachment or a separate cutting torch. With this equipment all commercial metals can be welded; steel, wrought iron or cast iron can be cut; and local metal heating operations can be done effectively. Mounted on a hand truck as shown in figure 33, such an outfit is portable and can be taken wherever the work is located. In addition, goggles are required to protect the welder's eyes, gloves to protect his hands, and a friction lighter to light the torch without danger of burning them. Wrenches are needed for cylinders, regulators, and torches. Welding rod or flux, or both, are also usually required. Interchangeable tips or heads of different sizes must be provided for the torches if the same handles are to be used for a variety of operations.

16. Acetylene.—*a.* Acetylene is a fuel gas having a distinctive odor, composed of carbon and hydrogen, its chemical formula being C_2H_2. It is manufactured by the action of water on calcium carbide, a crushed, rock-like substance produced in an electric furnace from coke and limestone. The gas is contained in steel cylinders under a pressure of about 225 pounds per square inch when the cylinder is full. An acetylene cylinder is not hollow; it is filled with a porous material saturated with acetone, a liquid chemical which absorbs many times its own volume of acetylene. The acetylene is dissolved in the acetone under pressure in the same way that carbon dioxide gas (CO_2) is dissolved under pressure in a bottle of soda water. This treatment makes the acetylene safe, even under the high 225-pound pressure, and allows enough acetylene to be stored in a cylinder for several days' use under average conditions. The usual capacity of an acetylene cylinder is about 300 cubic feet. The cylinder itself is a strong steel container provided with a valve for attaching the regulator and drawing off the acetylene. Acetylene, once it has left the cylinder, is called "free."

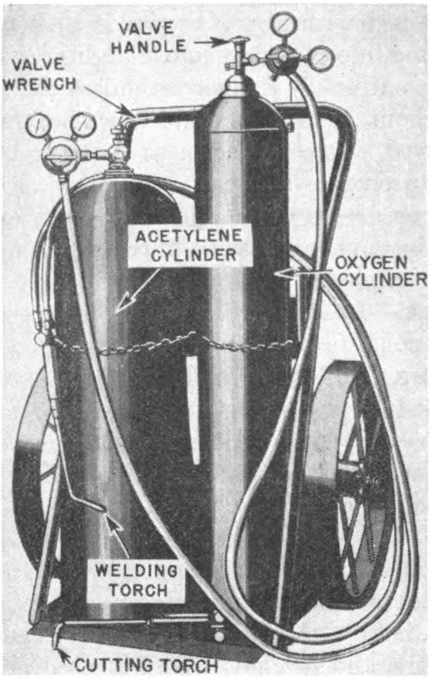

FIGURE 33.—Portable oxyacetylene welding outfit.

In this state it is liable to explode spontaneously when used at gage pressure over 15 pounds per square inch. A safety fuse plug which melts and releases the gas from the container is provided in case of fire. A cylinder of acetylene of 300 cubic feet capacity weighs 232.5 pounds full and 214 pounds empty. Smaller cylinders containing approximately 100 cubic feet are available. Empty cylinders must be returned to the manufacturer for recharging.

b. For safety's sake, remember that acetylene will burn and will form explosive mixtures with air. Handle acetylene cylinders carefully and store them in a well-ventilated, dry place away from combustible materials, stoves, radiators, or furnaces. Keep the valve end up. Never tamper with fuse plugs.

17. Oxygen.—*a.* Oxygen is a colorless, odorless, and tasteless gas. It is necessary for the combustion of most substances and combines chemically with them when they burn. Oxygen itself is not inflammable but is said to support combustion. For ordinary fires, such as forge and furnace fires, the oxygen in the air supports combustion of the fuel. Except for a very small percentage of rare gases, such as argon, neon, and helium, the atmosphere is composed of about one-fifth oxygen and four-fifths nitrogen. Nitrogen does not aid in combustion but merely cools off the fire. It can be seen, therefore, that the pure oxygen is a much more active agent than air in supporting combustion.

b. The bulk of the oxygen used in industry today is obtained from the atmosphere by the liquid air process; a small amount is made from water by the electrolytic process. Air is liquefied by a process of compression, cooling, and expansion, and oxygen is separated from the resulting extremely cold liquid by fractional distillation, in which advantage is taken of the fact that liquid nitrogen boils at a lower temperature than liquid oxygen. The distilling apparatus delivers practically pure oxygen to a storage holder, from which it is compressed into steel cylinders for distribution.

c. Oxygen is produced by the electrolytic process, as follows: Water is a chemical compound of hydrogen and oxygen (H_2O), each of which is a gas in its uncombined state. Under suitable conditions, an electric current passed through water decomposes it into its two elements. Bubbles of oxygen rise from the positive electrical terminal or electrode and hydrogen bubbles from the negative electrode. Each gas is led to a storage holder and then compressed in cylinders.

d. Oxygen cylinders are very strong, seamless, drawn-steel containers into which the oxygen is compressed to the extremely high pressure of 2,000 pounds per square inch. This pressure is measured at 70° F. and becomes somewhat greater when the cylinder is at a higher temperature and somewhat less when it is at a lower temperature. The pressure decreases as the oxygen is drawn off and the cylinder emptied. Unlike acetylene cylinders, oxygen cylinders are hollow. They are provided with specially designed valves to resist the high pressure. Every oxygen cylinder valve has some kind of a safety device to blow off the oxygen in case the cylinder is directly exposed to fire. The usual oxygen cylinder contains 220 cubic feet of oxygen and is 56 inches in height (including valve) and 9 inches in diameter. It weighs about 148 pounds full and 130 pounds empty. Smaller cylinders containing 110 cubic feet are available. The cylinder must be returned to the manufacturer when empty.

e. Oxygen is not an inflammable gas but causes other burning materials to burn more violently when they are exposed to it. It will cause oily or greasy substances to burst into flame with explosive violence without any other ignition. Always remember this when using it. Never confuse oxygen with compressed air and never use it to supply head pressure on a tank. It would be fatal to put pressure on the tank of a kerosene preheating torch, for instance. Never use oxygen for pneumatic tools, to start internal combustion engines, to blow out pipe, or to "dust" clothes. Oxygen cylinders are strong enough to withstand ordinary handling, but they should not be dropped off platforms,

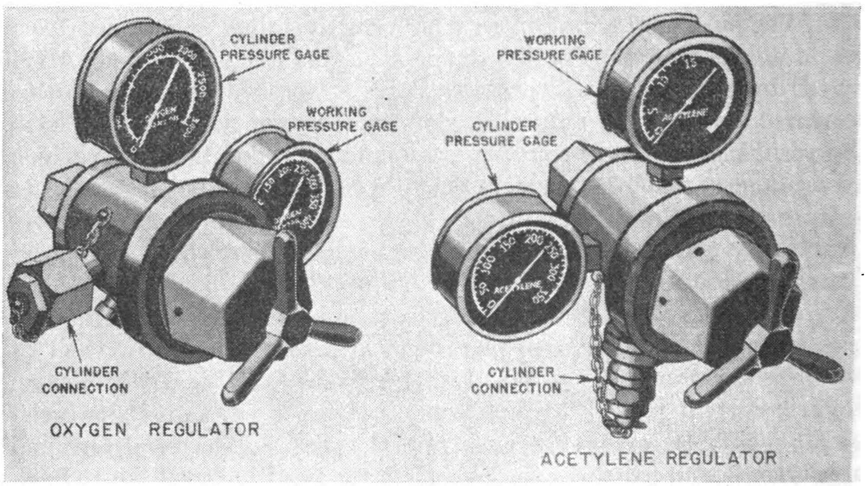

FIGURE 34.—Oxygen and acetylene regulators.

knocked about, or placed where heavy articles may drop on them. Do not store them in hot places or where oil may drop on them from overhead bearings or machines.

18. Regulators.—*a. General.*—The function of a regulator (fig. 34) is to reduce the high pressure of the gas in the cylinder to a low constant working pressure at the torch. For example, a cylinder contains oxygen at a pressure of 2,000 pounds per square inch, and a pressure of only 10 pounds per square inch is wanted at the torch to do some welding. The regulator must reduce the cylinder pressure from 2,000 to 10 pounds per square inch and must maintain this working pressure as the cylinder pressure decreases. Therefore, a regulator must have a sensitive regulating mechanism in addition to a reducing valve.

(1) A regulator for either an acetylene or an oxygen container has a union nipple for attaching it to the cylinder and an outlet connection for the hose leading to the torch. There are two gages on the body of the regulator: one shows the pressure in the cylinder, and the other the working pressure being supplied to the torch. The working pressure is adjusted by a hand screw. When this screw is turned to the left (counterclockwise) until it turns freely, the valve inside the regulator is closed and no gas can pass to the torch. Turning the handle to the right (clockwise) opens the valve, and gas passes to the torch at the pressure shown on the working pressure gage. The more the hand screw is turned to the right, the higher the pressure shown on the working pressure gage. Typical regulators are shown in figure 34.

(2) Before opening the valve on a cylinder to which a regulator is attached, the pressure-adjusting screw must be fully released by turning it to the left (counterclockwise) until it turns freely. Otherwise, when the cylinder valve is opened, the valve and seat will be forced together by the full pressure of the gas, which, in the case of an oxygen cylinder, may be as high as 2,200 pounds per square inch. The impact would ruin the valve seat, and the regulator would be unsafe to use until repaired.

b. Construction.—The details of regulator construction vary with different manufacturers but the fundamentals of operation are the same in all. The basic differences in the various makes are that some have movable valves with stationary seats, while others have stationary valves with movable seats, and some have rubber diaphragms while others have metal ones. A common type of regulator is shown in cross section in figure 35. Some type of safety release mechanism, such as a breakable disk or ball relief valve, is provided for the working pressure chamber of every regulator. If the regulator valve fails to close completely, a high pressure will be generated. This condition is sometimes known as "creep." Cylinder pressure gages are provided with safety devices to relieve the pressure if the bourdon tube in the gage breaks. Working pressure gages are usually provided with vent holes for the same purpose.

c. Pressure reduction operation.—The cylinder pressure is reduced to working pressure as follows: When the pressure-adjusting screw (figure 35) is turned to the left (counterclockwise) until fully released, the high pressure valve is held closed by the small valve spring. When the cylinder valve is opened, gas from the cylinder enters the regulator through the inlet connection and passes through the inlet screen to the high pressure chamber where it assists the valve spring in keeping the valve seated. The screen keeps out particles of dirt or other matter that might damage the valve seat. As long as the valve is closed, the gas is confined to the high pressure chamber. The cylinder pressure gage is connected to this chamber through a drilled hole and registers the cylinder pressure. When the pressure-adjusting screw is turned to the right (clockwise), it compresses the pressure-adjusting spring and forces it against the diaphragm and the valve, which is connected to the diaphragm. When the pres-

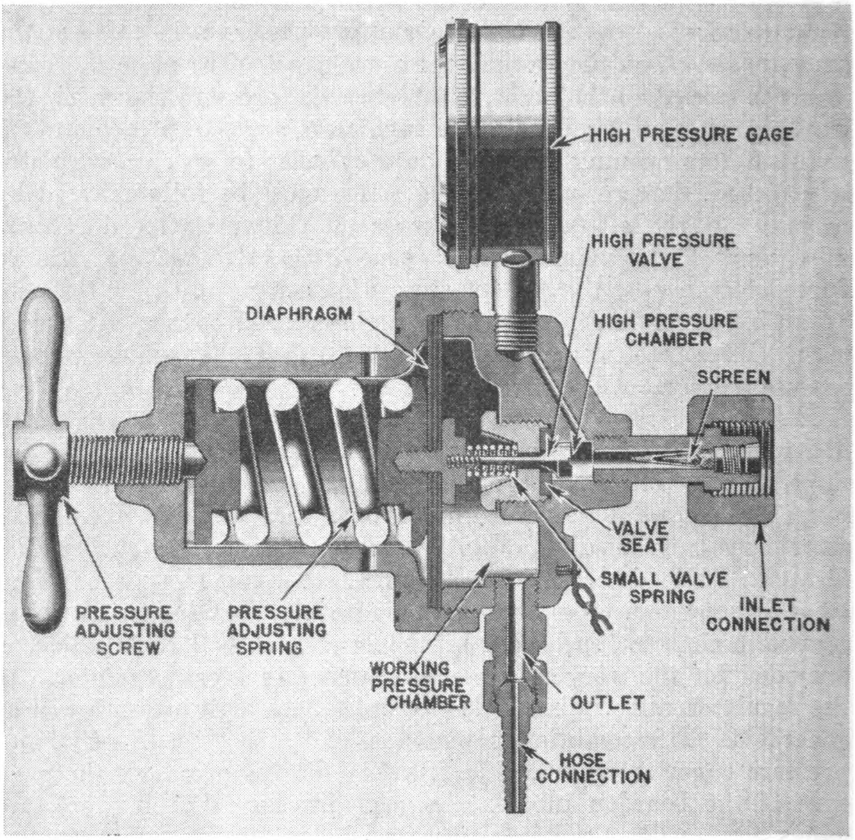

FIGURE 35.—Single stage regulator.

sure of the pressure-adjusting spring overcomes the opposing combined pressure of the valve spring and the high pressure gas on the head of the valve, the valve opens. Gas then flows from the high pressure chamber through the opening around the valve stem into the working pressure chamber, thence through the outlet and hose connection to the torch. If the torch valve is open, the gas flow will continue at the pressure indicated on the working pressure gage, which is connected with the working pressure chamber. Increasing the pressure by the pressure-adjusting spring increases the pressure in the working pressure chamber. Thus any working pressure, within the capacity of the regulator, can be obtained by turning the pressure-adjusting screw until the working pressure gage indicates the pressure wanted. The correct torch valve should always be open when the working pressure is being adjusted.

d. Pressure regulation.—The gas pressure in the working pressure chamber to which the torch valve is connected is regulated as follows: If the torch valve is closed, pressure immediately builds up in the working pressure chamber and presses against the diaphragm. The diaphragm, being flexible, moves in or out with changes in pressure in the working pressure chamber. As the pressure on the diaphragm increases, it compresses the pressure-adjusting spring and closes the valve, shutting off the flow of gas. As soon as the pressure on the diaphragm is reduced slightly by opening the torch valve, the pressure-adjusting spring decompresses and reopens the valve. For the sake of simplicity, only the action of the mechanism in starting and stopping the flow of gas has been explained. Actually the mechanism functions constantly while the torch valve is open. As gas is drawn from the cylinder the pressure in the cylinder falls. The sensitive diaphragm reacts constantly to the gradual drop in pressure and allows the pressure-adjusting spring to open the valve farther to compensate for this and maintain the working pressure fairly constant until the cylinder pressure is down to the working pressure.

e. Two-stage regulators.—In more recently developed regulators, the pressure reduction is accomplished in two separate steps. This type of regulator has two independent diaphragm and valve assemblies, as shown in figure 36, which makes operation more efficient. The full cylinder pressure enters the regulator and is reduced to a lower pressure in the first stage, which is automatic and nonadjustable. The second stage is the same as the first stage except that it has a larger diaphragm, lighter springs, and is adjustable by the operator. The second stage functions only within a limited range and insures more constant delivery pressure adjustment than is possible with single stage regulators.

f. Oxygen regulator.—An oxygen regulator is designed so that the regulating mechanism will take care of the full cylinder pressure of about 2,000 pounds per square inch. It is customary to provide a cylinder pressure gage with a capacity of 3,000 pounds per square inch on an oxygen regulator. This gage usually has a second scale that indicates the contents of the cylinder in cubic feet at 70° F. For welding, the regulator is designed to deliver a maximum working pressure of 50 pounds per square inch and usually has a working pressure gage with a capacity of 100 pounds per square inch. For cutting, maximum oxygen pressures may vary from 125 to 200 pounds per square inch, so the working pressure gage usually has a capacity of 400 pounds per square inch.

g. Acetylene regulator.—(1) Acetylene regulators operate the same as oxygen regulators, but since the cylinder pressure is not as high as

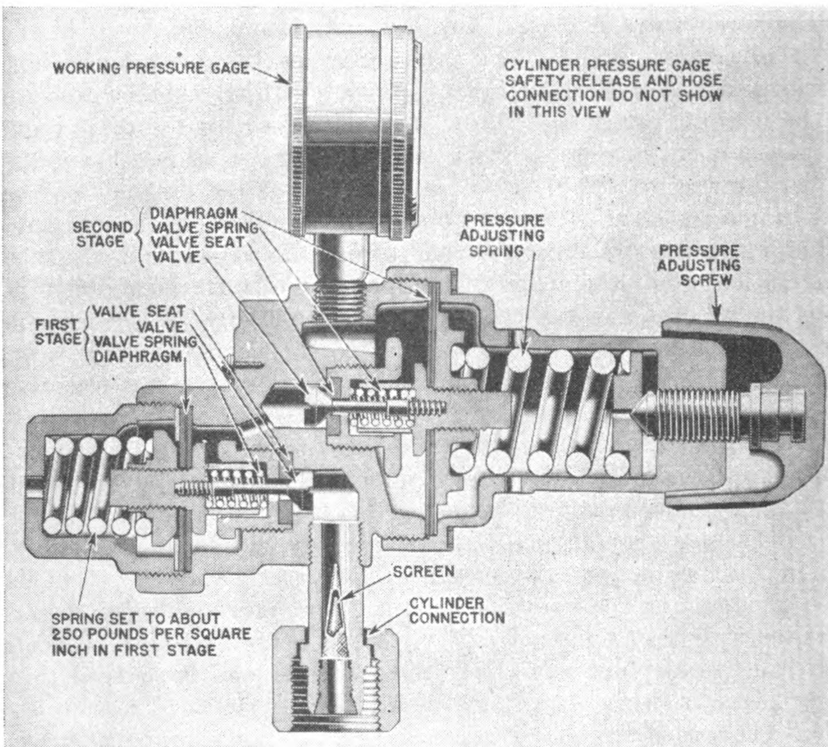

FIGURE 36.—Cross section of two-stage regulator.

oxygen cylinder pressure, lighter springs are used. An acetylene regulator has a cylinder pressure gage with a capacity of 350, 400, or 500 pounds per square inch and a working pressure gage with a capacity of from 30 to 50 pounds per square inch. Some acetylene working pressure gages are graduated only to 15 pounds per square inch, because it is unsafe to use acetylene at higher pressures. The same acetylene regulator is used either for welding or cutting. Unlike oxygen regulators, acetylene regulators do not fit all cylinders.

Straight 45° and 90° adapters can be obtained for connecting regulators having cylinder connections of certain types and dimensions to cylinder valves of different types and dimensions.

(2) Note that all regulator gages have capacities greater than the pressures they are expected to handle. This excess capacity is provided as a safety factor to prevent the instruments being strained.

(3) The warning "Use no oil" applies to oxygen regulators as it does to *all equipment where oxygen is handled under pressure.* Use no oil on acetylene regulators because of their nearness to, and possible confusion with, oxygen regulators.

19. Welding torches.—The oxyacetylene welding torch mixes acetylene with oxygen in definite proportions, burns the mixture at its tip, and directs the flame on the parts to be welded or heated.

a. Construction.—The details of construction vary with different manufacturers, but all welding torches are essentially the same. They are made from brass tubing and brass castings or pressure forgings, fastened together by silver solder and threaded connections. Every welding torch has two needle valves, one for adjusting the acetylene pressure and one for adjusting the oxygen pressure. Welding heads or tips are made from drawn copper. Interchangeable tips or heads are usually provided so one torch can handle a wide range of work, from the lightest to the heaviest.

b. Types.—There are two general types of welding torches—low pressure and medium pressure. Acetylene at a pressure of less than 1 pound per square inch is designated as low pressure; from 1 to 15 pounds per square inch, medium pressure. Low pressure torches employ the injector principle. Torches of this type are designed so the high pressure oxygen jet produces a suction effect which draws the acetylene in. Some medium pressure torches are designed to operate with equal pressures of oxygen and acetylene and are called equal pressure or balanced pressure torches.

(1) *Low pressure.*—A low pressure welding torch is shown in figure 37. Oxygen enters through the oxygen hose connections at the end of the torch and passes through the needle valve and through the tube and passage to the injector jet, which is in the detachable head of the torch. Acetylene enters the torch at the acetylene hose connection and passes through the needle valve and the tube and passages around the oxygen jet. It is drawn into the injector jet by the suction of the jet and mixes with the oxygen in the expansion chamber. The mixture then passes through the head to the tip where it is burned.

(2) *Medium pressure.*—A medium pressure welding torch is shown in figure 38. The oxygen and acetylene enter and pass through this torch in about the same way as they do in the low pressure torch. The principal difference is that a mixing chamber is provided instead of an injector. Here the acetylene, flowing longitudinally, meets the cross current of oxygen flowing in radially through the holes in the sides. (In other models the oxygen flows longitudinally and the acetylene radially.) The cross currents form a whirlpool, thoroughly mixing the two gases as they enter the welding head. The mixture then passes to the tip where it is burned.

c. Interchangeable heads and tips.—One of the valuable features of the modern welding torch is the system of interchangeable heads

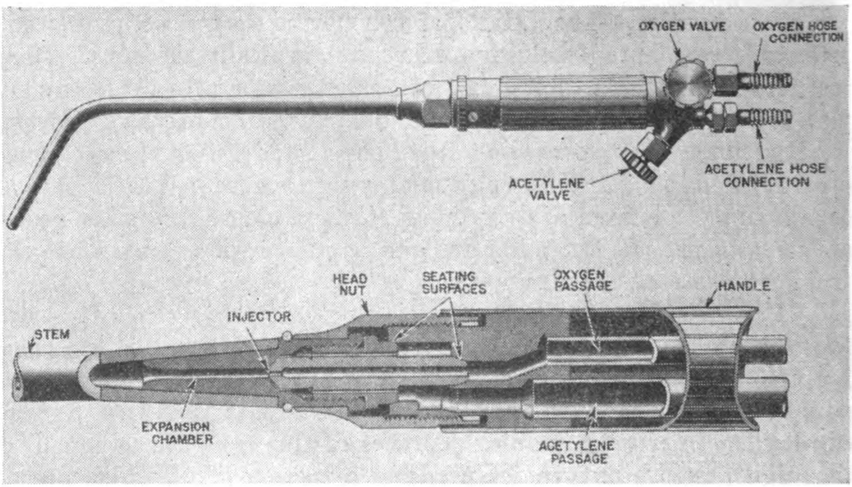

FIGURE 37.—Low pressure welding torch.

and tips which allows one torch to be used for various jobs. Tables provided by the manufacturers give the sizes of tips to use for different kinds and thicknesses of metal. A welding torch with five standard interchangeable welding heads is shown in figure 39. These heads are available with detachable tips as shown in figure 40, or with an integral stem. A detachable tip is preferable when it receives rough handling.

d. Welding accessories.—Welding accessories, such as hose and fittings, welding rod, flux, goggles, gloves, wrenches, friction lighters, trucks, and tables, should be of good quality and made especially for the purpose. Makeshifts are dangerous. A welding table (fig. 41) while not essential is very convenient.

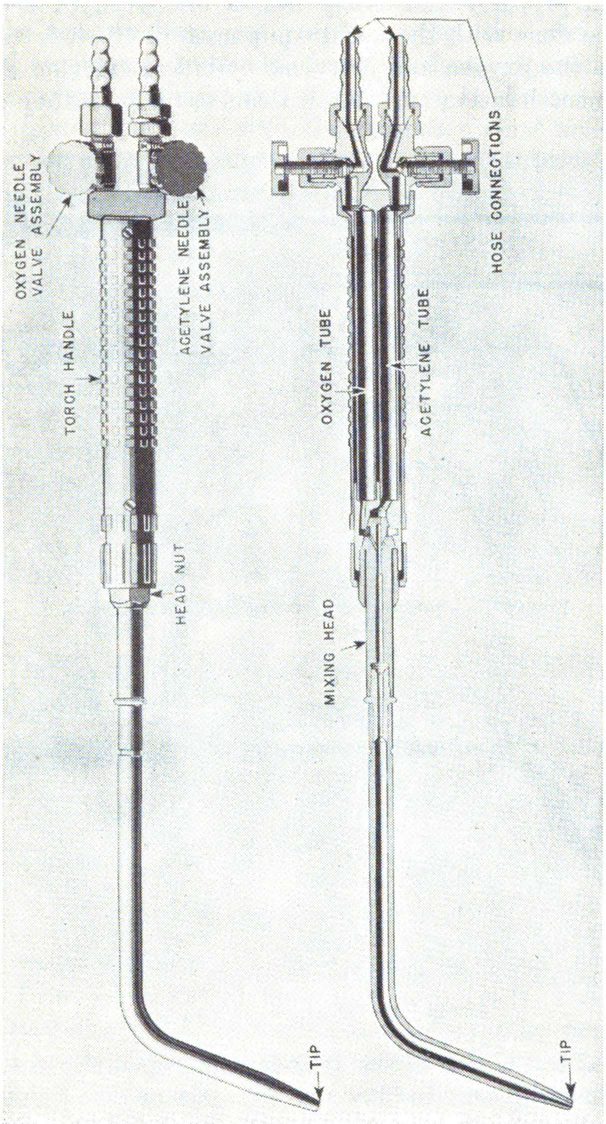

FIGURE 38.—Medium pressure welding torch.

20. Setting up equipment.—*a. Procedure.*—So far the functions of individual items of equipment required for oxyacetylene welding have been discussed. The next requirement is to learn how to assemble them properly and safely into a unit ready for operation. This may be done with the usual equipment in 10 steps as follows:

(1) Place the oxygen and acetylene cylinders erect on a truck or in a permanent location and fasten them securely so they cannot be

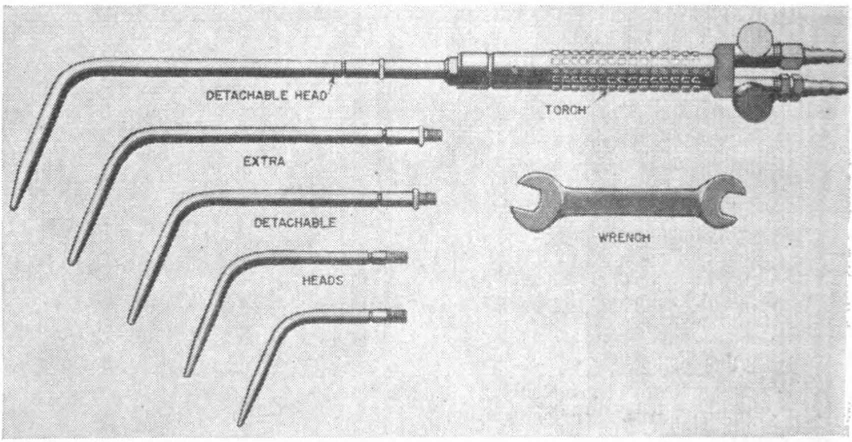

FIGURE 39.—Welding torch with interchangeable heads.

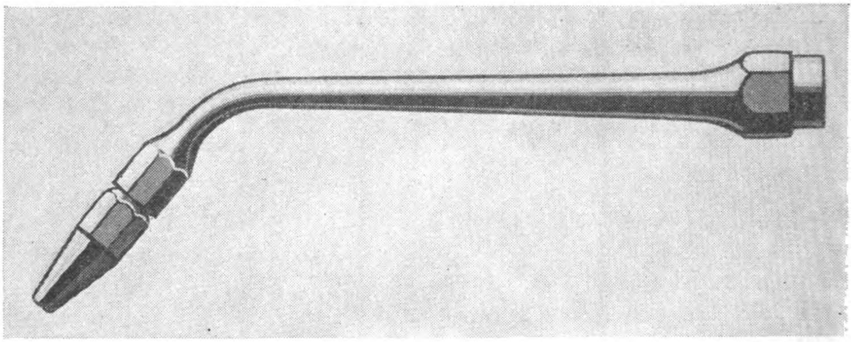

FIGURE 40.—Detachable welding tip.

upset. Stand at the side of the cylinders and open the oxygen cylinder valve for an instant to blow out any dust or dirt that may have lodged in the valve during transit. Then do the same with the acetylene cylinder. This procedure is known as "cracking the valve." *Do not stand in front of valves.*

(2) Connect the oxygen regulator to the oxygen cylinder and the acetylene regulator to the acetylene cylinder and screw the nuts up

tight, using the wrench made specially for the purpose. To prevent a dangerous interchange of regulators, the threads on each cylinder valve are different. Usually oxygen valve threads are right hand and acetylene valve threads are left hand. *Note this difference.*

(3) There are two hose, one green and the other red, which are often taped together at intervals of every 2 feet. Connect the green hose to the oxygen regulator and the red hose to the acetylene regulator and tighten the nuts with the wrench. Hose and regulator fittings are not interchangeable. Those for oxygen hose have right hand threads and those for acetylene hose have left hand threads.

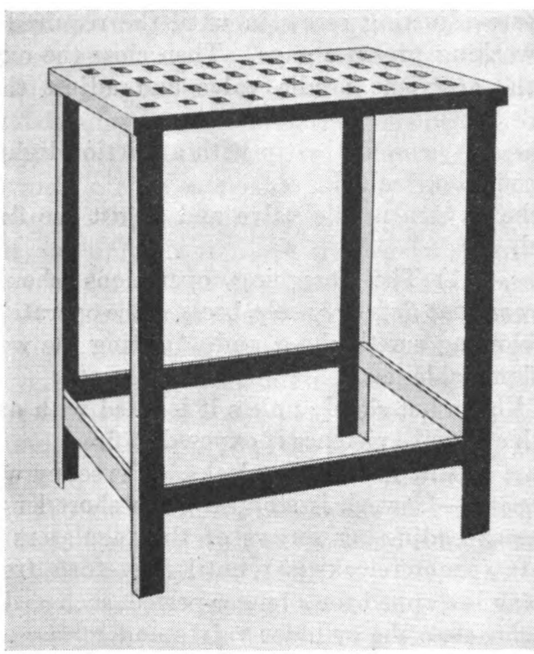

FIGURE 41.—Welding table.

(4) Fully release both regulator adjusting screws by turning them to the left (counterclockwise) until they turn freely, then open the cylinder valves slowly. After the hand on the cylinder pressure gage has stopped moving, open the oxygen cylinder valve all the way as this valve has a double seal. Do not open the acetylene valve more than 1½ turns and leave the special wrench on the valve while the cylinder is in use. *Never open cylinder valves unless regulator adjusting screws are released.*

(5) Point the oxygen hose away from the body, and turn the regulator adjusting screw in for a moment until sufficient gas pressure

is exerted to blow out any substance that may have lodged in the hose. Do the same with the acetylene hose.

(6) Connect the green oxygen hose to the oxygen needle valve on the torch. Then connect the red acetylene hose to the acetylene needle valve on the torch. The oxygen and acetylene valves are marked and the hose connections are not interchangeable. The oxygen hose connection has a right hand thread and the acetylene connection has a left hand thread.

(7) Attach the correct welding head or tip to the torch, setting the tip at the proper angle, and tighten the nut.

(8) Open the oxygen needle valve on the torch and turn the oxygen regulator pressure-adjusting screw in until the required pressure is shown on the working pressure gage. Then close the oxygen needle valve. Open the acetylene needle valve and adjust the acetylene pressure.

(9) Light the acetylene at the tip with a friction lighter or spark lighter as it is sometimes called.

(10) Open the oxygen needle valve and adjust the flame until it becomes neutral.

b. Precautions.—(1) The foregoing operations should be performed *away from open fires or sparks*, because the operations of cracking the valve, blowing out the hose, and adjusting the working pressure release inflammable gas.

(2) Hose will burn but slowly unless it is filled with oxygen; then it will burn with explosive violence if exposed to fire.

(3) Do not use a flame for locating leaks. Use soapy water.

c. Stopping work.—If work is stopped for a short length of time, release the pressure adjusting screws of the regulators by turning them to the left (counterclockwise) until they turn freely. When welding or cutting is stopped for a longer period, such as during lunch hour or overnight, close the cylinder valves and release all gas pressure from the regulators by opening the torch valves for a moment. Then close the torch valves and release the regulator pressure-adjusting screws.

21. Oxyacetylene flame.—*a. General.*—The sole purpose of the equipment and procedure so far described is to produce an oxyacetylene flame.

(1) A flame is a stream of burning gas. This is true whether the combustible material producing the flame is a solid, liquid, or gas. If the fuel is solid or liquid it is changed to a gas by heat before it burns as a flame. The oxyacetylene flame is particularly suitable for welding because of its very high temperature (estimated at 6,000° F.) and because if properly adjusted it will not harm most metals.

(2) When the torch is first lighted, and before the oxygen needle valve has been opened, the flame is long and bushy with a yellowish appearance. Oxygen for combustion is being provided by the air. The flame is smoky, containing a large quantity of unburned carbon soot, indicating that combustion of the acetylene is not completed.

(3) As the oxygen valve is opened a bright inner cone of flame, white to blue in color, appears. Here the premixed gases burn at extremely high temperatures. Surrounding this inner cone is an outer flame envelope or sheath flame of cooler burning gases, which contains varying amounts of incandescent carbon soot, depending upon the proportion of oxygen to acetylene.

(4) Mixtures of pure oxygen and acetylene cannot burn completely to form a single-cone flame. The temperature produced is so high that the products of complete combustion (carbon dioxide and water vapor) would be decomposed into their elements. Thus acetylene burns in the inner cone of the flame with the oxygen supplied through the torch to form carbon monoxide and hydrogen, both combustible gases. These gases burn completely, as they cool off, with the oxygen from the surrounding air to form the cooler sheath flame. Theoretically, 1 part of acetylene requires 2½ parts of oxygen for complete combustion. This mixture will not result in complete burning of acetylene since the elements of acetylene cannot completely combine with oxygen because of the high temperature. Actually, a mixture of 1 part of acetylene and 1 part of oxygen is used, the oxygen of the surrounding air supplying the additional 1½ parts of oxygen necessary for complete combustion. Since the inner cone of the flame contains only the gases, carbon monoxide and hydrogen, which are reducing (able to combine with oxygen and remove it) in character, oxidation of the metal does not occur.

b. Neutral flame.—This equal mixture of gases gives a neutral or balanced flame. The neutral flame has a characteristic appearance and is easily obtained with a little practice. It has two sharply defined zones. The inside portion consists of a brilliant white cone from 1/16 to ¾ inch long. Surrounding this is a larger cone or envelope flame, only faintly luminous and of a delicate bluish color. It is shown in figure 42. The neutral flame is of particular importance to the operator because it is used for most welding, cutting, and heating operations, and is the basis of reference for other flame adjustments.

c. Reducing flame.—The excess-acetylene, reducing, or carbonizing flame, as it is variously known, is formed when there is more acetylene than oxygen in the mixture. When this occurs, the flame consists of three easily recognizable cones instead of the two existing in the

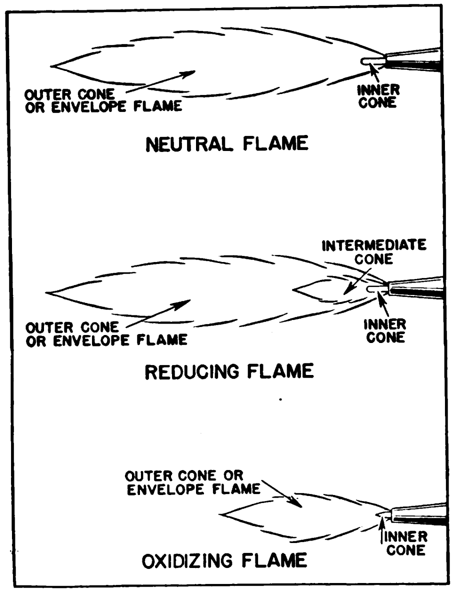

FIGURE 42.—Oxyacetylene flames.

neutral flame. There is still the sharply defined inner cone and the bluish outer envelope, but between these there is a third cone of whitish color surrounding the inner cone (see fig. 42). The length of the intermediate cone may be taken as a measure of the amount of excess acetylene in the flame. The reducing flame is used for certain special techniques in welding steel (Lindeweld, Aircoweld), and sometimes for welding high-carbon steels, stove castings, and furnace grates. A slightly reducing flame is sometimes used for welding aluminum, nickel, and monel metal, and for applying hard facing materials.

d. Oxidizing flame.—When there is more oxygen than acetylene in the mixture the flame has the general appearance of the neutral flame, but the inner cone is shorter, more pointed, and becomes somewhat purplish. There is also a distinct hissing sound. These are the characteristics of the oxidizing flame, also shown in figure 42. This flame is ruinous to most metals and should generally be avoided. A slightly oxidizing flame is sometimes used in bronze welding, or brazing, and a stronger oxidizing flame is sometimes used for fusion welding of brass and bronze.

22. Adjusting the flame.—After the torch is lighted, with only the acetylene turned on, adjust the acetylene needle valve until acetylene is coming out fast enough to cause a gap of about 1/16 to 1/8 inch between the tip and the flame. Then open the oxygen needle valve slowly. The flame will change gradually from yellow to blue and show the three distinct parts of the excess acetylene flame. The intermediate cone will become smaller and smaller, and the instant it disappears completely, the neutral flame is formed. As the oxygen needle valve is opened still more (or the acetylene needle valve is partially closed), the oxidizing flame appears. The length the inner cone is decreased, compared to the inner cone of the neutral flame, indicates the amount of excess oxygen in the flame. Because of the difficulty of distinguishing exactly between oxidizing and neutral flames, an adjustment to neutral is always made from the excess acetylene flame.

23. Joint design.—Proper joint design for welding sheet, plate, or pipe is of particular importance because even the most skillful welding may fail to produce a strong joint if it is not properly designed.

a. Sheet metal.—Metal up to 1/8 inch in thickness is considered sheet metal.

(1) The butt weld (fig. 43) is the simplest joint in sheet metal. It is used between two pieces lying in the same plane and for joints in rounded sections, such as the lengthwise seam in a cylindrical tank.

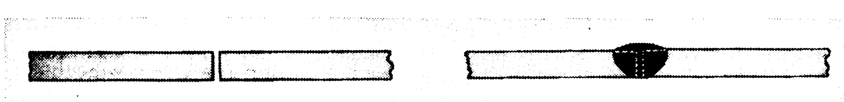

FIGURE 43.—Butt weld for sheet metal.

(2) The corner weld (fig. 44) is widely used in sheet metal work. It is very similar to the butt weld. The parts to be joined are usually held in correct alinement by jigs or fixtures during welding.

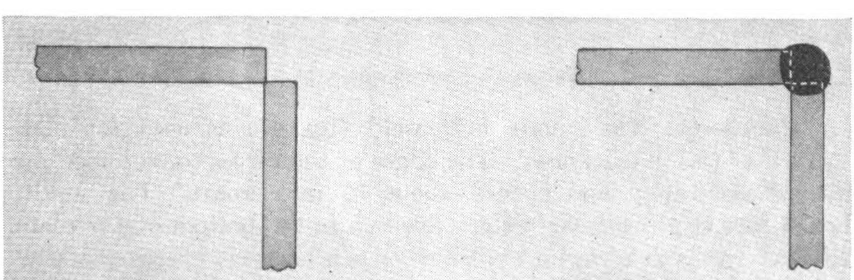

FIGURE 44.—Corner weld.

(3) The flange weld (fig. 45) is used mostly in sheet metal lighter than 20-gage (0.0375 inch). The edges are prepared for welding by turning up a flange extending above the upper surface of the sheet a distance equal to the thickness of the sheet. Flange welds are usually made by melting down the flange without adding welding

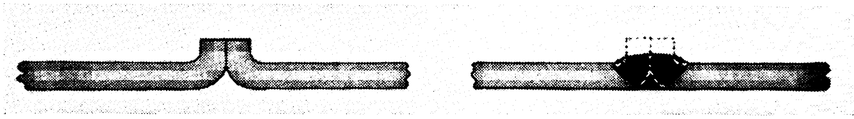

FIGURE 45.—Flange weld for thin sheet metal.

rod. When this weld is used the operator must be careful to secure penetration to the bottom of the point.

(4) The single lap weld (fig. 46) made along the edge of overlapping sheets is not recommended because it has little resistance to bending.

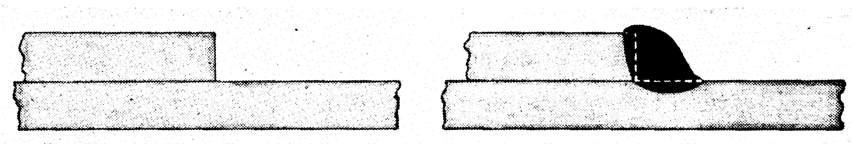

FIGURE 46.—Lap weld; second weld necessary to form double lap weld is shown by dotted line.

(5) The double lap weld (indicated by the dotted line in the figure) has more strength, but it requires nearly twice as much welding as the simpler and more satisfactory butt weld. Lap welds should be avoided whenever possible.

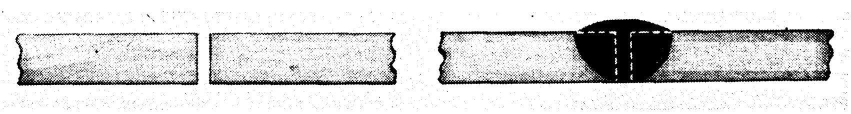

FIGURE 47.—Square butt weld.

b. Plate.—(1) The square butt weld (fig. 47) is used for plate $\frac{3}{16}$ inch or less in thickness. The edges of the pieces to be joined are squared accurately and spaced about $\frac{1}{8}$ inch apart. The welder should fuse the metal completely through to the bottom of the plate. All butt welds are known as "open" when there is a space left between the pieces to be joined and "closed" when the pieces are pressed tightly together.

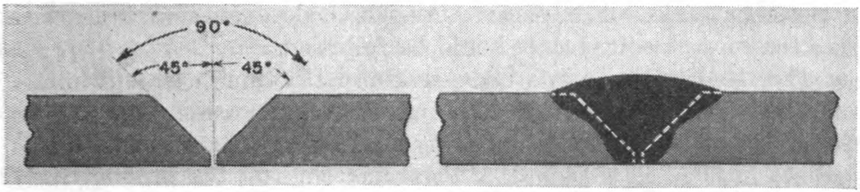

FIGURE 48.—Single-V butt weld.

(2) The single-V butt weld (fig. 48) is used for plate over 3/16 inch and up to 1/2 inch in thickness. Both edges forming the joint are beveled, usually to 45°, to form a 90° V. This beveling can be done either by grinding, by a milling machine, or by use of a cutting torch. If done with a cutting torch, the oxide should be carefully removed from the bevel by chipping or grinding, before welding. Beveling in plate or pipe is never carried clear across the section. About 1/16 inch of the original edge is left for lining up the edges as shown in figures 48 and 49. Weld penetration and reinforcement should be as shown in figure 48. By reinforcement is meant the part of the weld that extends beyond the cross section of the plate.

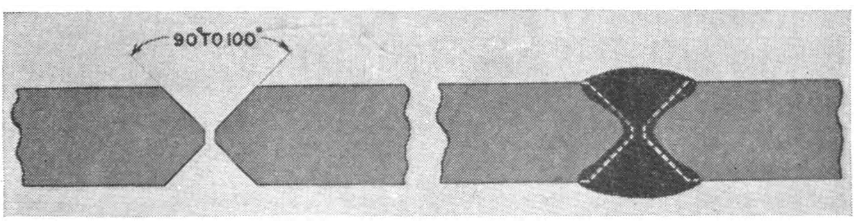

FIGURE 49.—Double-V butt weld.

(3) Plate thicker than 1/2 inch should be beveled from both sides to form a double V, whenever possible, as shown in figure 49.

(4) Outside corner welds should be made the same as for sheet metal as shown in figure 44. For cylindrical tanks it is preferable to dish the heads and use butt welds. Sometimes inside corner welds are necessary. In such cases the edges of the plate should be beveled to aid the welder in obtaining full penetration to the bottom of the weld.

(5) Fillet welds (fig. 50) should be avoided whenever possible in plate work. They are used to join flanges or sleeves to the surfaces

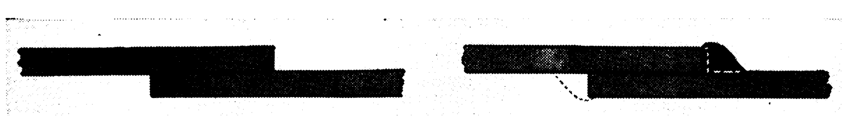

FIGURE 50.—Fillet weld.

of pipes or tanks. For pressure vessels, codes governing the construction of such equipment should be followed.

c. Pipe.—(1) Pipe joints are essentially the same as plate joints. For line joints in pipe, that is, joints in straight runs of pipe, the square butt weld (fig. 47) is recommended for pipe having a wall less than 3/16 inch thick; the single-**V** butt weld (fig. 48) for pipe 3/16 inch thick and over. The ends should be beveled 45° to form a 90° **V**.

(2) In the case of a branch connection, where one pipe fits into an opening in another pipe, the opening should be beveled to form a proper **V** at all points. The beveling will not be uniform but will vary continuously.

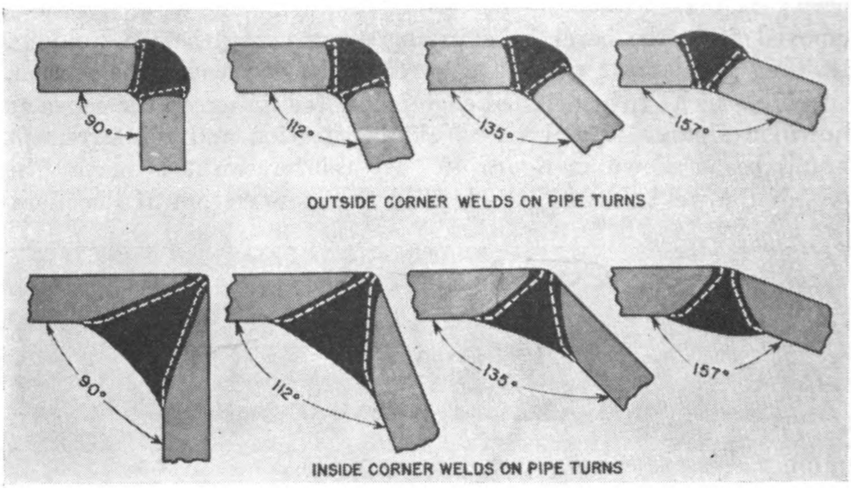

FIGURE 51.—Outside and inside corner welds in pipe turns.

(3) In welded pipe turns, the weld varies from an outside corner weld on the outside of the turn to an inside corner weld at the inside of the turn. Here again, beveling is not uniform but varies continuously. Figure 51 shows weld sections at the outside and inside of pipe turns of various degrees.

d. Castings.—In repair welding of castings, the edges of the break are usually beveled to form a 90° **V**. Where the metal is very thick and welding can be done from both sides, a double-**V** weld is preferable. Castings must often be beveled with a cold chisel.

24. Welding methods.—*a. General.*—(1) Right-handed welders usually hold the torch in the right hand and the welding rod in the left, while left-handed welders usually hold the torch in the left hand and the welding rod in the right. Some prefer to weld from right to left, while others prefer to weld from left to right. However, the various methods are based upon the same general procedures.

(*a*) A pool or puddle of molten metal should be made to advance even along the seam as the weld is made.

(*b*) The end of the welding rod should melt by placing it in the puddle; it should not be held over the puddle and allowed to drip into it.

(*c*) The inner cone of the flame should not come in contact with the welding rod or the metal being welded.

(*d*) Most important of all, the molten metal should penetrate all the way down to the bottom surface of the weld, but the molten metal should not drip in beads from the bottom.

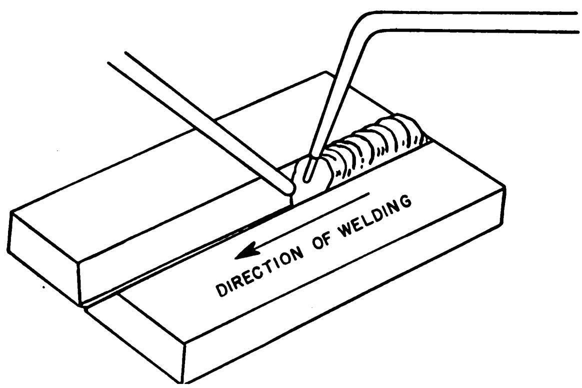

FIGURE 52.—Forehand, puddle, or ripple welding.

(2) The entire operation demands that the welder have sufficient knowledge to control the metal by means of the flame, and enough manual skill to handle both torch and welding rod uniformly and easily along the seam.

b. Forehand, puddle, or ripple welding.—This is the usual method and is illustrated in figure 52. When using this method hold the welding rod ahead of the torch tip in the direction of welding. Point the flame in the direction of welding and downward at an angle of about 60° so that it will preheat the edges of the joint. Move the torch tip and welding rod in opposite semicircular paths to distribute the heat and the molten metal uniformly. A wide V, 90° included angle, is necessary with this method of welding to permit wide movement of the torch tip and welding rod.

c. Backhand welding (fig. 53).—This is another method which should also be mastered by the student. In this method hold the torch tip ahead of the welding rod in the direction of welding.

Point the flame back at the molten puddle and the completed weld downward at an angle of about 60° with the work. The torch can be held with very little motion of the flame to and fro across the weld. Move the rod in full circles in the puddle or in semicircles across the puddle. With backhand welding it is possible to use a narrower V—a 60° angle is sufficient.

d. Multi-layer welding.—This method is used for thick sections to avoid carrying too large a puddle. The operator is able to concentrate on getting good penetration at the root of the V in the first layer. On succeeding layers he can devote himself entirely to getting good fusion with the sides of the V and the preceding layer.

e. Position welding.—As piping and other construction involve welding in all positions—flat, vertical, overhead, and horizontal, a

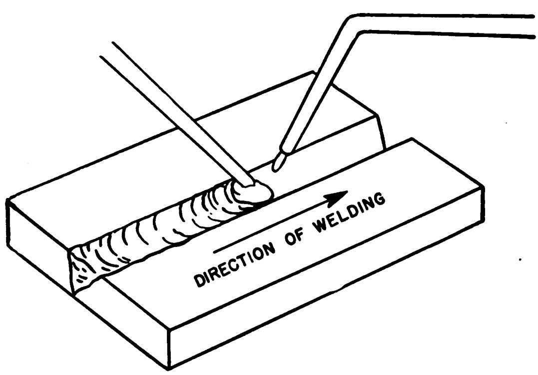

FIGURE 53.—Backhand welding.

thorough knowledge of how to control the weld metal in these various positions is essential.

(1) Due to gravity, the molten weld metal in the puddle always seeks a lower level. This tendency is restrained by the following forces:

(*a*) Cohesion of the puddle.

(*b*) Support provided by the base metal and solidified weld metal.

(*c*) Pressure of the flame against the end of the puddle.

(*d*) Manipulation of the welding rod in the molten metal. The most important force counteracting gravity is the cohesion of the molten metal, which determines the quantity of molten metal that will adhere or stick to base metal and welding rod without running or falling. The amount of heat applied and the composition of the weld metal affect cohesion. Excessive heat increases the fluidity of the molten metal, increasing the tendency of the puddle to run or fall. Certain welding rods contain alloying elements which decrease the fluidity of the molten metal, thereby permitting a larger puddle of metal to be carried in vertical and overhead welding.

(2) When welding directly overhead it is possible to maintain a surprisingly large puddle of molten metal if just one precaution is observed. Water or oil sprayed lightly on the under side of a flat surface will fall only after a complete drop has taken shape. Thus, if the welding puddle is kept from forming into a drop, cohesion prevents its fall.

(3) When welding vertically, as when bringing a puddle up the side of a pipe joint, the influence of cohesion in maintaining the puddle decreases. This is because the same amount of liquid that could be suspended on the under side of a flat surface will collect and run on a vertical surface. Consequently, the presence exerted by the burning gases must be relied upon to a considerable extent in maintaining a puddle of fair size. The solidified weld metal just below the puddle acts as a shelf and supplies additional support. As the welding nears the top of the pipe, the solidified weld metal and the V of the joint provide more and more support for the puddle while the flame pressure and cohesion are needed less and less. It is at a point near the top that the largest and most fluid puddle can be carried.

(4) If the puddle is started at the top, however, and carried to the bottom of the joint—the reverse of the preceding method—different conditions exist. At the beginning, the V provides considerable support for the puddle as before, but as the side of the joint is approached, the pressure of the flame must be relied upon more and more to keep the molten metal in place. In this case, where there is no shelf or solidified weld metal to provide partial support, the puddle carried must be relatively shallow if cohesion and flame pressure are to keep the metal from running. To aid in keeping the puddle shallow, manipulation of the welding rod is employed. The end of the welding rod, constantly melting, is used to distribute the molten metal throughout the puddle by a slow but constant movement, circular, elliptical, or in a straight line, so the metal will not collect at one spot and run or fall. By this means, the molten metal is placed near the rear edge of the puddle for the short interval required to cool it to a plastic state, from which it solidifies quickly as the inner cone of the flame is moved further away. In this manner, weld metal can be deposited rapidly and accurately in any position of welding. When the bottom of the joint is reached, the same condition exists as before for overhead welding. The puddle is kept from forming into a drop by means of flame pressure and the welding

rod, while cohesion holds it in place. For other positions of welding and other types of joints, the same fundamentals of puddle control apply.

25. Expansion and contraction.—*a. General.*—(1) Heat expands metal and subsequent cooling contracts it. Uneven heating will, therefore, cause uneven expansion and uneven cooling will cause uneven contraction. This sets up stresses in the metal which will warp or buckle it unless precautions are taken. If the metal is restrained from returning to its original size and shape, internal stresses are left within the metal which may cause distortion or breakage unless relieved.

(2) Welding a long seam tends to draw the seam together as the weld progresses. One way of overcoming this is to set the edges of the pieces to be welded nearly in contact at the starting end, and separate them at the other end. This separation varies according to the metal and its thickness. The average spacing allowance per foot of seam is as follows:

	Inch per foot
Steel	1/4 to 3/8
Brass and bronze	3/16
Aluminum	1/5
Copper	3/16
Monel metal	3/8
Lead	5/16

b. Sheet Metal.—(1) Sheet metal under 1/16 inch thick is best handled by flanging the edges and tack welding at intervals along the seam before welding. When this is done the tack welds should be melted out and rewelded as the seam progresses.

(2) One of the commonest methods of preventing sheet metal from warping and buckling is to remove the heat from the base metal adjacent to the weld. In the case of a flat seam, for example, a section of railroad rail or heavy bar stock laid on each side of the seam will prevent the heat from spreading too far and also help prevent movement of the parts by resisting the forces of expansion and contraction. In production work, jigs and fixtures, some of which are water cooled, are used for the same purpose. Wet asbestos cement may be placed along both sides of a seam. In extreme cases a stream of water can be played over the main body of the sheet.

c. Plate.—Plate has somewhat less tendency to warp than sheet. However, before welding long, straight seams, the plate should be spaced about 1/4 inch per foot to allow for the contraction of the seam. For welding the circumferential seams of pipe, tanks, and pressure vessels, it is, of course, not possible to allow an increasing space around the entire seam. When pipe is lined up for welding, an even spacing of $\frac{3}{32}$ to $\frac{1}{4}$ inch, depending on the size of the pipe, is left between pipe ends. Tack welds are then made at intervals to hold the pipe in alinement during welding. For large tanks and pressure vessels, the tack welds are usually supplemented by a series of wedge clamps which are progressively removed ahead of the weld to control the seam contraction.

d. Castings.—(1) Expansion and contraction of castings are provided for by preheating. Small gray-iron castings are heated all over, usually by means of the torch, to a good red heat before welding. After welding, a reheating and controlled slow cooling, or annealing, will relieve all internal stresses and assure a proper gray-iron grain structure. For larger castings, temporary charcoal-fired furnaces are often built of fire brick and covered with asbestos sheet. Very often only local preheating is necessary. In this case only the part of the casting adjacent to the weld is preheated. Gasoline or kerosene torches, temporary furnaces, and sometimes the torch may be used for this purpose.

(2) The foregoing procedures apply to gray-iron castings. The same methods apply to steel castings or castings to be bronze-welded, except that less heat may be used.

(3) Before welding a crack that extends from an edge of a casting, it is always advisable to drill a small hole about $\frac{1}{2}$ to 1 inch beyond the visible end of the crack. Should the crack start to run when the heat is applied, it will then run only as far as the drilled hole.

(4) Some special methods of expanding certain castings prior to welding, when it is inconvenient to preheat them all over, are shown in figure 54.

26. Welding iron and steel.—*a. General.*—(1) By far the greatest amount of welding is done on iron and steel. Wrought iron and low-carbon, mild, and medium steels, including steel castings, galvanized iron, steel, and wrought iron pipe, may be welded either with low-carbon or special high strength welding rods. Alloy steels, including stainless steel, may require special rods and flux. The heat of welding burns off the zinc coating of galvanized iron near the weld. The oxides of steel melt at a lower temperature than the steel itself and float on the top of the puddle. Therefore, flux is not necessary. The envelope flame should be kept over the weld puddle to prevent the rapid oxidation of the molten metal. Continually removing the flame from the puddle will cause oxidation. Oxides on steel are in the form of scale and when cool can be knocked off with a hammer. Too large a flame overheats and burns the metal in the puddle and should be avoided. Wrought iron and steel are welded by the methods

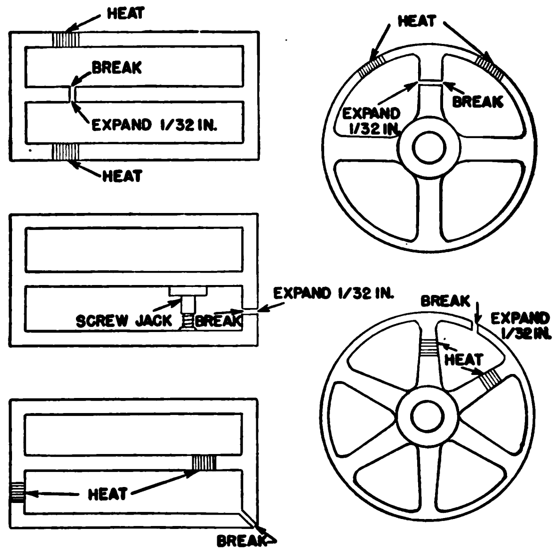

FIGURE 54.—Methods of expanding castings prior to welding.

described in paragraph 24. A neutral flame is generally used. An oxidizing flame cannot be used. A reducing flame is sometimes used for tool steel. Tool steel is not very satisfactorily welded, however; more often it is bronze-welded or brazed.

(2) Goggles are worn during all welding operations to protect the welder's eyes from flying hot particles and from the intense light. When galvanized material is being welded, inhaling the resulting zinc-oxide fumes may cause nausea. Therefore, always weld this material in a well-ventilated location when possible. The nausea may be overcome by drinking milk.

b. Welding cast iron.—In preparing a gray-iron casting for welding, it should first be cleaned of all grease, oil, sand, scale, rust, paint, or other foreign matter. Then bevels are chipped, ground, or cut to form 90° V's. The casting is then preheated either locally or in its entirety. Cast iron welding rod is used and ripple welding is most commonly employed. Puddling with the cast iron rod works out the oxides and foreign matter and brings them to the surface of the puddle. Blow holes can be prevented by holding the envelope flame over the weld puddle, thus keeping the oxygen of the air from coming in contact with the molten metal. Whenever possible, welds should be completed without stopping, even if welders have to relieve each other. Cast iron melts at a temperature below that of iron oxides which makes the use of a good flux essential. Cast iron will run freely without warning if heated sufficiently. For this reason skill is required to control the molten metal at the edge of a casting, in building up a lug, and in making a vertical weld. Iron castings should be carefully reheated and annealed after welding by leaving them in the temporary furnace for several hours or overnight, or by burying them in warm, dry sand, spent lime, or crumbled asbestos paper until they become cool.

27. Bronze welding or brazing.—*a.* This is not a true fusion welding process although it has extensive and very useful applications. It consists of joining metals with a higher melting point than bronze, such as cast iron, steel, nickel, and copper, by a bronze bonding material of considerably lower melting point. Molten brass or bronze will flow onto the properly heated and fluxed surface of higher melting point metals and give a bond of excellent strength. The bronze is supplied in the form of welding rod. Bronze welding is the only satisfactory process for joining malleable iron and high-carbon or tool steels, whose valuable properties are either destroyed or impaired by fusion. Bronze welding also provides a convenient method of joining dissimilar metals, such as malleable iron or copper, to iron or steel. Bronze welding cannot be used where the part is to be heated subsequently to a temperature higher than the melting point of bronze. Also, bronze loses strength rapidly at temperatures above 500° F. Bronze welding is widely used for building up wearing surfaces, particularly on cast iron, steel, and manganese bronze. Holes and bushings that have become worn can be repaired quickly by filling the hole and redrilling.

b. For bronze welding it is important that the base metal be clean and free from foreign matter so the bronze can "wet" the base metal. If the edges to be joined are ¼ inch or less in thickness, surface chipping or grinding to bright metal will suffice. Thicker metal should be beveled to a 90° V. The edges of the metal for about ½ inch back of the bevel should be cleaned off. Even after such cleaning, many metals retain a superficial coating of oxide that will prevent the bronze from coming into intimate contact with the base metal. Therefore, it is necessary to remove this coating by means of a suitable flux.

c. Only enough preheating to take the chill off the parts to be welded, that is to a black heat, is required for bronze welding.

d. A slightly oxidizing flame is recommended for bronze welding. A spot on the cleaned surface of the base metal about 2 inches in diameter is heated with a circular motion of the torch to a red heat. When the metal just begins to glow, heat the end of the welding rod in the flame and dip it into brazing flux. Then touch the end of the fluxed rod on the heated spot on the metal. If the metal is the proper temperature, the bronze will flow in a thin layer and spread out over the heated area. If the metal is too hot the bronze will boil and form into drops which roll off as fast as the rod is melted. The tinning and building up of the bronze are done in one continuous operation, the tinning action taking place just ahead of the puddle of weld metal. The inner cone of the flame should be kept $\frac{1}{8}$ to $\frac{1}{4}$ inch from the metal. Usually the flame is pointed ahead of the completed weld at an angle of about 45°, with the puddle under and slightly behind the flame. In heavy sections the weld is made in layers. When the bronze weld is completed, it should be allowed to cool slowly to room temperature, which can be done conveniently by covering it with asbestos paper. No stress should be placed upon a bronze-welded joint until it is completely cool.

e. Bronze welding rod contains zinc which gives off fumes during welding. The same precautions regarding ventilation etc., recommended for welding galvanized iron in paragraph 26 should be observed.

28. Welding aluminum.—*a.* As the behavior of aluminum under the welding flame is quite different from that of steel, a different welding technique is required. Pure aluminum has a relatively low melting point (1,215° F.) and it conducts heat more than four times as fast as steel. Because of this high heat conductivity it is advisable to use a welding tip one size larger than that used for steel of the same thickness. Because of its light color and low melting point, aluminum does not give any indication by change of color that the metal is approaching the welding heat. When the melting point is reached, the metal collapses suddenly. By observing the behavior of aluminum as it melts under the torch flame, the welder will learn how to control the rate of fusion.

b. The surface of a molten puddle of aluminum oxidizes rapidly, forming an oxide that has a higher melting point than aluminum. For this reason it is customary to use a suitable flux which combines chemically with this oxide to form a fusible slag that rises to the surface of the puddle where it is easily removed. Cast aluminum can be welded successfully without flux by the use of a pick and paddle. The pick, which is simply a piece of steel wire pointed at the end and bent in the form of a hook, is used to pick out the oxide from the weld. The paddle, which is a piece of steel wire flattened at the end and bent at an angle, is used for smoothing the weld. The pick and paddle method is much slower than welding with flux and is not recommended if flux is available.

c. The flange joint can be used for 16-gage and lighter sheet. The upturned edges of the flanges should be painted with flux before welding. Aluminum sheet up to 17-gage can also be welded with the square butt joint. Before welding, paint flux on the edges of the sheet. For aluminum from 17- to 7-gage, it is recommended that the edges of the joint be notched through their entire thickness, as shown in figure 55. The notches are best made 1/16 inch deep and 3/16 inch apart with a sharp cold chisel. These notches help the welder obtain full penetration because flux works down to the bottom of the sheet. There is less chance of melting holes through the sheet and less distortion of the work. For heavier stock, notched single-V and double-V joints are used (fig. 56).

d. The selection of welding rod for welding aluminum depends upon the composition of the base metal. Manufacturers' recommendations should be followed. For welding commercially pure aluminum, wire or strips cut from the base metal may be used.

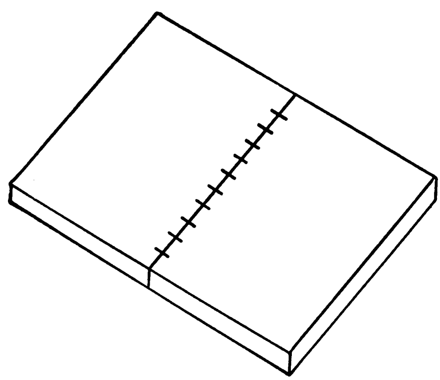

FIGURE 55.—Notched square butt joint for aluminum.

e. The torch flame should be neutral or have a very slight excess of acetylene. The flame should be soft and of low velocity. Hold the tip at an angle of about 30° to the work to avoid blowing holes through the heated metal. The end of the inner cone of the flame should be about 1/8 inch away from the work, and the flame directed so it heats both edges of the joint evenly and also the end of the welding rod. The edges should begin to melt before the welding rod is added. It is necessary to direct a considerable portion of the flame on the rod itself as the molten puddle will not melt the rod as in steel welding. Metal from the welding rod should be fused thoroughly with the base metal as it is added. Inasmuch as fusion takes place rapidly, the weld progresses quickly along the seam.

f. Even in the case of sheet aluminum it is good practice to warm up the entire sheet with the blowpipe flame before welding. It is customary to preheat aluminum plate 3/8 inch or more in thickness before welding and is particularly necessary when it is to be welded from both sides. This can be done with a second oxyacetylene torch or by city gas or kerosene torch. Aluminum castings require preheating prior to welding. If a stick drawn across the metal as a test chars and leaves a black mark, the metal is hot enough, or if

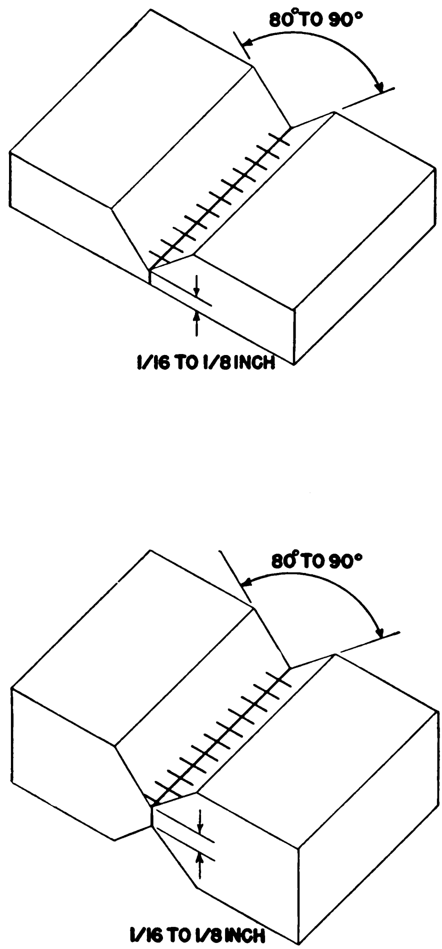

FIGURE 56.—Notched single- and double-V joints for aluminum.

sawdust thrown on the work chars and becomes black the casting is ready for welding. This is about the same temperature that will melt half-and-half spool solder when it is touched to the work. After welding, castings should be covered and cooled slowly.

g. After aluminum is welded, the flux should be carefully removed to prevent subsequent corrosion. This is sometimes done with a steam jet. Washing in a hot 2-percent nitric acid solution or a warm 10-percent sulphuric acid solution, followed by rinsing, is sometimes done.

29. Welding copper.—*a.* Copper is a red metal which is difficult to distinguish from some of the bronzes. If the metal is melted under the blowpipe, using a neutral flame, it can usually be distinguished readily. If it gives off white smoke, or contains enough volatile metal to leave a ring of whitish or yellowish crust around the edges of a cold frozen puddle, the metal is bronze.

b. Commercially pure (electrolytic) copper contains a small amount of oxide and is not suited to welding because a weak zone invariably develops in the base metal adjacent to the weld. Deoxidized copper is entirely satisfactory for fusion welding. It is made by adding a small amount of silicon (manganese, phosphorus, or boron have also been used) which removes the last trace of oxygen from the copper.

c. The weldability of copper can be tested by heating a piece of it to a bright red, just below the melting point, and then hammering it vigorously on an anvil. If it breaks, it contains oxide and is unsuitable for fusion welding. It can be joined satisfactorily by bronze welding, although deoxidized copper is preferable even for that.

d. For fusion welds in copper, completely deoxidized welding rod, as well as base metal, must be used. A welding head one or two sizes larger than that required for steel of the same thickness is used, since copper conducts heat away much faster than steel. A neutral flame is necessary; no flux is required. The same joint designs as described for steel are used and the same welding technique employed, except that the molten puddle is somewhat more "runny." Whenever possible, cover the work with asbestos paper to reduce heat losses. Large sections should always be preheated to a dull red before welding, and the same practice is desirable even for small parts.

e. Copper pipe can be fusion welded, but it is usually either bronze-welded or fabricated with sweat solder fittings.

30. Welding brass and bronze.—*a.* Brass is essentially an alloy of copper and zinc, and bronze is essentially an alloy of copper and tin. However, other alloying elements such as lead, tin, manganese, and iron often appear in brass; and zinc, lead, and nickel are often found in bronze.

b. In fusion welding either brasses or bronzes, the more volatile metals, zinc, tin, and lead, start to boil out before the base metal is red hot. This tendency can be overcome by making the flame just sufficiently oxidizing to stop the boiling without forming too heavy a coating of oxide on the puddle. Flux is used freely, usually being mixed to a paste with water and painted on the welding rod and along the scarf of the base metal. Welding rods of different composition are provided by the manufacturers, or strips cut from the base metal may be used. Forehand welding is recommended. Castings should be preheated.

c. Bronze welding is widely used to produce satisfactory joints for general industrial purposes. Yellow brass has a melting point so near that of the welding rod that the welding operation is a cross between bronze welding and fusion welding. This applies to the welding of brass pipe. The important factor is to melt the wall of the **V** just sufficiently to insure positive sweating of the base metal in advance of the puddle.

31. Oxyacetylene cutting.—*a. General.*—(1) The procedure of torch cutting is based on the fact that steel will burn in an atmosphere of pure oxygen after it is brought up to the kindling temperature, just as a piece of paper will burn in air after being brought up to the kindling temperature by means of a match. The main difference is that in the case of the paper, the products of combustion, carbon dioxide and water vapor, are gaseous and pass off into the air, while in the case of the steel, the product of combustion is iron oxide, which is a solid at ordinary temperatures. Its melting point is, however, somewhat below the melting point of steel. The heat generated by the burning iron is sufficient to melt the iron oxide so that it runs off as molten slag, exposing more iron to the oxygen jet. The jet can thus be moved along to produce a clean cut.

(2) Another way of looking at it is that burning iron is extremely rapid-rusting, the rust being molten.

(3) Theoretically the heat generated by the burning iron would be sufficient to heat adjacent iron red hot, so that once started, the cut could be continued indefinitely with oxygen only. Practically, the smoothness of this operation is disturbed by excessive radiation at the surface, and by pieces of dirt, paint, or scale on the metal. Accordingly, the preheating flames of the cutting torch remain burning throughout the cutting operation.

(4) Although it resembles the welding torch in some respects, the cutting torch (fig. 57) is a different tool, its function being to sever rather than to unite. It has an additional tube for high pressure oxygen, and the cutting tip or nozzle is made with a number of holes. Through the center hole passes a jet of pure oxygen under pressure, which can be directed against the steel to be cut. Mixed

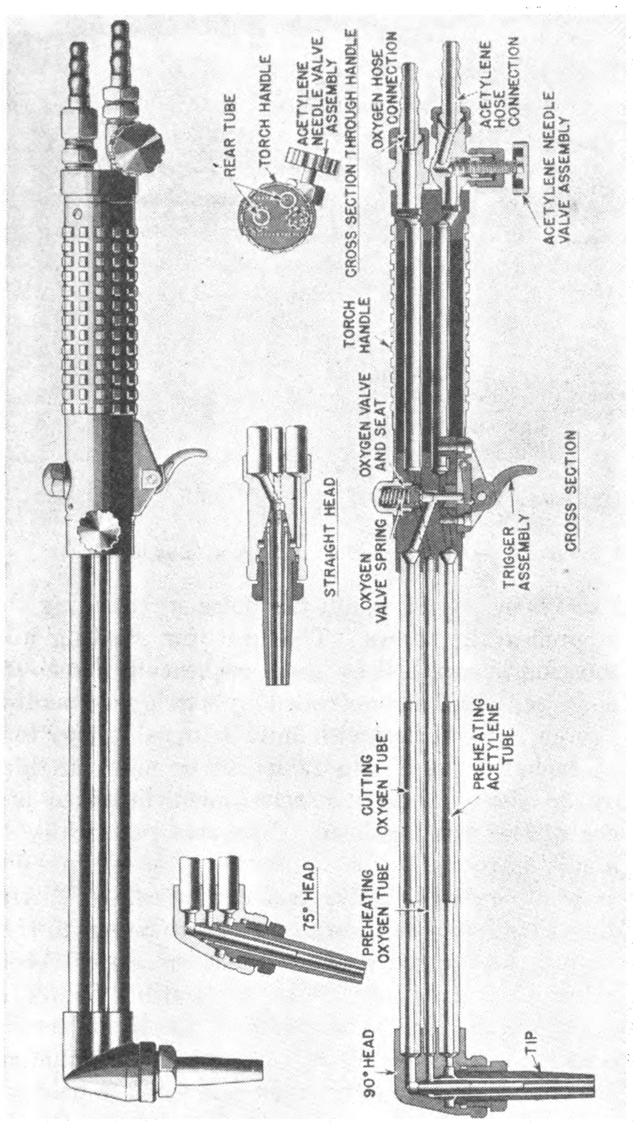

FIGURE 57.—Cutting torch.

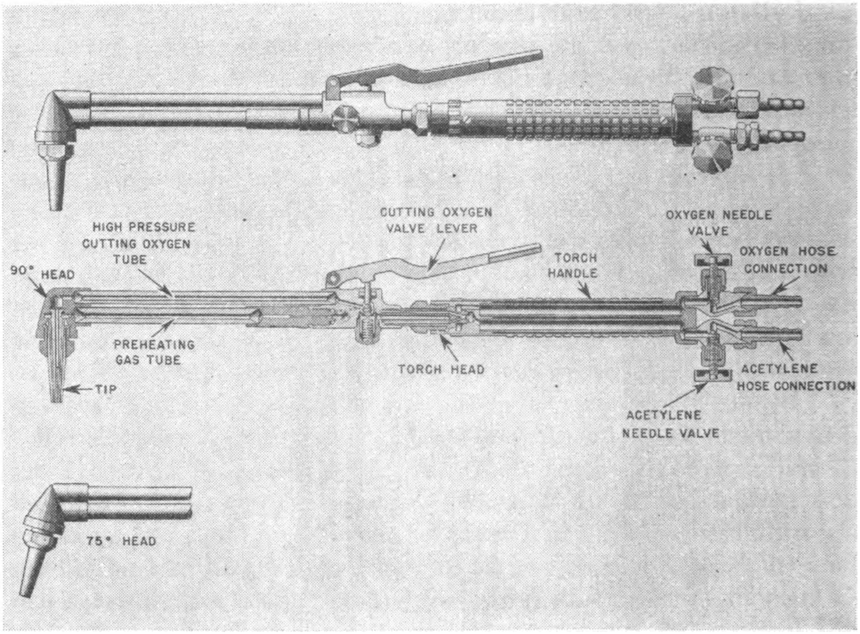

FIGURE 58.—Cutting attachment for a welding blowpipe.

oxygen and acetylene pass through the holes surrounding the center hole for the preheating flames. The heat for starting and maintaining combustion is supplied by these preheating flames surrounding the cutting jet, which is controlled by a trigger-operated valve. The cutting torch is furnished with interchangeable tips for cutting steel from 1/4 inch, or thinner, to 12 inches or more in thickness.

(5) Figure 58 shows a cutting attachment fitted to a welding torch in place of the welding head. It serves practically the same purpose as a cutting torch.

b. Cutting steel, wrought iron, and cast steel.—(1) Attach the proper welding tip for the thickness of metal to be cut to the cutting torch and adjust the oxygen and acetylene pressures according to the manufacturer's instructions. The preheating flames are first adjusted to neutral. To start cutting, hold the torch perpendicular to the work with the inner cones of the preheating flame about 1/16 inch above the end of the line to be cut. The torch is held stationary in this position until this spot has been raised to bright red heat; then open the cutting oxygen valve slowly and move the torch slowly but steadily over the line to be cut. If the cut has started properly, a shower of sparks will fall from the opposite side of the work, indicating that the cut is penetrating clear through. The movement should be just fast enough so the cut continues to penetrate the work completely. If cutting has been properly done the result will be a clean, narrow cut comparable to one made by hot sawing. When cutting billets or round bars, time and gas are saved if a small point of steel is raised with a chisel where the cut is to start. This small raised portion will heat quickly, and cutting may commence immediately as the metal becomes a fuel once the cutting starts.

(2) Steels with a carbon content higher than 0.35 percent and most alloy steels should be preheated to 500° or 600° F. before cutting. This will avoid the surface checking that occurs when such steels are cut at ordinary temperatures. These steels may also require annealing or heat treatment after cutting. Manufacturers of cutting torches furnish definite procedure instructions for this work.

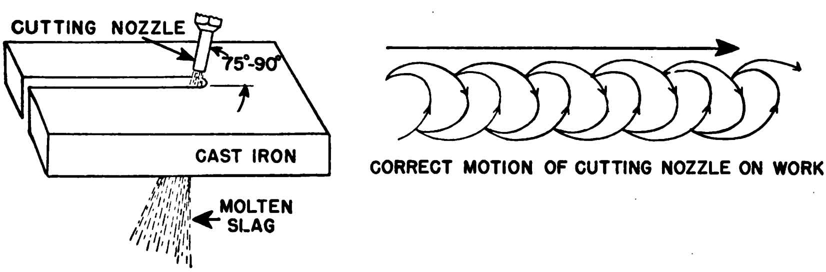

FIGURE 59.—Cast iron cutting technique.

(3) Stainless steels are designed to resist oxidation and therefore have considerable resistance to oxyacetylene cutting. Special techniques are required for them.

c. Cutting cast iron.—Cast iron melts at a lower temperature than its oxide and, when it melts, mixes with it. It is therefore much more difficult to cut than steel. It must be preheated to a much higher temperature and requires an oxygen pressure from 25 to 100 percent greater than steel of the same thickness. It can be cut by using a rather complicated technique illustrated in figure 59.

32. Backfire and flashback.—*a.* Should the oxyacetylene flame backfire (go out with a loud snap or pop), it can be relighted instantly if the metal being welded is hot enough to ignite the gases, otherwise a lighter should be used. A backfire may be caused by touching the tip against the work, by overheating the tip, by operating the torch at incorrect pressures, by a loose tip or head, or by dirt on the tip or head seat.

b. Should the flame flashback (burn back inside the torch), immediately shut off the torch oxygen valve, then close the acetylene valve. After a moment relight the torch in the usual way. Even with improper handling of a torch a flashback will rarely occur. When one does occur it indicates that something is radically wrong with the torch or the manner of operating it. Incorrect delivery pressure of the gases is a probable cause.

33. Special precautions.—*a.* Never do any welding or cutting on used barrels, drums, tanks (including gasoline tanks), or other containers until they have been cleaned so thoroughly that no trace of inflammable material remains. Such materials, when heated, form explosive mixtures with air. Where live steam is available, it can be used to remove volatile materials. Washing with strong caustic soda will remove heavier oils. Even after thorough cleaning, the container should, whenever possible, be filled with water before any welding, cutting, or other hot work is done on it. It will usually be found possible to place the container in such a position that it can be filled with water to within a few inches of the point where welding or cutting is to be done. A vent must be provided for releasing the hot air from inside the container. A bung, hand hole, or other fitting can usually be found which is above the water level.

b. Never attempt to weld or cut a jacketed vessel, tank, or container until provision has been made to vent the confined air. A metal part that is suspiciously light is hollow inside and should be drilled before heating, otherwise it will explode like a bomb.

c. Do not cut material in such a position that sparks, hot metal, or the severed section will fall on the cylinder or hose, or on your legs or feet.

Section IV

ELECTRIC WELDING

34. General.—*a.* Almost the same results can be obtained by electric welding as by gas welding, but electric welding is faster and cheaper for many purposes. The student should therefore understand the equipment and methods used for it as well as for gas welding.

b. Electric welding equipment usually operates from 220- or 440-volt circuits, capable of inflicting severe, even fatal, shocks, although the welding circuits (between the equipment and the work) have low voltage and are not ordinarily dangerous. The student should pay particular attention to safety precautions when using motor generators or transformers connected to power lines.

c. There are two kinds of electric welding: arc welding and resistance welding. An electric current provides the welding heat in both types.

35. Arc welding.—*a.* Arc welding is the most generally used of the electric welding processes. The welding heat is obtained from an electric arc formed when the current jumps a gap between the base metal and an electrode or between two electrodes. Welding current may be either alternating or direct. Direct current (d. c.) is more extensively used today, but there is a trend toward wider use of alternating current (a. c.).

b. In d. c. arc welding the welding current is conducted to the work by multistrand, well-insulated copper cable. The usual direction of current flow is from the generator to the work, then to the electrode and electrode holder, then through another cable back to the generator, as shown in figure 60. This is known as straight polarity; the electrode is *negative* and the work is *positive.* With certain electrodes and for certain kinds of work, reversed polarity is more advantageous. In this case the direction of current from the generator is reversed by turning a switch so that the electrode becomes *positive* and the work *negative.* The circuit for alternating current arc welding is the same except that a transformer set is usually substituted for the motor generator set. Alternating current, as the name indicates, is constantly reversing in direction. It reverses twice every cycle; 120 times per second for 60-cycle a. c. Therefore, its polarity cannot be changed by a switch. A. c. circuits do not have positive and negative terminals as do d. c. circuits.

c. Arc welding is designated as either carbon arc welding or metal arc welding, depending on the character of the electrode used. In both processes the heat is highly localized and the temperature of the molten metal is considerably higher than in gas welding. Arc voltages ordinarily vary from 15 to 45 volts and the arc current from 20 to 600 amperes, although some processes use current values as high as 2,000 amperes. The magnitude of the current that can be used successfully depends on the size of the electrodes, the thickness of the parts being welded, and the rate of weld travel. In arc welding, a molten pool forms on the work at the arc, and manipulating the electrode makes the molten pool travel along the joint as desired. The carbon arc process resembles the gas welding process. The arc is used only for heating, and additional metal is added by a

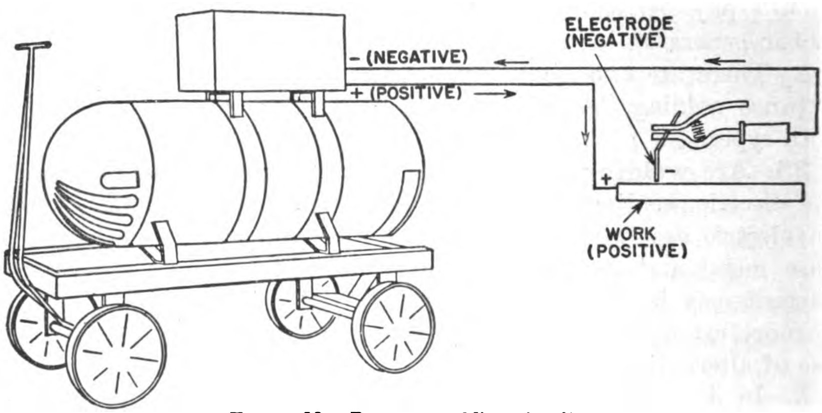

FIGURE 60.—D. c. arc welding circuit.

filler (welding) rod. In the metal arc process the tip of the electrode melts to supply the filler metal. Metal arc welding has a wider application than carbon arc welding.

36. Carbon arc method.—This method is always used with direct current. The electrode is usually negative so it will not be excessively consumed or too much carbon be absorbed by the weld metal. The procedure is essentially a puddling one, not adapted to welding in vertical or overhead positions. Its best application is in automatic welding in the flat position. The arc and the molten metal are usually shielded from the atmosphere by introducing a combustible material and fluxing agents into the arc.

37. Metal arc method.—This method carries metal across the arc from the electrode to the work in very small globules and deposits them in the molten pool on the work. The electrode is consumed and the metal deposited at a rate proportional to the current used. By proper choice of electrodes, either direct or alternating current may be used. The process is efficient for welding sections 1/16 inch or more in thickness and may be carried out in a flat, vertical, or overhead position. The best quality of weld is obtained by protecting the metal in the arc from the oxygen and nitrogen of the atmosphere by covering the electrode with suitable fluxing materials and combustible agents. This also covers the pool of molten metal with slag. A wide variety of electrodes is available for specific applications. The metal arc method is the most versatile and widely used of the electric fusion welding processes.

38. Atomic hydrogen arc welding.—Atomic hydrogen arc welding is actually a combination of arc welding and gas welding. A stream of hydrogen is made to pass through an electric arc established between two tungsten electrodes. The electrodes themselves do not enter into the weld, although they are slowly consumed by the intense heat. Hydrogen ordinarily is composed of molecules (very small particles) each consisting of two atoms (smaller particles) combined together (H_2). The arc splits each molecule apart into atoms (H). The breaking up of the molecules requires the expenditure of energy in the form of heat taken from the arc. After passing through the arc the atomic hydrogen recombines into the molecular form, giving up the heat taken from the arc. This is what makes the flame so extremely hot. The atomic hydrogen flame is used in essentially the same manner as the oxyacetylene flame. This process is more expensive than ordinary arc welding and is used for certain special purposes where ordinary arc or gas welding is not entirely satisfactory, such as welding along the edges or corners of thin sections, and welding stainless steels or monel metal. The hydrogen flame protects the readily oxidizable chromium, nickel, and other elements in these steels and alloys from the oxygen in the air. Filler metal of suitable composition can be melted in the atomic hydrogen flame as required.

39. Resistance welding.—*a. General.*—Resistance welding can be a spot welding, butt welding, flash welding, or seam welding process. It is accomplished by bringing the parts to be joined to welding heat by passing a heavy electric current through them and then squeezing them together. It is similar to forge welding in this respect. There is no arcing, except in the flash welding process. The resistance of the metal to the passage of the current heats it. Alternating current is generally used for resistance welding, because a transformer can be employed to supply the high amperage at the low voltage which the process requires. Resistance welding requires special equipment and is suitable mainly to mass production. Resistance spot and seam welding are used very rarely in maintenance and repair shops.

b. Spot welding.—This process is applied to the welding of overlapped metal sheets or other comparatively thin sections. The overlapped parts are held between copper electrodes, sometimes water-cooled, which apply pressure while electric current flows through them, and the current is cut off before the pressure is released. The area welded is approximately the same size as the electrode tip, usually one-eighth to one-fourth inch in diameter. Spot welding is particularly applicable to the fabrication of metal sheets up to one-fourth inch thick, and is used for many purposes where riveting was formerly employed. Automatic equipment makes the production of many welds per minute possible.

c. Butt welding.—In resistance butt welding the parts to be joined are pressed into contact and electric current is passed through the grips (electrodes) and across the junction of the two parts. When the contact surfaces become plastic, pressure is applied, and the parts are welded together.

d. Flash welding.—(1) Resistance flash welding is a modification of resistance butt welding and is carried out in much the same manner. Contact edges of the work are slightly separated, however, and arcing or flashing occurs from edge to edge of the joint. This arcing may burn or flash off a considerable amount of metal at the joint before the ends become sufficiently hot to form the weld by pressure. During the flashing period this loss in metal is compensated by feeding the two edges together to keep the distance between them uniform. Pressure is applied after flashing has heated the contact surfaces to welding temperature. Flash welding is applicable to welding larger joint areas than resistance butt welding, and requires less care in the preparation of joint surfaces and smaller current densities for satisfactory welding. A hydrogen atmosphere is often maintained at the weld to prevent oxidation of the joint surfaces.

(2) Both butt and flash resistance welding are widely used for joining ends of wires, bars, and tubes. They can produce tubing from flat strips by a continuous longitudinal butt weld as the formed strip passes through electrical contact rolls. In such tube welding processes very high currents are utilized, the weld being effected at point of contact in a fraction of a second.

(3) After completion of the weld, it may be heat-treated in the resistance welding machine, using the current to bring the portion between the grips or electrodes to the desired heat treating temperature.

e. Seam welding.—Resistance seam welding may be considered as a series of overlapping spot welds. The electrodes are generally in the form of rolls which also exert pressure as the overlapping sheets pass between them. Automatic equipment for this type of welding generally utilizes a current interrupter which so times the current impulses with relation to the speed of travel of the sheets that a series of overlapping spot welds actually results.

40. Electric arc cutting.—The carbon arc can be used for rough metal cutting and for burning out holes in plates to which tube fittings, connections, and the like are welded. This is strictly a melting process which depends upon gravity to remove the molten metal. It is not recommended for precise work or for heavy sections, for which the oxyacetylene cutting torch should be used. Nonferrous metals and some special alloy steels which are impossible or difficult to cut by the oxyacetylene process may be cut by the carbon arc. When the carbon arc is used for cutting, the arc should be manipulated to keep

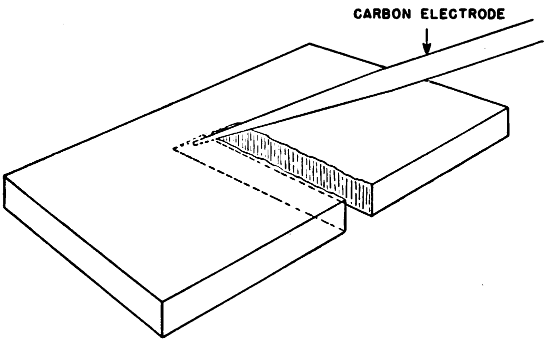

FIGURE 61.—Carbon arc cutting.

the bottom of the cut ahead of the top, as shown in figure 61, to give the molten metal a chance to drop out. The arc should also be moved from top to bottom of the cut in order to force the metal down. For some purposes a coated electrode can be used to better advantage than a carbon electrode; for example, when working through a hole in one plate to burn a similar hole in a plate underneath. The insulation provided by the coating on the electrode makes this possible where it would not be practicable either with the gas torch or carbon arc.

41. Arc welding equipment.—*a. Motor-generator set.*—The most satisfactory source of direct current for arc welding is a motor-generator set. The most common type is a portable unit supplying one arc. The generator is of the variable-voltage type which adjusts its output voltage to the arc demands. Independent control of arc volts and arc amperes is provided, as well as a switch for reversing the current polarity. An ammeter and a voltmeter are mounted on

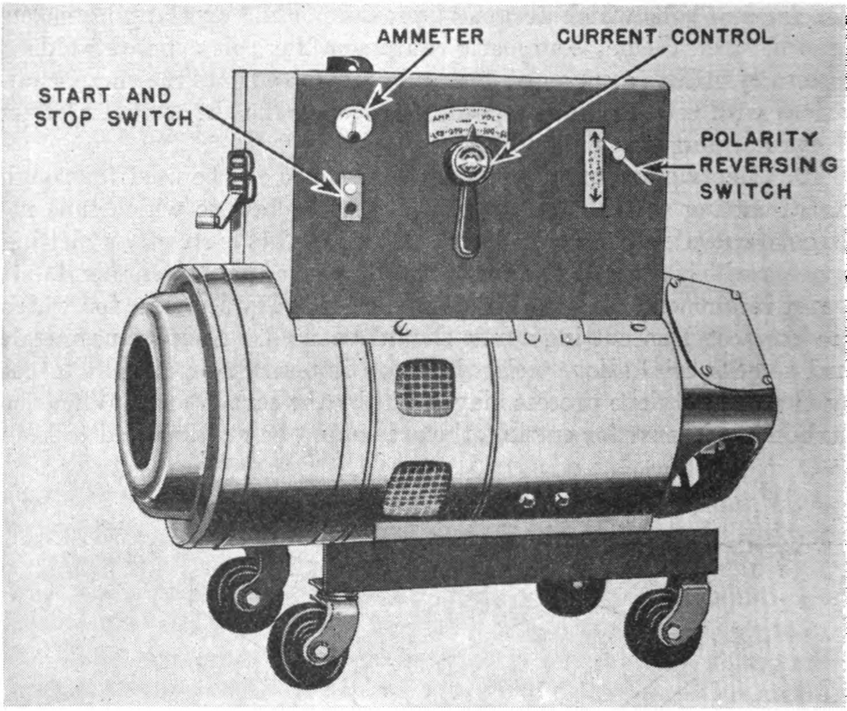

FIGURE 62.—Motor-driven d. c. arc welder.

each machine to indicate the current and voltage being used at any time. When power lines are available, an electric motor-generator set is generally used (fig. 62). When no power lines are available a portable gasoline engine-driven generator set (fig. 63) is used. A less common unit is a larger set capable of supplying several arcs. This type usually has a constant-voltage generator supplying 70 to 100 volts. The voltage for individual arcs is adjusted by resistance in each line.

b. Single-phase transformer.—Where alternating current power lines are available, single-phase transformers may be used. Current adjustment is provided on some designs by means of taps and on others by a movable core or coil controlled by a handwheel. The latter type is shown in figure 64. On some units, open-circuit voltage can be adjusted within the limits desired by means of taps on the secondary coil of the transformer. The arc welder (fig. 64) has an adjustment to regulate amperage only and no indicating instruments are needed or provided.

c. Accessories.—In addition to a suitable source of current, each operator must have the following arc welding accessories: two cables,

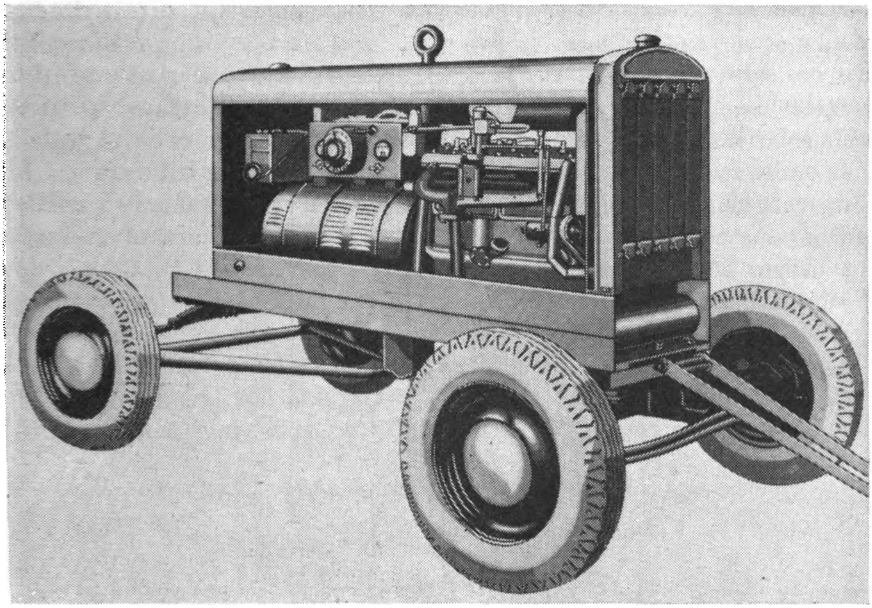

FIGURE 63.—Gasoline engine-driven d. c. arc welder.

an electrode holder, metal and carbon electrodes, a face shield, gloves, and other protective clothing.

(1) *Cables.*—The size of cables used in arc welding should vary with the capacity of the machine supplying the current and its distance from the work. Welding cables are durable and rubber covered. The cable to the electrode is more flexible than the cable to the work, being composed of more and finer copper strands. Table III indicates the size of cable to be selected under various conditions.

TABLE III

Machine size in amperes	Cable sizes for lengths		
	Up to 50 feet	50 to 100 feet	100 to 250 feet
100	2	2	2.
200	2	1	2/0.
300	0	2/0	4/0.
400	2/0	3/0	4/0.[1]
600	2/0	4/0	4/0.[1]

[1] The longest length of 4/0 cable recommended for a 400-ampere welder is 150 feet; for a 600-ampere machine, 100 feet. For greater distances the cable size is increased. The question of the longest cable practical to use is determined by considering the weld production, efficiency, and ease of handling.

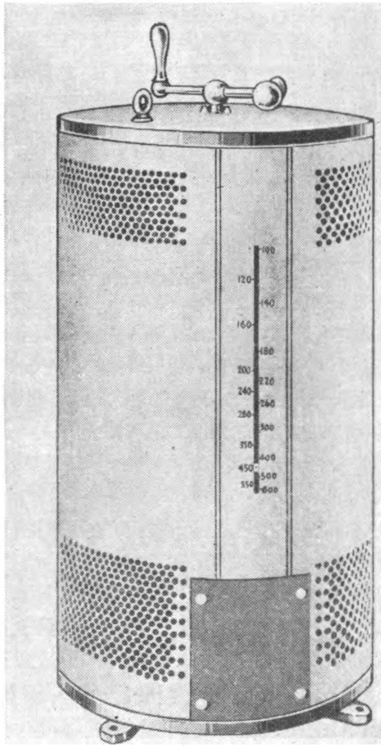

FIGURE 64.—Transformer type a. c. arc welder.

(2) *Electrode holders.*—An electrode holder is a clamping device which holds the electrode and enables the operator to manipulate it. It should hold the electrode securely at various angles with good electrical contact yet permit the electrodes to be easily changed. It should be light in weight, but still have ample current carrying capacity, and be provided with an insulating handle that will remain cool in use. A popular type is shown in figure 65.

(3) *Electrodes.*—Metal electrodes are used for most purposes. They range in size from 1/16 to 3/8 inch and larger in diameter and in lengths of 14 and 18 inches. Bare electrodes are used to a limited extent, but all important metal arc welds are now made with coated electrodes because of the greater strength and ductility of the weld metal compared to that obtained from bare wire. A large variety of materials is used for covering electrodes, but all fall into three groups: those consisting principally of combustible material, those consisting principally of mineral substances, and those using

a combination of combustible and mineral materials. The combustible coating protects the arc by producing a gaseous envelope which excludes oxygen and nitrogen. Mineral coatings give protection by forming a sheath of molten slag about the arc and a heavy layer of slag over the weld metal pool. The coatings of the electrodes also aid in stabilizing the arc, and to a very large degree determine the welding characteristics of the electrode. Electrode coatings may also be used to some extent for introducing alloying elements into the weld metal. The coatings range all the way from light washes to heavy wrapped or extruded coatings constituting 10 percent or more of the weight of the electrode. A heavy coating melts more slowly than the metal of the electrode and thus extends a little beyond the end of the metal rod and shields the arc. Metal electrodes are provided with a wide variety of coatings for particular applications.

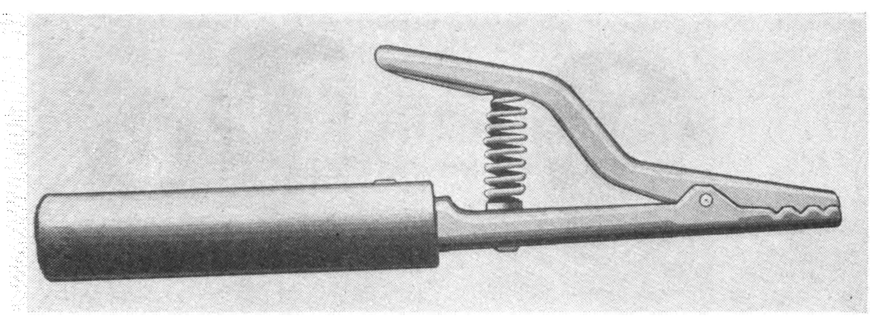

FIGURE 65.—Typical electrode holder.

Carbon electrodes for hand welding and cutting are available in 12-inch lengths from 5/32 to 1 inch in diameter. They are made of pure graphite or baked carbon; the graphite lasts longer under high currents but is more expensive and breaks just as easily as baked carbon.

(4) *Head shields and face shields.*—It is essential that every welder wear a face or head shield to protect his eyes from the dangerous ultraviolet and infrared rays of the arc. The ultraviolet rays can burn the skin with the same effect as severe sunburn; the infrared rays, if viewed directly, can cause temporary painful injury to the eyes. Protective shields of the type shown in figure 66 are generally made of some kind of pressed fiber insulating material with flat black to minimize reflection; they have a glass window in front and should be as light in weight and as comfortable as possible. The windows are usually 2 by 4 1/8 inches, and the glass is of a composition which absorbs practically all the infrared and ultraviolet rays

of the arc as well as some of the visible rays. This glass is, in turn, protected from molten metal splatter and breakage by a chemically treated clear "nonspatter" glass which covers the exposed side of the lens. Welders' helpers, foremen, supervisors, inspectors, and others working close to a welding arc use special goggles to protect their eyes from occasional flashes. A popular goggle has adjustable elastic headbands and is light, cool, well-ventilated, and comfortable. Clear cover glasses and greenish tint lenses in various shades are available for this goggle.

NOTE.—*Remedy for eyeburn:* Eyeburn or so-called "hot sand in the eyes," resulting from looking at the arc without shield or goggles, does not permanently injure the eyes but the pain may be intense for several hours. Immediate relief may be obtained by placing a drop of 2-percent Butyn solution in each eye; its anesthetic effect lasts about 2 hours. Two applications are usually sufficient. If Butyn is not available, treat the eyes with sweet oil once an hour

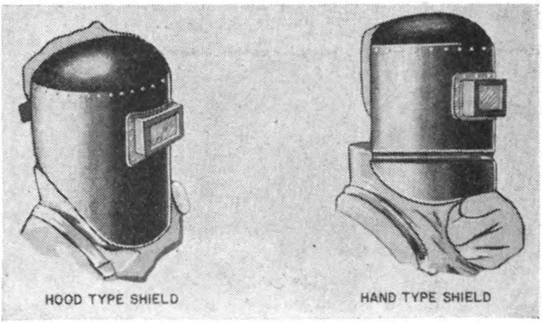

FIGURE 66.—Head shield and face shield.

until the acute burning sensation disappears. The pain may be relieved by ordinary doses of aspirin. A 10-percent solution of argyrol may be used afterward to aid in healing but should *not* be used more often than once in 5 hours.

(5) *Aprons.*—During the arc welding process some sparks and globules of molten metal are thrown out from the arc. For protection from possible burns it is advisable that the operator wear a leather or other kind of protective apron. Some operators wear spats or leggings and sleevelets of leather or other fire-resisting material as well. Some protection should be provided for the operator's ankles and feet, inasmuch as a globule of molten metal can cause a small but painful burn on the foot before it can be extracted from the shoe. The operator should turn the cuffs of his pants down at the bottom so that molten metal will not fall into them.

(6) *Gloves.*—Gauntlet-type gloves, preferably of leather, are generally used by operators for protecting their hands from the arc

rays, molten metal, spatter, sparks, and so on. Gloves also provide protection when handling the work. A welder properly clothed for arc welding is shown in figure 67.

(7) *Miscellaneous accessories.*—(*a*) As a protection to other workers from the arc rays, molten metal splatter, and sparks, the immediate area of each welding operation should be inclosed by either a portable or permanent structure, booth, or screen. A form of welding booth

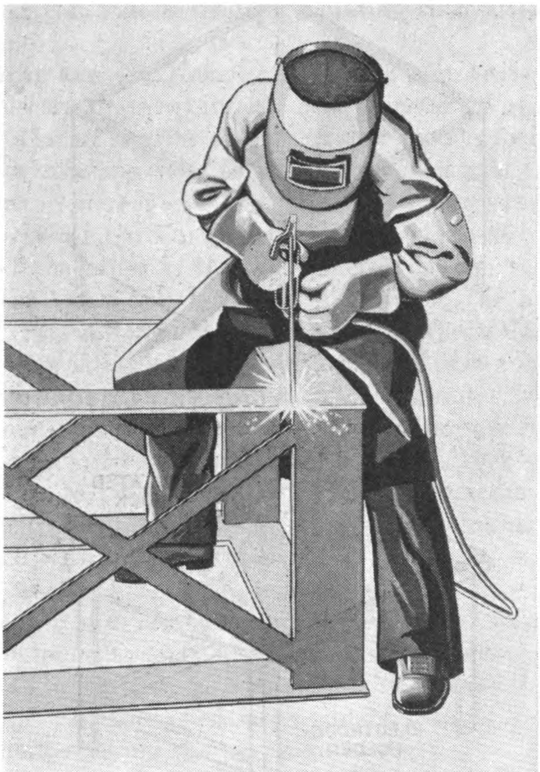

FIGURE 67.—Operator properly clothed for arc welding.

is illustrated in figure 68. When the welding machine must be taken to the work, it is advisable to surround the area of welding operation with portable screens painted dead black to minimize reflection of the arc rays.

(*b*) Most welding operations require the use of a table or bench. Every operator has his own idea of the proper type of welding table. However, the one shown in figure 69 has proved very practical. As the table illustrated indicates, a suitable and well-insulated container for electrodes should be provided, as well as an insulated hook for supporting the electrode holder when not in use.

(*c*) Other tools which will prove of value in any shop where welding is done include wire brushes for cleaning the welds, cold chisels for chipping, clamps for holding work in position for welding, and wedges; and where work is large or heavy a crane or chain block. A drill, air hammer, and grinder are also often of value.

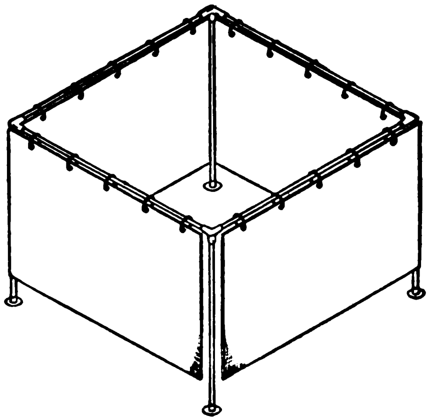

FIGURE 68.—Welding booth.

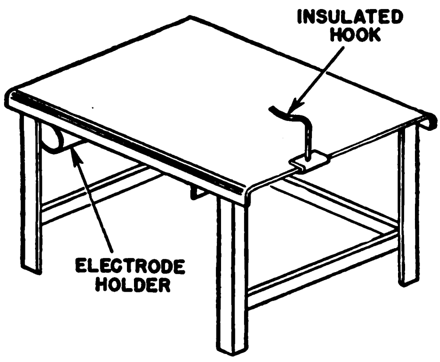

FIGURE 69.—Welding table.

(8) *Backing equipment.*—(*a*) A great deal of use will be found in general welding for blocks, strips, and bars of copper for backing up joints while welding. Copper is most satisfactory for this purpose because of its high heat conductivity and the fact that it is not likely to fuse into the weld. Such backing is very helpful in preventing molten metal from running through the joint, especially when light gage metal is being welded. It also helps prevent light stock

from melting away or burning up, especially when it is metal with a low melting point, such as aluminum. Either steel or copper backing may be used but copper is preferable in most cases. When steel is used for backing it must be clean and free from rust.

(b) Carbon blocks, asbestos, and fire clay are sometimes used to build dams or molds for holding molten metal within certain prescribed limits when depositing pads for building up bearing surfaces, etc. A mixture of sodium silicate (water glass) and fire clay or carbon powder can also be used for building such molds or dams of special shape.

42. Welding arc.—*a. General.*—(1) When an arc is formed across a gap in an electrical circuit intense heat is instantly generated. The result is that a small amount of the metal or carbon forming the electrode is vaporized, and it is this vaporized material that acts as a conductor for the current as it continues to flow across the gap.

(2) In the welding arc, one side of the gap is the carbon or metallic electrode and the other is the work metal. When the electrode is touched to the work and instantly withdrawn, the arc is formed. The heat of this arc melts the work metal for welding purposes. Three types of welding arcs, the carbon arc, the bare-metal arc, and the shielded-metal arc, will be considered in detail.

(3) The temperature developed in the welding arc is so high that it cannot be measured with absolute accuracy. It is generally estimated, however, to be about 7,000°. The temperature of a shielded arc formed with heavy coated electrodes is even higher than that of an arc formed with bare electrodes.

b. Carbon arc.—This is the original method of arc welding, in which a filler rod provides additional metal in the joint. Figure 70 shows the component parts of the arc. The carbon arc is silent, stable and easy to maintain as compared with the metallic arc. Likewise, its length can be varied more widely without putting out the arc and without sticking the electrode to the work. Hence, its manipulation is more easily learned by the beginner. Carbon arc welding is somewhat similar to gas welding but, due to the more intense heat, the electrode must be manipulated more rapidly than the torch. A long taper on the electrode, similar to a dull lead pencil, makes control of the arc easier. Such a taper (shown in fig. 70) can be put on the end of the carbon electrode, if it is too blunt, by means of a bench grinder.

c. Bare-metal arc.—(1) In this type of arc the filler rod is used as the electrode. It melts down in the heat of the arc to supply such additional metal as the joint requires. The advantages of this method in most types of work, as compared with the carbon arc, are

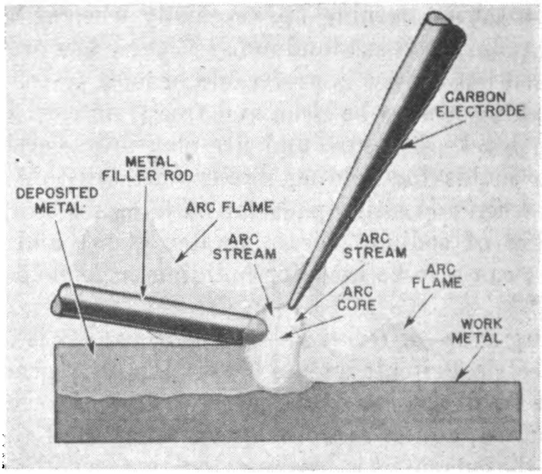

FIGURE 70.—Diagram of carbon welding arc.

obvious. Except for the different method of applying the additional metal, which flows through the arc stream, the component parts of the arc are similar to those of the carbon arc (fig. 71).

(2) It is generally believed that most of the metal transferred from the electrode to the work is in the form of small molten globules carried across in the arc stream. This is particularly true with nonferrous metals, which cannot usually be welded overhead because the globules are larger than they are in steel welding and must be helped across the arc by gravity. With steel electrodes, however, it

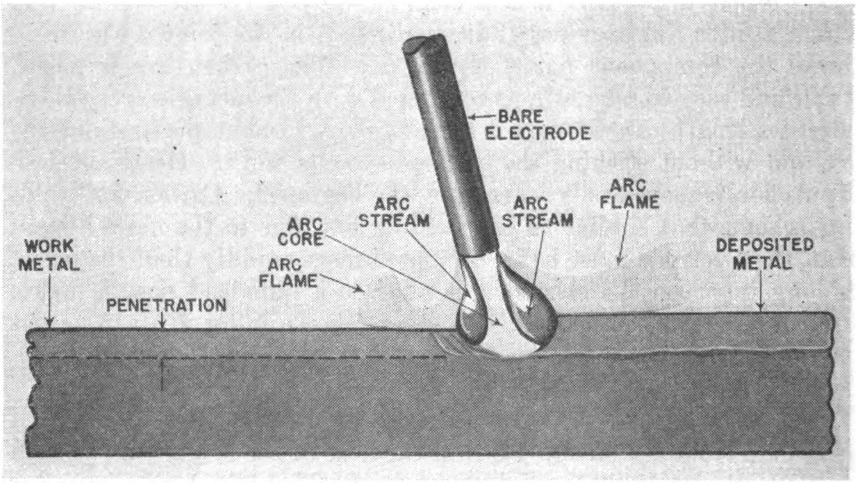

FIGURE 71.—Diagram of bare-metal welding arc.

is believed that at least a part of the electrode material is vaporized by the intense heat of the arc so that it expands; the resulting pressure forces it across to the lower pressure area of the work where the lower temperature causes it to condense. The theories of cohesion and capillary attraction are also involved. It is practical to weld overhead or vertically with steel electrodes.

d. Shielded arc.—(1) The shielded arc, whose component parts are illustrated in figure 72, is also a metallic arc. The electrode itself is usually the same type as the bare electrode but is heavily coated by wrapping, extruding, or dipping. Wrapped or extruded coatings have found favor in most applications because of their greater uni-

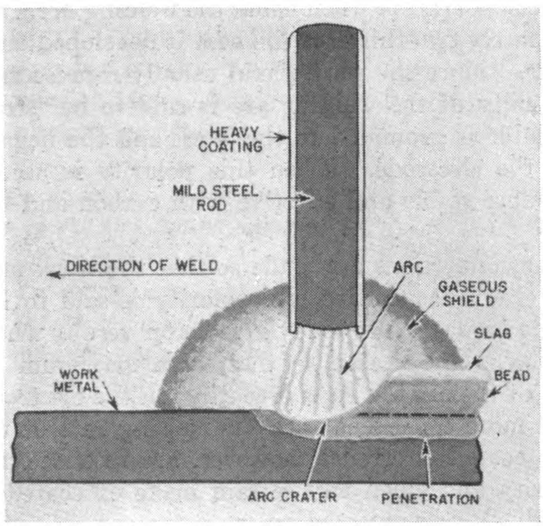

FIGURE 72.—Diagram of shielded-metal welding arc.

formity. In either case the coating is of materials that, when subjected to the heat of the arc, form a gaseous shield around the arc as indicated in the illustration. The coating melts slower than the metal of the electrode and therefore extends slightly beyond the end of it, which has a directing and stabilizing effect on the arc.

(2) The gases in the shield do not affect the molten weld metals themselves while forming a dense wall that protects the molten metal from the oxygen and nitrogen in the atmosphere. Part of the electrode coating material floats to the top of the welding bead to form a slag coating which serves the same purpose after the metal is deposited as the gaseous shield does while the metal is passing across the arc. Molten metal is extremely susceptible to the action of oxy-

gen and nitrogen. Oxidation means corrosion, and nitrides (compounds of nitrogen) have a weakening effect upon the structure of metal. The metal deposited with a shielded arc is therefore of better quality than that deposited with an unshielded arc, and due to the greater heat developed in a shielded arc the metal is deposited more rapidly, as has been pointed out heretofore. Also, the shielded arc is more stable and easier to maintain.

(3) After the weld has cooled, the slag coating is easily removed by chipping and wire brushing. It is very important that it be removed from every bead, before depositing another on top of it, to avoid trapping slag in the weld.

43. Arc polarity.—*a.* The effect of polarity is something that must be taken into consideration when using the welding arc. It is believed that approximately two-thirds of the heat is developed on the positive side of the arc. Since the work metal usually represents the greater mass, the polarity of the welding arc is said to be "straight" when the positive cable is grounded to the work and the negative cable is connected to the electrode. When this polarity is used, the arc is a great deal more stable and effective with carbon and bare metallic electrodes.

b. When the connections are made so that the work metal is negative and the electrode positive, the polarity is said to be "reverse." Most coated electrodes in use today give better results when used with reverse polarity. One reason is that with maximum heat on the electrode side of the arc the special coating on the electrode is burned off at a speed more consistent with the melting rate of the electrode metal. Some coated electrodes, however, are intended for use with straight polarity and when any certain make of coated electrode is used the supplier's recommendation as to the correct polarity should be followed.

c. Reverse-polarity electrodes have given best results in metallic arc welding of cast iron, in which case it is desirable to keep the heat out of the casting as much as possible. The most successful electrodes for cast iron are especially coated, although not so heavily as the shielded-arc type of electrodes for welding mild steel. Nonferrous electrodes, such as copper, bronze, aluminum, nickel, and monel metal, either coated or uncoated, are used with reverse polarity when welding with the metallic arc.

d. The carbon arc should always be used with straight polarity no matter what type of filler rod is used or on what kind of metal it is deposited. A certain amount of the carbon electrode is carried across the arc to the pool of molten work metal, and it is usually desirable to hold this transfer to a minimum. Observation of a direct-current carbon-arc lamp shows that the positive carbon burns up far more rapidly than the negative carbon and that the latter actually increases in size, indicating a considerable transfer of carbon from positive to negative. With the welding carbon on the negative side, therefore, it will be consumed less rapidly and less carbon will be carried into the weld. Further, experience shows that the carbon arc is very unstable when reverse polarity is used. Straight and reverse polarity apply only to d. c. machines, as explained in paragraph 35*b*.

44. Magnetic flare.—*a.* The arc is a conductor of electricity and as part of the circuit through which current flows from the generator through the welding cable, arc, work metal, and ground cable back to the generator, it is subject to magnetic influences. Magnetic flare, usually called "arc blow," is more pronounced with direct current than with alternating current, which is an important reason for the increasing use of alternating current. Where welding must be done in corners on heavy plates, magnetic flare presents a serious problem, and alternating current, if available, is generally used for such work.

b. In average work there are ways of reducing the annoyance of magnetic flare with the direct-current arc. Often this can be accomplished by changing the location of the ground connection on the work metal. In other cases, wrapping a few turns of the ground cable around the work may give the desired results. Sometimes a small electric magnet, connected to the shop power lines and located near the point at which welding is being done, will give a neutralizing effect.

45. Arc length.—*a.* Experience has shown that, with bare electrodes, better welds may be expected from a short arc, although too short an arc may result in undesirable porosity in the weld. On the other hand, a long arc means more exposure of the molten weld metal to the harmful effects of oxygen and nitrogen in the air. A short arc concentrates the heat on the work, while a long arc allows more heat to escape into the air and is more inclined to "blow." A long arc is more likely to go out frequently and tends to deposit the weld metal on the work without proper penetration and fusion. In general, the length of the arc with a bare electrode should not exceed the diameter of the electrode.

b. With coated electrodes a longer arc is used. The resulting shielded arc protects the weld metal from the oxygen and nitrogen in the air, and its greater heat insures better penetration and fusion. With some types of coated electrodes the metal melts up somewhat inside the coating as the latter burns off, so that the true length of the arc may not be visible.

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46. Arc voltage.—*a.* The voltage across the arc is determined by the length of the arc; the shorter the arc, the lower the voltage and vice versa. This is due to the peculiar characteristics of the arc that cause its resistance to decrease as current passing through it increases. The open-circuit voltage of a welding machine is measured across the welding terminals at no-load. The arc is more stable and less susceptible to the effects of air currents, magnetic conditions, or vapors rising from the work when the open-circuit voltage is at least double the arc voltage.

b. If the open-circuit voltage is too low it is difficult to start the arc, particularly when low current values are being used as when welding light sheet metal. For practical purposes the open-circuit voltage should be not less than 50 or 60 volts and should be adjustable to the higher values required for certain welding conditions. The arc voltage is not accurately registered by the voltmeter on a welding machine because it shows voltage across the welding terminals and does not take into consideration the voltage drop in the welding cables, etc. The voltage across an arc of proper length with bare electrodes will be from 14 to 25 volts, depending upon the diameter of the electrode used. With coated electrodes, the voltage will be somewhat higher due to the longer arc used, as heretofore discussed, this being the reason for the development of welding machines rated at 40 instead of 25 volts as formerly.

47. Welding current.—*a.* The amount of welding current to be used depends upon so many variables that it is impossible to tabulate exact values. The operator must learn by practice and experience the proper values for various welding jobs. In many large plants

TABLE IV.—*Approximate range of current values for metallic electrodes*

Thickness of metal to be welded	Diameter of electrode (inch)	Bare electrodes		Coated electrodes	
		Voltage across arc	Welding current (amperes)	Voltage across arc	Welding current (amperes)
22–18 gauge	1/16	15–17	25–30	16–18	30–35
18–16 gauge	3/32	15–17	35–80	16–18	40–90
1/16–1/8 inch	1/8	17–20	90–135	20–22	90–140
1/8–3/16 inch	5/32	18–20	115–175	20–25	115–220
1/4 inch and up	3/16	18–25	150–260	28–30	150–275
3/8 inch and up	1/4	18–25	200–300	30–32	200–325
3/8 inch and up	5/16	18–25	250–325	30–32	250–400
1/2 inch and up	3/8	20–28	300–400	32–36	300–500

NOTE.—Bare electrodes larger than 1/4 inch are very rarely used.

where arc welding is used extensively, welding engineers are in charge of procedure. They make exhaustive studies of the work to be done and issue special instructions as to the current values to be used by the operators for each welding operation, as well as the type and size of electrodes, etc.

b. While greater speed may be attained by using higher currents with a given size of electrode, care should be taken not to use currents excessive enough to injure the weld metal. The approximate values in table IV are merely suggestions. Adjustments must be made according to the kind of material welded, type of electrode used, size and shape of the work, type of joint, position in which the welding is to be done, speed required on the job, skill of the operator, and equipment available.

48. Design of joints.—Design of joints for arc welding is about the same as for gas welding described in paragraph 23. However, U-joints and J-joints are advocated by some authorities for arc welding as a means of economizing electrodes.

a. The single-U butt joint (fig. 73) is suitable for all usual load conditions and is used for work of the highest quality. It replaces the single- or double-V joint for joining plates ½ to ¾ inch thick, although it is also used on heavier plate. For plates of this thickness, single- or double-V joints would require a considerable amount of weld metal. Machining the plate to a single U reduces the amount of weld metal needed but increases machining costs. The joint is welded from one side except for a single bead which is put in last on the side opposite the U.

b. The double-U butt joint (fig. 74) is suitable for all load conditions and is used for welding heavy plates (¾ inch and thicker) where the welding can be done from both sides. This joint requires

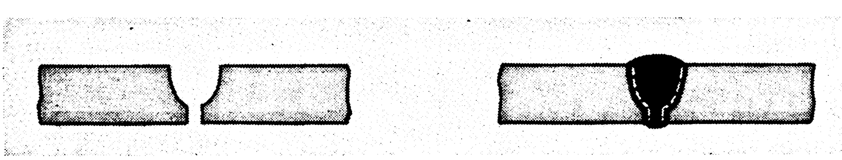

FIGURE 73.—Open single-U butt joint.

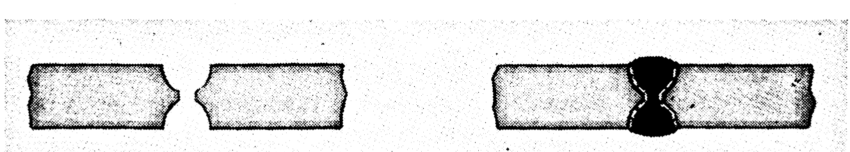

FIGURE 74.—Open double-U butt joint.

less weld metal than the single U but costs more to machine. Choice between double U and double V should be made by comparing the machining and welding costs of the two, then selecting the joint which is cheaper.

c. The single-J T-joint (fig. 75) is suitable for severe loads, and while it may be used for usual size plates it is more often applied to 1-inch and heavier plates. The welding is done from one side only. However, it is advisable to put in a final finish bead on the side opposite the J. Although somewhat more costly to machine than the single V, the single-J T-joint is lower in electrode cost.

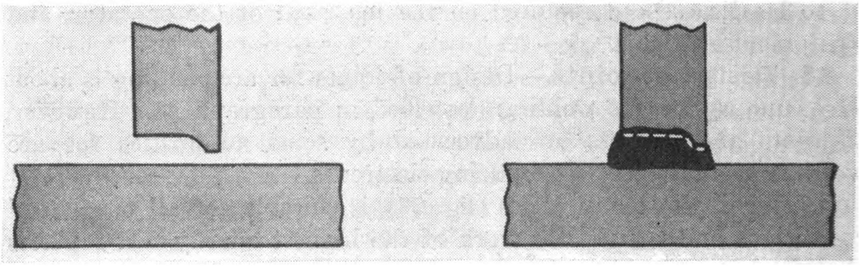

FIGURE 75.—Single-J T-joint.

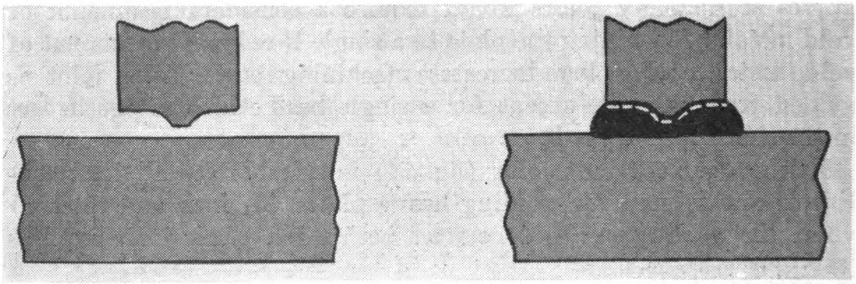

FIGURE 76.—Double-J T-joint.

d. The double-J T-joint (fig. 76) is suitable for exceedingly severe loads of all types in heavy plate (1½ inches and heavier) where welding can be done from both sides. Although the machining costs for the double-J T-joints are higher than for other types of T-joints, less electrode is required, and consequently the cost per joint is reduced.

e. Examples of arc welds and their locations are shown in figure 77.

49. Expansion and contraction.—The theories of expansion and contraction discussed in paragraph 25 are the same for arc welding as for gas welding except that the former usually proceeds faster, and the base metal does not heat up as much; that is, the heat is localized nearer the weld. Therefore, somewhat different allowances are made in some cases.

50. Preparation of work for welding.—*a.* In addition to beveling, if used, the work should be clean. Scale, rust, grease, oil, paint, and any other foreign matter should be removed by a chisel, wire brush, or rag. Otherwise, it will be difficult to strike and maintain a welding arc and good results cannot be expected.

b. When cleanliness of the finished weld is important for the sake of appearance, it is common practice to spray or paint the joint and adjacent surfaces before welding with an especially prepared coating material to prevent weld spatter adhering. This does not make the weld metal brittle or porous or cause injurious fumes and corrosion.

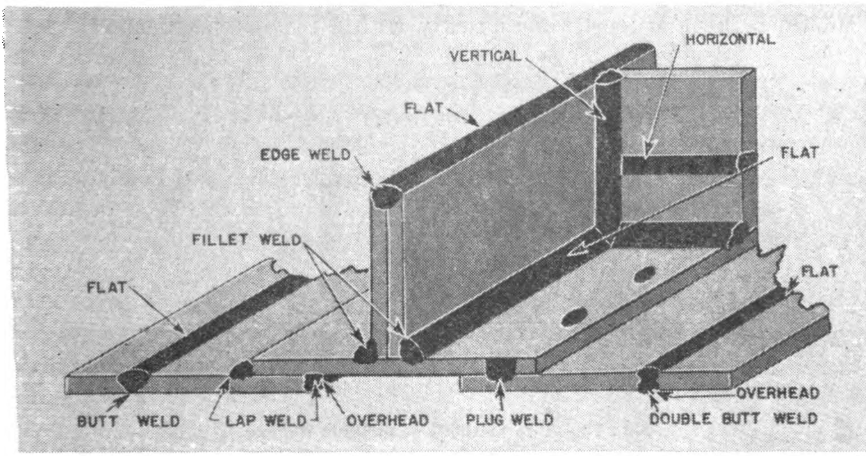

FIGURE 77.—Examples of arc welds and their locations.

It withstands preheating temperatures and does not have to be removed afterwards.

51. Striking the arc.—*a. Precaution.*—No matter where you are working—in the school, in the shop, or outdoors—*never strike an arc, even for an instant, unless your eyes and the eyes of everyone in the vicinity are protected from the rays.* While no permanent injury has been known to result from exposure to the rays of an arc, such exposure may cause extreme pain if eyes or skin are exposed frequently, even for very short periods of time. Remedies have been prescribed in paragraph 41*c* in case this precaution is neglected.

b. Procedure.—(1) Place the electrode in the holder. Strike an arc between the lower end of the electrode and the work, using one of the two methods shown in figure 78. The method shown at the left is by the straight up and down motion and must be executed very rapidly to prevent the electrode sticking to the plate. Some operators find it easier to employ the scratching method shown at the right. In this, the electrode tip is brought quickly along the dotted line from point A to point B where instantaneous contact is made with the plate and the electrode withdrawn more slowly to point C, where it is held.

(2) In either case the electrode should be withdrawn promptly as soon as it strikes the plate until the lower end is about 1/8 inch above the surface of the plate and the arc gives off a continuous crackling or "frying" sound. Beginners should practice striking an arc until they can consistently strike and hold it for 3 or 4 seconds without sticking the electrode to the plate or breaking the arc. Hold the electrode perpendicular to the plate while practicing.

c. Freeing the electrode.—When the electrode sticks to the plate it should be broken loose very quickly with a rapid twisting or bend-

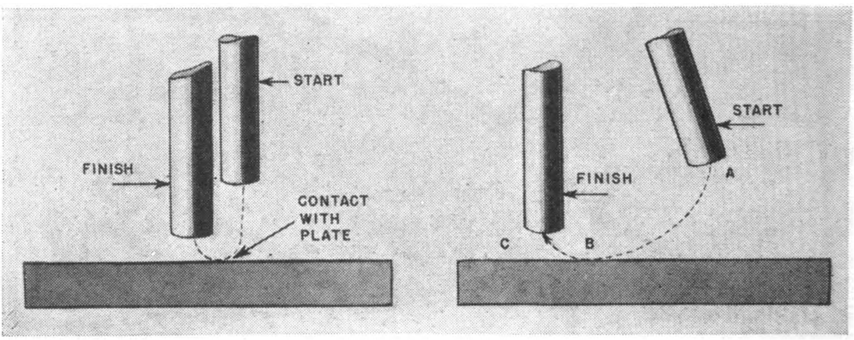

FIGURE 78.—Two methods of striking the arc.

ing motion, otherwise it will heat up very rapidly. In this case the electrode holder must be disengaged and the electrode broken loose with a hammer or chisel after it cools. Practice for accuracy in striking the arc at a predetermined point may be obtained by covering one side of a plate with crosses made with a piece of soapstone as shown in figure 79. Hold the shield away from your face so you can see to bring the tip of the electrode to a point directly above the center of one of the crosses, to a point in the air about 1/4 inch from the surface of the plate. Then place the shield in front of your face and try to strike the arc in the center of the cross at which you have aimed. Practice this exercise, using both sides of the plate, until you can strike the arc accurately at the center of any cross selected. Move the shield away in order to aim at the selected cross, *but always replace the shield in front of your face and eyes before allowing the electrode to touch the plate.* You should be able to strike the arc in the center of at least 10 consecutive crosses and hold it there for 3 or 4 seconds without sticking or breaking the arc, before you go on to the next exercise.

52. Laying short beads.—*a. Preparation.*—(1) The student should start with ¼-inch mild-steel plate laid flat on the bench, a ⁵⁄₃₂-inch bare mild-steel electrode, a current of about 150 amperes, and

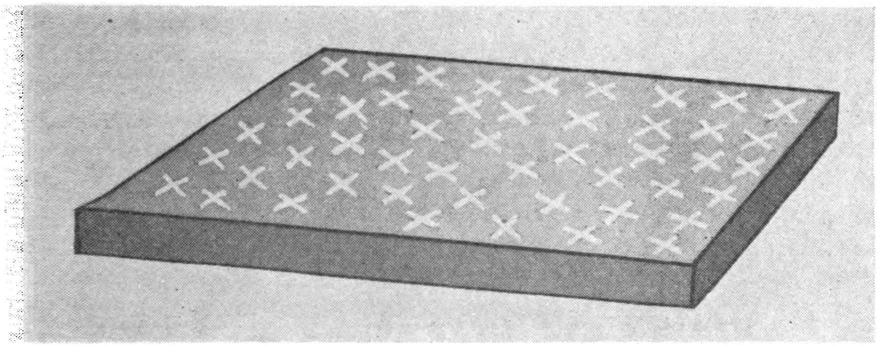

FIGURE 79.—Practice-for-accuracy chart.

straight polarity. Before proceeding, it is important to know the difference between good and bad beads so the student can practice the right way and learn to avoid the wrong ways. Depositing a length of weld metal is generally called "laying a bead" and a finished weld may consist of one or more beads. A bead may be laid alongside or on top of others in order to produce a completely welded joint in heavy metal or a built-up pad of the desired thickness.

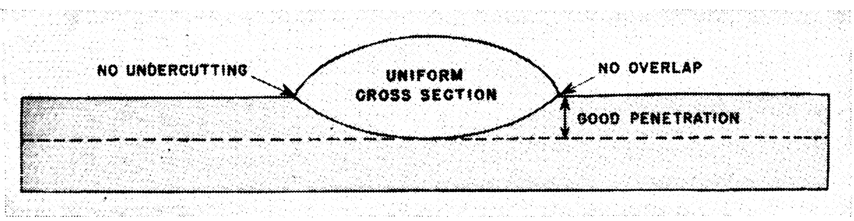

FIGURE 80.—Cross section of good bead.

(2) A good bead must penetrate the work metal to a reasonable depth to insure complete fusion, which can be accomplished only when deposited metal and work metal are melted together. The penetration of the weld metal as indicated by the depth of the crater in the weld is generally a good test of fusion. The bead should also be uniform in cross section without overlapping or undercutting the work metal, as shown in figure 80. Only metal that is properly fused with

the work metal is worth depositing from the electrode. Overlapping metal is wasted and undercutting weakens the weld.

(3) Good beads result from using good quality electrodes of the right type for the job, on work metal that has been properly cleaned and prepared, with the proper current value, the correct length of arc, and by moving the electrode at the correct speed along the line of

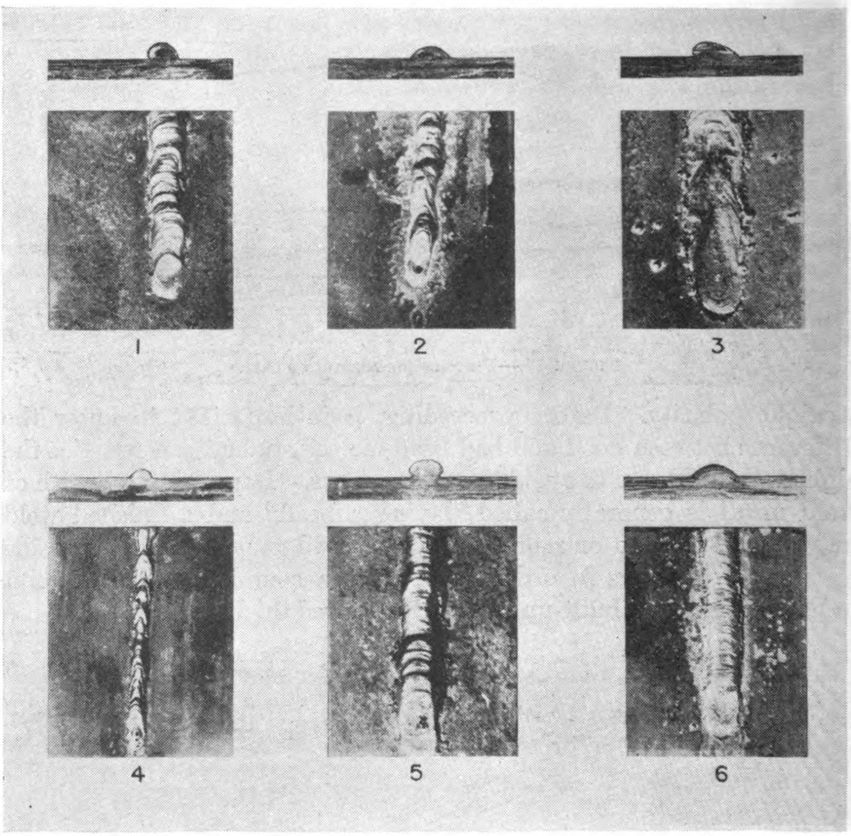

FIGURE 81.—Examples of good and bad beads.

weld. Feed it down at a rate which will provide the correct amount of additional metal in the joint with sufficient penetration to insure ample and uniform fusion. Study the photographs of actual beads in figure 81.

(*a*) Bead No. 1 shows the results when insufficient current is used. Note the excessive height of deposited metal with excess metal overlapping along the edges of the bead, and the shallow crater which indicates insufficient penetration.

(*b*) Bead No. 2 is the result of holding too long an arc. Note the poor penetration and irregularity of form of the bead. Holding too short an arc may cause some porosity but too long an arc is worse, particularly when working with bare electrodes.

(*c*) Bead No. 3 is the effect produced when using too high current. Note the excessive spattering which wastes electrodes and requires extra cleaning. Also note the evidence of weakening undercutting along the edges of the bead. Quality should not be sacrificed for speed.

(*d*) Bead No. 4 results when the electrode is moved too rapidly along the line of weld. Note the small amount of metal deposited, the irregularity of the bead, and the poor penetration.

(*e*) Bead No. 5 is the result when progress along the line of weld is too slow. Note the piling up of metal as a result of holding the

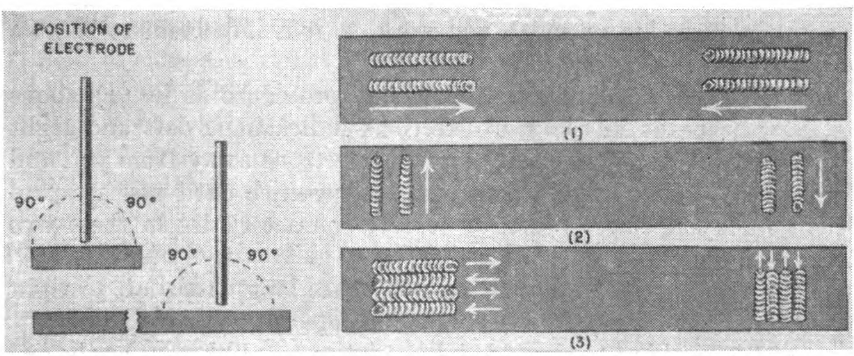

FIGURE 82.—Method of practicing short beads.

electrode too long in one spot. Also note how the deposited metal overlaps along the edges of the bead.

(*f*) Bead No. 6 is an example of a good welding head. It is smooth and regular in form. The edges are sharply defined without overlapping or undercutting along the edges. Spattering is reduced to the minimum. The deep crater indicates that the weld metal has penetrated thoroughly into the plate to insure good fusion with the work metal.

(4) Study these examples until you thoroughly understand the difference between good and bad beads and the reasons for unsatisfactory performance. Then practice until you can consistently match the bead illustrated in No. 6.

b. *Procedure*.—(1) Holding the electrode perpendicular to the work, as indicated in figure 82, lay a dozen beads 1½ inches long, about ½ inch apart, working from left to right, as indicated at the left in (1), figure 82. Then lay another dozen similar beads, working from right to left as indicated at the right in (1), figure 82. The electrode must be fed down into the crater to maintain a short arc at all times, and progress along the line of weld must be at the correct rate of speed to result in a bead of proper characteristics.

(2) Wire-brush the beads and compare them with the beads in figure 81 to determine what you may be doing incorrectly. Inspect the craters at the ends of all beads. In this exercise the crater should be about $\frac{3}{16}$ inch in diameter and $\frac{1}{16}$ inch deep in the work metal. Saw through some of the beads and compare the cross sections with the diagram in figure 80. Chip off some of the beads with hammer and chisel to determine whether or not penetration is uniform for their full length. When you have discovered your weaknesses, practice this exercise over and over until you can consistently lay these short beads perfectly in either direction. In practical work you will not always be able to choose the direction in which you work, so it is important to be able to lay a bead in any direction.

(3) On another plate repeat the same procedure as in (1) above but lay the beads in the two directions indicated at left and right ends of (2), figure 82. First, move the electrode away from you and then toward you. Inspect as before and practice until you are proficient in laying short beads of correct characteristics in these two directions.

(4) On another plate lay beads $1\frac{1}{2}$ inches long, from left to right and from right to left alternately, as indicated at the left end of (3), figure 82. In this exercise it is important to break the arc at the end of each bead and wire-brush that bead thoroughly before laying the next one in the opposite direction, immediately alongside the previous one. Continue this exercise until you have both sides of the plate covered with a smooth, regular pad of weld metal having thorough penetration into the plate. Saw through the padded plate frequently to check for penetration and uniform thickness of weld metal which is free from porosity.

(5) On another plate repeat the same procedure as in (4) above, but lay the alternate beads away from you and toward you, as indicated at the right end (3), figure 82. Inspect the pads as before and continue until you are proficient.

c. Varieties of beads.—The fundamentals of laying a good bead have been described. If the student has become proficient in these procedures, the various types and combinations of beads used in practical welding will come easily with further practice. It is beyond the scope of this manual to provide a complete course of exercises in laying the various beads used in making arc welded joints. Complete exercise courses are furnished in the literature of the manufacturers of arc welding equipment, and cover: laying long beads, weaving the bead, building up pads of metal, welding butt joints (various types), welding outside corner joints, welding inside corner joints, and welding lap joints, all with the welds in the horizontal or flat position. Exercises are also given for the same welds in the vertical and overhead position, both with bare and coated electrodes, some of which require reverse polarity for best results. Still other practice exercises are prescribed for welding light-gage steel, which requires a small electrode, low current and special care to avoid "burning through" the thin metal.

d. Vertical and overhead welds.—These are more difficult than flat welds and require more practice on the part of the welder before they can be accomplished successfully. The molten metal must be controlled in such a way that it will not become fluid enough to run out of the joint. This is done by moving the electrode away from the molten pool until it solidifies without interrupting the arc. This requires a fraction of a second, following which the arc is returned to the nonfluid metal and another deposit made. Electrodes no larger than 3/16 inch are used for vertical and overhead welding. With bare electrodes more current is generally used than for flat welding; with coated rods less current is ordinarily used. Reverse polarity is often an advantage. In vertical welding of thin stock (up to 3/16 inch), better results are usually obtained by starting at the top and welding down, with a single straight bead. Heavier stock is welded from the bottom up; the metal already deposited furnishes support for the molten metal as the weld progresses. The first pass is a straight bead and subsequent beads are woven. Overhead welds are built up by a series of straight beads; they are not woven.

53. Arc welding cast iron, alloy steels, and nonferrous metals.—*a.* While the great bulk of arc welding is done on low- or medium-carbon steel, the process is used to some extent for repairing iron castings, welding alloy steels (such as stainless steels), and for welding nonferrous metals, such as aluminum, copper, brass, and bronze. These welding processes require special electrodes containing proper shielding and fluxing elements, as well as excess alloying elements to replace those burned out. Different operating techniques must be employed because of the lower melting points and greater fluidity of most of these metals, and because their rates of expansion and contraction when heated differ from those of steel. Most nonferrous metals cannot be welded in the overhead position because the arc transfers larger globules of these metals than of steel, and so must be assisted by gravity in depositing the metal.

b. The melting points of the more commonly welded metals are given in table V. These temperatures are approximate except for the pure metals. The melting point of every alloy varies according to its composition.

TABLE V

Metal	Melting point ° F.	Metal	Melting point ° F.
Aluminum	1, 215	Nickel	2, 646
Brass	1, 742	Steel (mild)	2, 768
Bronze	1, 652	Steel (hard)	2, 552
Copper	1, 981	Tin	450
Cast iron	2, 192	Wrought iron	2, 730
Lead	621	Zinc	786

c. Copper, cast iron, nickel, and wrought iron expand at about the same rate as steel when heated. Brass and bronze expand about one and one-half times as much; aluminum and tin about twice as much; lead about two and one-half times as much; and zinc about three times as much.

Appendix

BIBLIOGRAPHY

In the preparation of this manual the following sources have been consulted for illustrations and text material. They contain more detailed information than is contained herein, and it is suggested that it would be advantageous for the student to consult them as collateral reading.

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(For explanation of symbols, see FM 21–6.)

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