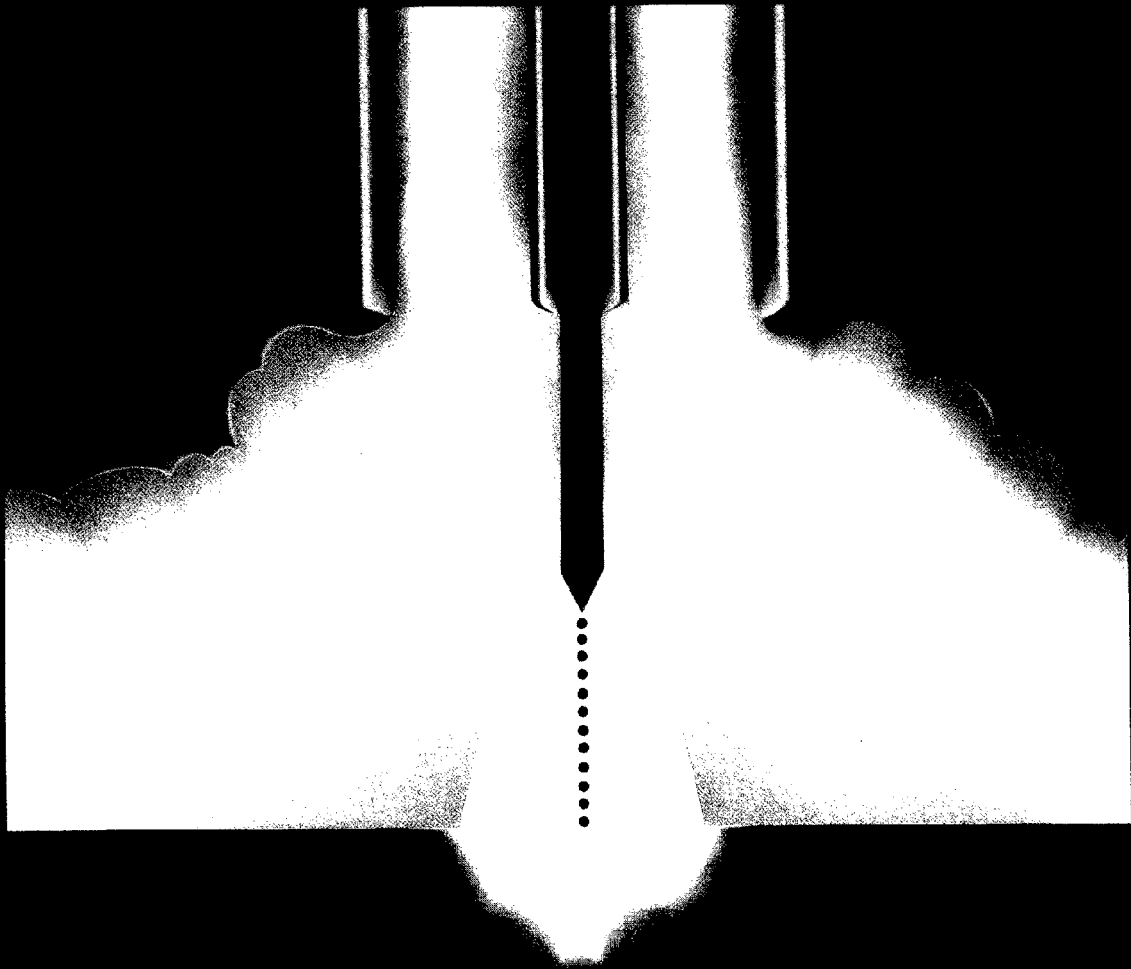


Recommended Practices for Shielding Gases for Welding and Plasma Arc Cutting



American Welding Society

Keywords — shielding gases, plasma, gas, purging
gas, dew point

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Recommended Practices for Shielding Gases for Welding and Plasma Arc Cutting

Prepared by
AWS Committee on Arc Welding and Cutting

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Abstract

This document is concerned with six industrial gases: argon (Ar), carbon dioxide (CO₂), helium (He), hydrogen (H₂), nitrogen (N₂), and oxygen (O₂). Properties, uses, safe handling, distribution, mixtures and effects on arc characteristics and welds are presented for flux cored arc welding (FCAW), gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), electrogas welding (EGW), plasma arc welding (PAW), and plasma arc cutting (PAC). Gas purging, gas distribution and safety practices are also covered.



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Foreword

(This Foreword is not a part of ANSI/AWS C5.10-94, *Recommended Practices for Shielding Gases for Welding and Plasma Arc Cutting*, but is included for information purposes only.)

These recommended practices, prepared by the AWS Subcommittee on Shielding Gases of the AWS Committee on Arc Welding and Cutting, are intended as a guide in the use of shielding gases. They should be supplemented with the instructions provided by manufacturers of the shielding gases or welding and cutting equipment.

The Shielding Gases Subcommittee has prepared these recommended practices as guidelines for utilizing shielding gases in a safe and efficient manner. The subcommittee is continuing its activities to provide additional data. This document will be revised on a periodic basis.

Communications on these recommended practices are welcome and should be addressed to: Secretary, AWS Committee on Arc Welding and Cutting, American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126.

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Recommended Practices for Shielding Gases for Welding and Plasma Arc Cutting

1. Scope

The intent of this publication is to present basic concepts relating to gas usage for each arc process and its variations. These concepts, combined with basic information about arc welding or cutting processes, will enable the reader to make an educated decision when selecting a gas.¹ In addition, safe practices and specific technical data are included as guides in an effort to establish optimum operation of the selected arc welding or cutting process.

The reader will learn the process and specific advantages and disadvantages for each. Standard welding and cutting equipment are normally designed to permit the use of several gases.

Note: The scope of this document does not include information for oxyfuel or heat treating processes.

2. Purpose

The purpose of a gas is twofold, to promote a desirable weldment or cut and to protect the molten metal from atmospheric contamination. The basic properties of gases as related to the performance of the welding or cutting process include ionization potential (see Table 1), thermal properties (see Table 1), and reactivity.

Ionization Potential is the energy necessary to remove an electron from a gas atom. The ionization potential of a gas at arc temperatures influences the arc voltage as well as the thermal energy delivered to the weld. As ionization potential increases, greater welding voltage is necessary

to sustain the arc. The ionization potential of helium (24.5 eV) is much higher than that of argon (15.7 eV); therefore, it is easier to start an arc with argon shielding.

Thermal Conductivity of a gas is its ability to conduct heat. Argon, which has a low thermal conductivity, produces an arc that has a narrow hot core and a cooler outer zone. Helium has a high thermal conductivity and conducts heat outward from the core, resulting in a wider, hotter arc core.

Reactivity, as it applies to shielding gases, is a comparative measurement of how readily a given shielding gas will react with the molten weld metal. Argon and helium are inert and therefore have no effect on the weld metal. The following gases react with metals, and their properties are listed:

(1) *Hydrogen*, a reducing gas, will preferentially react with metallic oxides of the molten weld metal, thereby helping to prevent oxide inclusion; however, when used on hardened steels, this shielding gas can produce some adverse effects, such as underbead cracking.

(2) *Oxygen* and *carbon dioxide* fall into a category of reactive gases known as oxidizers; they will react with the molten metal in the arc and in the weld pool to form oxides.

(3) *Nitrogen*, when exposed to elevated temperatures associated with welding, will react with carbon steel to form nitrates.

2.1 Argon. Argon (Ar) is heavier than air, is not life sustaining, is chemically inert, is colorless and odorless both as a gas and as a liquid, and constitutes slightly less than one percent of the earth's atmosphere. Argon promotes good arc initiation due to its low ionization potential, making it an ideal shield against atmospheric contamination in a number of industrial and welding processes.

1. In this document, the use of the term *gas* also includes "gas mixture."

soluble in liquids than any other gas. Helium is used for shielding in some welding applications.

2.3 Hydrogen. Hydrogen (H_2), the lightest known element, is chemically active and not life sustaining; its high heat conductivity makes its mixtures useful in selected welding and cutting applications. See **WARNING 5.3(4)**.

2.4 Nitrogen. Nitrogen (N_2), which is lighter than air, is not life sustaining and accounts for 78 percent of the earth's atmosphere by volume. Nitrogen will combine with other elements at high temperatures, therefore it is not recommended as a primary gas, but is used in combination with other gases for selected applications. Nitrogen is generally used as protection against atmospheric contamination in many nonwelding applications.

2.5 Oxygen. Oxygen (O_2), which is heavier than air, accounts for 50 percent of the earth's crust and 21 percent,

elements except the inert gases. Additions of oxygen to inert gases influence process characteristics of gas metal arc welding (GMAW) and flux cored arc welding (FCAW).

2.6 Carbon Dioxide. Carbon dioxide (CO_2), which is heavier than air and will not sustain life, is a colorless gas with a faintly pungent odor and somewhat acidic taste. Most reactive gases cannot be used alone for shielding; carbon dioxide is an exception. It is extensively used independently as well as a component of gas mixtures. Carbon dioxide cannot be used for GMAW spray transfer. It is used only for short circuit or globular transfer.

2.6.1 Gas Purity (see Table 2). The purity of carbon dioxide can vary considerably, depending upon the process by which it is manufactured. Standards have been established that specify the degree of purity for welding grade carbon dioxide for arc shielding.

Table 2
Gas Type, Purity, and Dew Point Requirements for Shielding Gas Components

Gas	AWS Class	Product State	Minimum Purity (percent)	Maximum Moisture (ppm)	Approximate Dewpoint at Maximum Moisture Content		CGA Class
					°F	°C	
Argon	SG-A	Gas	99.997	10.5	-76	-60	Type I: G-11.1 Grade C
		Liquid	99.997	10.5	-76	-60	Type II: G-11.1 Grade C
Carbon Dioxide	SG-C	Gas	99.8	32	-60	-51	{ G-6.2 Grade H
		Liquid	99.8	32	-60	-51	
Helium	SG-He	Gas	99.995	15	-71	-57	Type I: Grade L
		Liquid	99.995 ^b	15	-71	-57	Type II: Grade L
Hydrogen	SG-H	Gas	99.95	32	-60	-51	Type I: G-5.3 Grade B
		Liquid	99.95 ^c	32	-60	-51	Type II: G-5.3 Grade A
Nitrogen	SG-N	Gas	99.9	32	-60	-51	Type I: G-10.5 Grade F
		Liquid	99.998	4	-90	-68	Type II: G-10.5 Grade L
Oxygen	SG-O	Gas	99.5	noncondensed	-54	-48	Type I: G-4.3 Grade B
		Liquid	99.5	noncondensed	-82	-63	Type II: G-4.3 Grade B

Notes:

a. Moisture specifications are guaranteed at full cylinder pressure, at which the cylinder is analyzed.

b. Including neon

c. Including helium

The purity specified for welding grade carbon dioxide gives a dew point temperature of -60°F (-51°C) (34 ppm moisture). The total impurities in carbon dioxide should not exceed 50 ppm.

2.6.2 Dew Point. Dew Point is the temperature at which, in a given mixture of gas and water vapor, water will condense out of the gas. Such condensation is sometimes a critical factor in a particular application. Table 3 shows the dew point of carbon dioxide versus the percent of moisture in carbon dioxide.

Table 3
Dew Point of Carbon Dioxide Versus Percent of Moisture in Carbon Dioxide

Dewpoint °F	% Moisture by Weight	ppm Moisture in CO ₂
-90	0.000353	4
-80	0.00078	8
-70	0.00166	17
-60	0.0034	34
-50	0.0067	67
-40	0.0128	128
-30	0.0235	235
-20	0.0422	422
-10	0.074	740

2.7 Air. Air is a gaseous mixture comprised of approximately 78 percent nitrogen, 21 percent oxygen, and a balance of various amounts of argon, hydrogen, carbon dioxide, and rare gases such as neon, krypton, and xenon. Air cannot be used as a shielding gas for welding. Some of the components of air will react or combine with some base metal and weld metal elements to form unwanted compounds which reduce the strength and integrity of the weld deposit.

Because of the high percentage of nitrogen in air, air is commonly used as the low-cost substitute for nitrogen or oxygen for plasma arc cutting (PAC) of carbon steels.

3. Applications of Gas in Welding and Cutting

3.1 Gas Tungsten Arc Welding

3.1.1 Process Description. Gas tungsten arc welding (GTAW) is an arc welding process that uses an arc between a tungsten electrode (nonconsumable) and the weld pool (Figure 1A). Shielding is usually provided by an inert gas. Welds are produced with or without the addition of filler metals. Both manual and automatic techniques are used. GTAW can produce high-quality welds and offers these specific advantages over other arc welding processes:

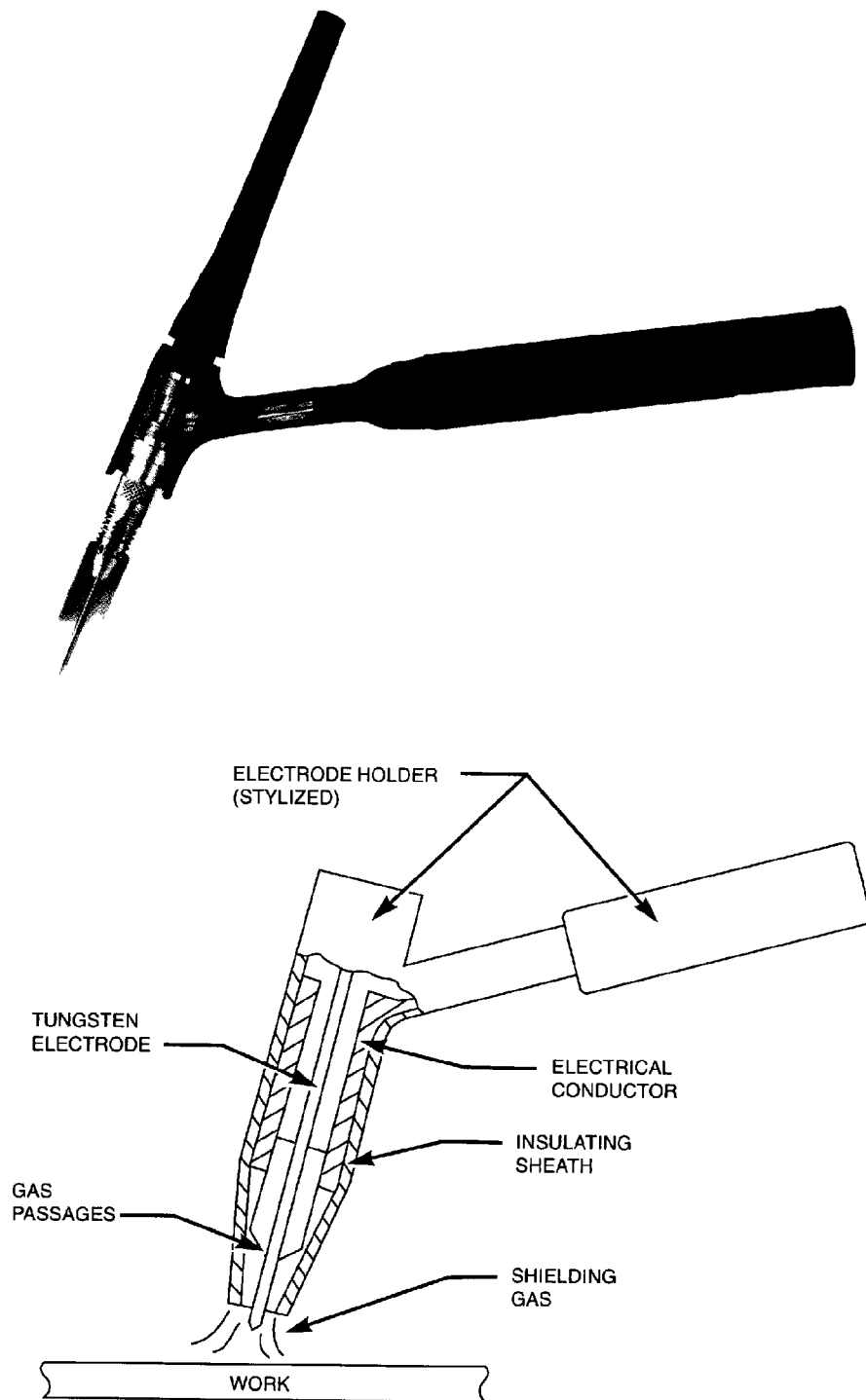


Figure 1A—Gas Tungsten Arc Welding Process

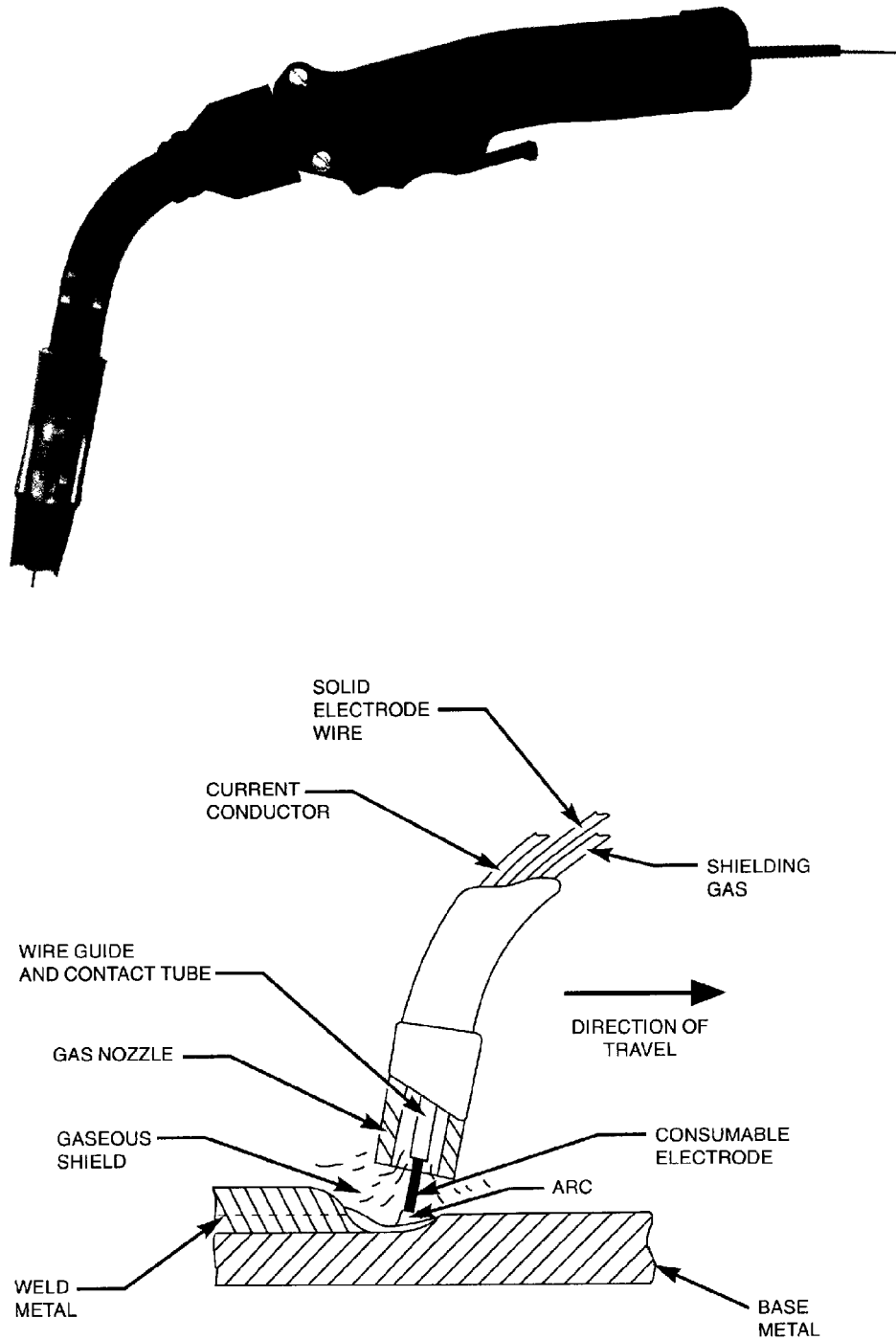


Figure 1B—Gas Metal Arc Welding Process

- (1) Can be used to weld most metals and alloys (see Table 4)
- (2) Is easily used in all welding positions
- (3) Provides excellent control on thin and intricate parts
- (4) Produces no slag or spatter. Postweld cleaning frequently is not required
- (5) May be used without addition of filler metal in many applications
- (6) Is easily automated
- (7) Is the preferred process for critical applications, with ferrous and nonferrous materials

3.1.2 Shielding Gases

(1) **Argon.** Argon, an inert gas, is the most commonly used shielding gas for the GTAW process. It has low thermal conductivity and provides a narrow arc column. Argon affords welders considerable manipulative flexibility. Its low arc voltage characteristic permits arc length variations with minimal influence on arc energy and weld bead shape. Argon provides relatively easy arc initiation due to its low ionization potential. Argon is preferred over helium for alternating current (ac) welding applications because of enhanced cleaning action, arc stability, and weld appearance. Argon is heavier than air, providing adequate shielding at lower flow rates than helium.

(2) **Helium.** Helium is a chemically inert shielding gas that has high thermal conductivity and high ionization potential. Arc voltages are higher with helium than argon

for a given current setting and arc length. This increases the heat input which affects bead width and depth of arc penetration. For this reason, helium is often mixed with argon for welding base metals with high melting temperatures or high thermal conductivity.

When using direct current electrode negative (DCEN) for mechanized GTAW of aluminum, helium shielding provides greater depth of fusion and higher travel speeds than argon. Mechanical removal of surface oxides is generally required when using GTAW with DCEN and helium shielding gas for welding aluminum.

Although it offers definite advantages for some applications, helium produces a less stable arc and less desirable arc starting characteristics than argon. Helium usually requires higher shielding flow rates than argon.

(3) **Argon+Helium.** Helium is added to argon to take advantage of the best operating characteristics of each gas. The superior arc starting and stable arc characteristics of argon with helium's higher thermal conductivity produce high-quality gas tungsten arc welds on aluminum using alternating current. Increased travel speeds and greater depth of fusion, for both manual and mechanized welding of nonferrous alloys, can be produced as helium content is increased. Helium content usually ranges between 25 and 75 percent.

(4) **Argon+Hydrogen.** Additions of hydrogen increase the heat input, permitting faster travel, increased depth of fusion, better wetting action, and broader weld bead profile. Hydrogen in argon mixtures provides a reducing

Table 4
Shielding Gases For Gas Tungsten Arc Welding

Metal	Positions	Polarity	Electrode	Shielding Gases
Aluminum Alloys	all	AC	pure, zirconia	argon, argon + helium, helium + argon
Copper & Copper Alloys	all under 1/8 in.	DCEN AC	thoria ¹ pure, zirconia	argon, argon + helium, helium, helium + argon argon, helium + argon
Nickel & Nickel Alloys	all	DCEN	thoria ¹	argon, argon + helium, helium + argon, argon + hydrogen (5% max)
Magnesium Alloys	all	AC	pure, zirconia	argon, argon + helium, helium + argon
Carbon & Low Alloy Steels	all	DCEN	thoria ¹	argon, argon + helium
Stainless Steels	all	DCEN	thoria ¹	argon, argon + helium, argon + hydrogen (5% max) ²
Titanium Alloys	all	DCEN	thoria ¹	argon, argon + helium

Notes:

1. Tungsten alloyed with certain rare earth elements may also be used. See ANSI/AWS A5.12.

2. Austenitic steels only.

atmosphere in the arc, removing oxygen from the weld area. A typical argon-hydrogen mixture is 95 percent argon and 5 percent hydrogen. Mixtures of argon and hydrogen are often used to weld metals such as austenitic stainless steels, nickel, and nickel alloys. Argon-hydrogen mixtures should not be used to weld carbon or low alloy steels.

Hydrogen mixtures are mainly used on high-nickel alloy steels. Purging gases containing hydrogen should not be used with copper and its alloys.

Table 18 lists typical base metals with their common purging gases. Additional consideration must also be given to weld accessibility (location), joint design, and the welding processes.

Special safety precautions are required when mixing argon and hydrogen. **CAUTION: Users should NOT mix argon and hydrogen from separate cylinders without the use of approved mixing equipment. See WARNING 5.3(4).**

3.1.2.1 Shielding Gas Flow Rates. Shielding gas flow rates are influenced by the following:

- (1) Welding or cutting process
- (2) Type of base metal
- (3) Type and position of joint
- (4) Torch position
- (5) Amperage
- (6) Type of gas
- (7) Gas nozzle type and size
- (8) Manual or automatic welding mode

For example, argon can be used for GTAW on all base metals and requires a flow rate from 10 to 35 scfh (5 to 16 lpm). Helium is lighter than argon and therefore may require higher flow rates.

3.2 Gas Metal Arc Welding

3.2.1 Process Description. Gas metal arc welding (GMAW) is a welding process that uses an arc between a continuous filler metal electrode and the weld pool, (see Figure 1B). The arc continuously melts the wire as it is fed to the weld pool and is protected from the atmosphere by a flow of shielding gas.

3.2.2 Process Variations and Metal Transfer. The GMAW process includes distinctive metal transfer types: short circuiting transfer, globular transfer, normal spray transfer, pulsed spray transfer, and rotational current high-density spray (high deposition) transfer. Factors that determine metal transfer are current, wire diameter, arc length, power supply characteristics, and shielding gas.

3.2.3 Short Circuiting Transfer. Short circuiting transfer uses low welding current and arc voltage. The arc characteristics produce a small, fast-solidifying weld pool that is generally suited for the joining of thin base metals

in all positions, and for the filling of wide root openings. With material that is greater than 1/8 in. (3.2 mm), extreme care must be taken to prevent incomplete fusion. Since heat input is usually low, distortion of the workpiece is minimized.

The electrode feeds at a constant speed and contacts the workpiece or molten pool, at which time a short circuit occurs. The current from the power supply increases and heats the wire to a point where the end of the wire melts off, creating an arc between the wire end and the workpiece. There is no metal transfer across the arc (see Figure 2). The welding wire short circuiting sequence repeats itself from 50 to 250 times per second.

3.2.4 Globular Transfer. Globular transfer takes place when current and arc voltage are between the short circuiting and spray transfer range, regardless of the type of shielding gas. Carbon dioxide yields this type of transfer at all usable welding currents above the short circuiting range. Globular transfer is characterized by a drop size approximately 2 to 4 times the diameter of the electrode (see Figure 3). The mechanism producing globular transfer is generated in a specific current and voltage range. With carbon dioxide, the droplet is not propelled across the arc. The repelling force of the arc acting toward the wire end tends to hold the droplet on the end of the wire until it transfers by gravity.

3.2.5 Spray Transfer. In an argon-rich shielding gas, (see Table 5) the electrode metal transfer changes from globular to spray as welding current increases for any given electrode diameter. The change takes place at a value called the *globular to spray transition current*. Spray transfer in argon has a constricted arc column and pointed electrode tip (see Figure 4).

Molten metal transfers across the arc as small droplets. The metal transfer is axially directed to the workpiece. Since the metal droplets are small, the transfer rate can be as high as several hundred droplets per second.

3.2.6 Pulsed Spray Transfer. In pulsed spray welding, the shielding gas must be able to support spray transfer. With pulsed spray transfer, the current is cycled between a high and low value at a rate of up to several hundred cycles per second. The low level current is below the spray transition current, while the high current pulse is above the spray transition current. Metal is transferred to the workpiece only during the high current pulse. Ideally, one droplet is transferred during each pulse (see Figure 5).

The rate of pulsing can vary depending on the power supply design and control circuitry. The background current maintains the arc. The resulting lower average current levels allow the welding of base metals less than 1/8 in. (3.2 mm) with a spray-type metal transfer.

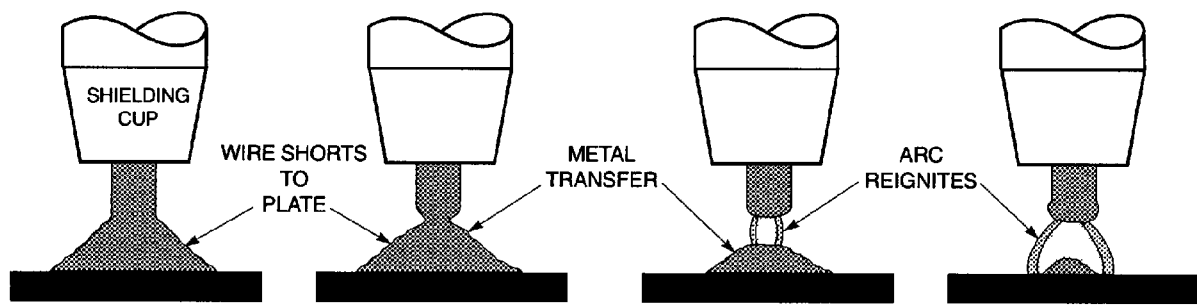


Figure 2—Short Circuiting Transfer

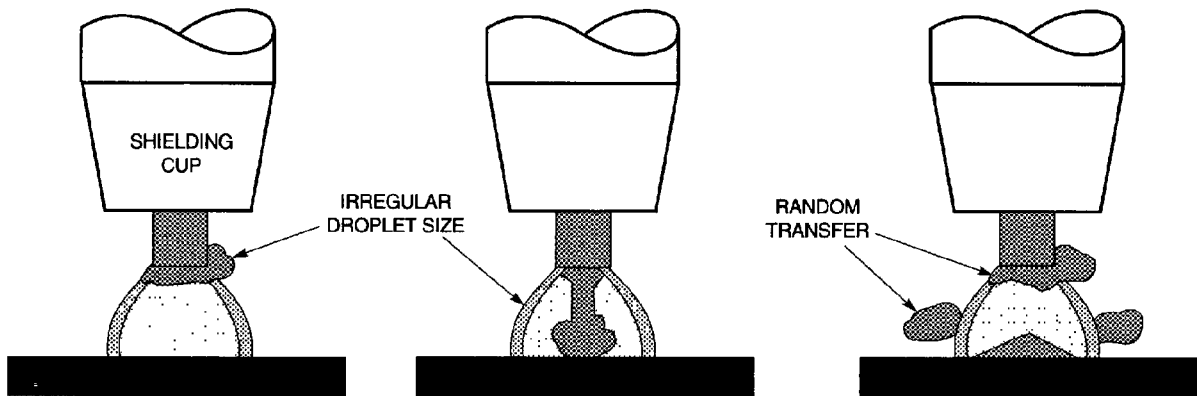


Figure 3—Globular Transfer

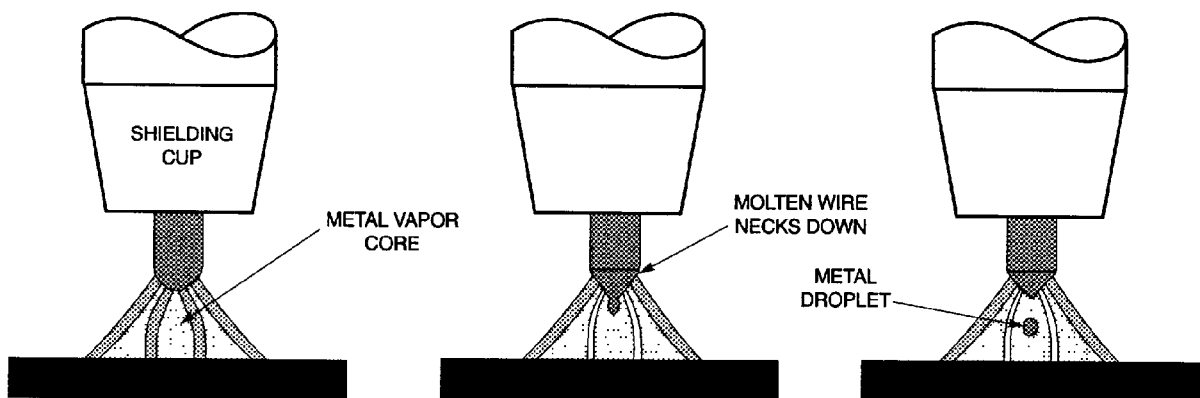


Figure 4—Spray Transfer

Table 5
Globular-to-Spray Transition Currents for Various Electrodes

Electrode Type	Electrode Diameter		Shielding Gas	Spray Arc Transition Current
	in.	mm		
Low-Carbon Steel	0.023	0.6	98% Argon + 2% O ₂	135
	0.030	0.8	98% Argon + 2% O ₂	150
	0.035	0.9	98% Argon + 2% O ₂	165
	0.045	1.2	98% Argon + 2% O ₂	220
	0.062	1.6	98% Argon + 2% O ₂	275
	0.035	0.9	95% Argon + 5% O ₂	155
	0.045	1.2	95% Argon + 5% O ₂	200
	0.062	1.6	95% Argon + 5% O ₂	265
	0.035	0.9	92% Argon + 8% CO ₂	175
	0.045	1.2	92% Argon + 8% CO ₂	225
	0.062	1.6	92% Argon + 8% CO ₂	290
	0.035	0.9	85% Argon + 15% CO ₂	180
	0.045	1.2	85% Argon + 15% CO ₂	240
	0.062	1.6	85% Argon + 15% CO ₂	295
	0.035	0.9	80% Argon + 20% CO ₂	195
	0.045	1.2	80% Argon + 20% CO ₂	255
	0.062	1.6	80% Argon + 20% CO ₂	345
Stainless Steel	0.035	0.9	99% Argon + 1% O ₂	150
	0.045	1.2	99% Argon + 1% O ₂	195
	0.062	1.6	99% Argon + 1% O ₂	265
	0.035	0.9	Argon + Helium + CO ₂	160
	0.045	1.2	Argon + Helium + CO ₂	205
	0.062	1.6	Argon + Helium + CO	280
	0.035	0.9	Argon + H ₂ + CO ₂	145
	0.045	1.2	Argon + H ₂ + CO ₂	185
	0.062	1.6	Argon + H ₂ + CO ₂	255
Aluminum	0.030	0.8	Argon	95
	0.047	1.2	Argon	13
	0.062	1.6	Argon	180
Deoxidized Copper	0.035	0.9	Argon	180
	0.045	1.2	Argon	210
	0.062	1.6	Argon	31
Silicon Bronze	0.035	0.9	Argon	165
	0.045	1.2	Argon	205
	0.062	1.6	Argon	270

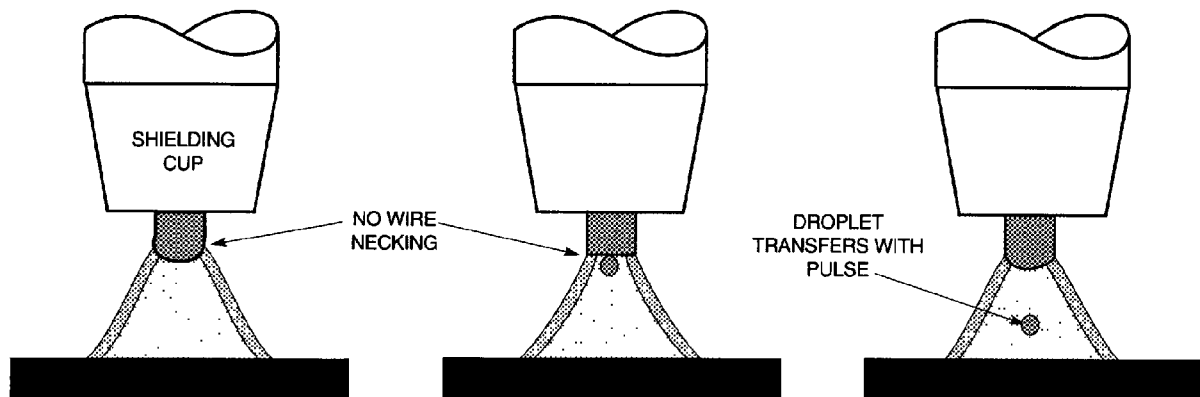


Figure 5—Pulsed Spray Transfer

3.2.7 High-Current-Density Spray Transfer. High-current-density spray transfer is a name given to a GMAW mode having specific arc characteristics created by a combination of wire feed speed, electrode extension, and shielding gas. Filler metal deposition rates range between 18 and 30 lb/hr (8 and 14 kg/hr) with an upper limit of 40 lb/hr (18 kg/hr). The arc characteristics of high-density transfer are further divided into rotational spray transfer and nonrotational spray transfer.

(1) High-Current-Density Rotational Spray Transfer. When using a solid carbon steel wire, a high wire feed speed is combined with a long electrode extension and an argon+carbon dioxide+oxygen or argon+ oxygen shielding gas to create an arc phenomenon known as *rotational spray arc transfer*. The long contact tube to workpiece distance produces resistance heating of the wire electrode and causes the electrode end to become molten. The electromechanical forces generated by the current flow in the wire cause the molten wire end to rotate in a helical path (see Figure 6). The shielding gas affects the rotational transition current by changing the surface tension at the molten electrode end. The gases named above produce rotational spray transfer at deposition rates of 18 to 30 lb/hr (8 to 14 kg/hr) using contact tip to workpiece distances of 7/8 to 1-1/2 in. (22 to 38 mm).

(2) High-Current-Density Nonrotational Spray Transfer. Nonrotational high-current-density spray transfer is produced when the molten wire end does not rotate. Rotation is suppressed when the thermal conductivity of the shielding gas increases and the surface tension of the molten electrode end increases. The droplet rate will decrease, and larger droplets will transfer across the arc. Shielding gases with higher carbon dioxide or helium

additions will raise the rotational spray transition current, thereby suppressing the tendency to rotate. The arc is elongated and diffused but looks similar to conventional spray transfer. The plasma stream is axial and narrower than that produced by rotational spray transfer. This more concentrated heat source can produce an increased depth of fusion compared with rotational spray transfer at the same welding current.

3.2.8 Shielding Gases. See Table 6.

3.2.8.1 Introduction. The atmosphere in the welding zone is displaced by a shielding gas to prevent contamination of the molten weld pool and filler metal. This contamination is mainly caused by nitrogen, oxygen, and water vapor present in the atmosphere.

Nitrogen in solidified steel reduces the ductility and impact strength of the weld metal and can cause cracking. Nitrogen can also cause weld porosity.

Oxygen in steel may combine with carbon in the steel to form carbon monoxide (CO). This gas may be trapped in the solidified weld pool, causing porosity. In addition, oxygen can combine with other elements in steel and form compounds that produce nonmetallic inclusions in the weld metal.

Hydrogen, present in water vapor, is absorbed by molten steel and can produce porosity or underbead cracking on some base metals.

To avoid problems associated with contamination of the weld pool, three basic gases are used for shielding. These gases are argon, helium, and carbon dioxide. Small additions of oxygen and hydrogen have proven beneficial for some applications. Of these gases, only argon and helium are chemically inert.

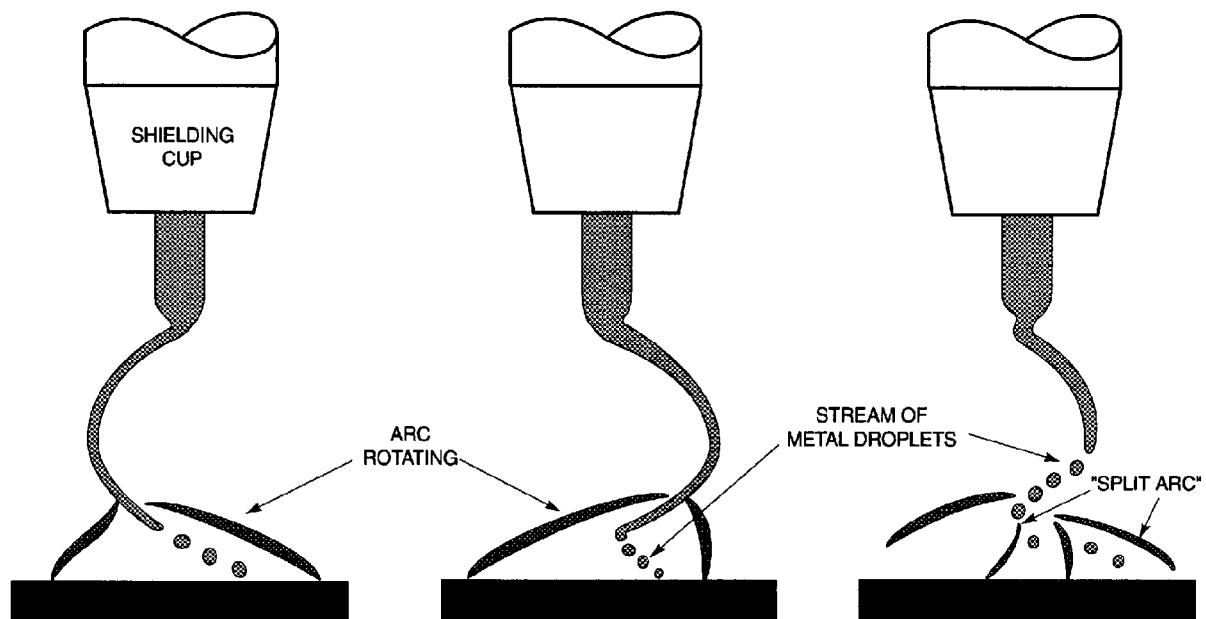


Figure 6—Rotational Spray Transfer

Table 6
Gas Selection for Gas Metal Arc Welding

Metal Type	Thickness	Transfer Mode	Recommended Shielding Gas	Advantages/Description
Carbon Steel	Up to 14 gauge	Short Circuit	Argon + CO ₂ Argon + CO ₂ + O ₂	Good penetration and distortion control to reduce potential burn-through.
	14 gauge – 1/8 in.	Short Circuit	Argon + 8 to 25% CO ₂ Argon + He + CO ₂	Higher deposition rates without burn-through. Minimum distortion and spatter. Good puddle control for out of position welding.
	Over 1/8 in.	Short Circuit	Carbon Dioxide, Argon + 15 to 25% CO ₂	High welding speeds. Good penetration and puddle control. Applicable for out-of-position welds.
		Short Circuit Globular	Argon + 25% CO ₂	Suitable for high current and high-speed welding.
		Short Circuit	Argon + 50% CO ₂	Deep penetration; low spatter; high travel speeds. Good out-of-position welding.
		Short Circuit Globular (buried arc)	Carbon Dioxide	Deep penetration and fastest travel speeds but with higher melt-through potential. High-current mechanized welding.

(continued)

Table 6 (continued)

Metal Type	Thickness	Transfer Mode	Recommended Shielding Gas	Advantages/Description
Carbon Steel (cont'd)		Spray Transfer	Argon + 1 to 8% O ₂	Good arc stability; produces a more fluid puddle as O ₂ increases; good coalescence and bead contour. Good weld appearance and puddle control.
		Spray Transfer	Argon + 5 to 20% CO ₂	Fluid puddle and oxidizing to weld metal causing higher amounts of slag and scale, as CO ₂ increases. Good arc stability, weld soundness, and increasing width of fusion.
		Short Circuit Spray Transfer	Argon + CO ₂ + O ₂ Argon + He + CO ₂ Helium + Ar + CO ₂	Applicable to both short circuiting and spray transfer modes. Has wide welding current range and good arc performance. Weld puddle has good control which results in improved weld contour.
		High Current Density Rotational	Argon + He + CO ₂ + O ₂ Argon + CO ₂ + O ₂	Used for high deposition rate welding where 15 to 30 lbs/hr. (7 to 14 kg/hr.) is typical. Special welding equipment and techniques are sometimes required to achieve these deposition levels.
	Over 14 gauge	Pulsed Spray	Argon + 2 to 8 % O ₂ Argon + 5 to 20 % CO ₂ Argon + CO ₂ + O ₂ Argon + He + CO ₂	Used for both light-gauge and heavy out-of-position weldments. Achieves good pulse spray stability over a wide range of arc characteristics and deposition ranges.
Low-and High-Alloy Steel	Up to 3/32 in.	Short Circuit	Argon + 8 to 20% CO ₂ Helium + Ar + CO ₂ Argon + CO ₂ + O ₂	Good coalescence and bead contour. Good mechanical properties.
		Short Circuit Globular	Argon + 20 to 50% CO ₂	High welding speeds. Good penetration and puddle control. Applicable for out-of-position welds. Suitable for high-current and high-speed welding.
	Over 3/32 in.	Spray Transfer (High Current Density & Rotational)	Argon + 2% O ₂ Argon + 5 to 10% CO ₂ Argon + CO ₂ + O ₂ Argon + He + CO ₂ + O ₂	Reduces undercutting. Higher deposition rates and improved bead wetting. Deep penetration and good mechanical properties.
		Pulsed Spray	Argon + 2% O ₂ Argon + 5% CO ₂ Argon + CO ₂ + O ₂ Argon + He + CO ₂	Used for both light-gauge and heavy out-of-position weldments. Achieves good pulse spray stability over a wide range of arc characteristics and deposition ranges.
Steel, Stainless, Nickel, Nickel Alloys	Up to 14 gauge	Short Circuit	Argon + 2 to 5% CO ₂	Good control of burn-through and distortion. Used also for spray arc welding. Puddle fluidity sometimes sluggish, depending on the base alloy.

(continued)

Table 6 (continued)

Metal Type	Thickness	Transfer Mode	Recommended Shielding Gas	Advantages/Description
Steel, Stainless, Nickel, Nickel Alloys (cont'd)	Over 14 gauge	Short Circuit	Helium + 7.5 Ar + 2.5 CO ₂ Argon + 2 to 5% CO ₂ Argon + He + CO ₂ Helium + Ar + CO ₂	Low CO ₂ percentages in He mix minimizes carbon pickup, which can cause intergranular corrosion with some alloys. Helium improves wetting action and contour. CO ₂ percentages over 5% should be used with caution on some alloys. Applicable for all position welding.
		Spray Transfer	Argon + 1 to 2% O ₂ Argon + He + CO ₂ Helium + Ar + CO ₂	Good arc stability. Produces a fluid but controllable weld puddle; good coalescence and bead contour. Minimizes undercutting on heavier thicknesses.
Stainless Steel	Over 14 gauge	Pulsed Spray	Argon + 1 to 2% O ₂ Argon + He + CO ₂ Helium + Ar + CO ₂ Argon + CO ₂ + H ₂	Used for both light-gauge and heavy out-of-position weldments. Achieves good pulse spray stability over a wide range of arc characteristics and deposition ranges.
Copper, Copper-Nickel Alloys	Up to 1/8 in.	Short Circuit	Helium + 10% Argon Helium + 25% Argon Argon + Helium	Good arc stability, weld puddle control and wetting.
	Over 1/8 in.	Spray Transfer	Helium + Argon Argon + 50% Helium Argon or Helium	Higher heat input of helium mixtures offset high heat conductivity of heavier gauges. Good wetting and bead contour. Can be used for out of position welding. Using 100% helium on heavier material thickness improves wetting and penetration.
		Pulsed Spray	Argon + Helium	Used for both light-gauge and heavy out-of-position weldments. Achieves good pulse spray stability over a wide range of arc characteristics and deposition ranges.
Aluminum	Up to 1/2 in.	Spray Transfer Pulsed Spray	Argon	Best metal transfer, arc stability and plate cleaning. Little or no spatter. Removes oxides when used with DCEP (Reverse Polarity).
	Over 1/2 in.	Spray Transfer Pulsed Spray	Helium + 20 to 50% Argon Argon + Helium	High-heat input. Produces fluid puddle, flat bead contour and deep penetration. Minimizes porosity.
Magnesium, Titanium & other reactive metals	All thicknesses	Spray Transfer	Argon	Excellent cleaning action. Provides more stable arc than helium-rich mixtures.
		Spray Transfer	Argon + 20 to 70% Helium	Higher heat input and less chance of porosity. More fluid weld puddle and improved wetting.

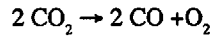
3.2.8.2 Argon. Argon is a chemically inert gas that is used alone and in combination with other gases for welding of ferrous and nonferrous metals. All GMAW modes can use argon or argon mixes to achieve good weldability, required mechanical properties, stable arc characteristics, and improved productivity.

The low ionization potential of argon helps create an excellent current path and superior arc stability. Argon produces a constricted arc column with high current density (see Figure 7), which causes the arc energy to be concentrated over a small surface area. The result is a depth of fusion profile with a distinct fingerlike shape as shown in Figure 8.

Argon is used for nonferrous base metals such as aluminum, nickel, copper, and magnesium alloys, as well as for reactive metals such as zirconium and titanium.

Argon and selected argon mixes provide spray transfer with excellent arc welding stability, penetration and bead profile. When welding ferrous base metals, argon is usually mixed with other gases such as oxygen, helium, and carbon dioxide.

3.2.8.3 Carbon Dioxide. Carbon dioxide is a chemically active gas. In the presence of an intense heat such as a welding arc, it dissociates into carbon monoxide and free oxygen and becomes active. This is shown by the following equation:



The free oxygen, which is available in considerable amounts, reacts with other elements in the weld pool. Although carbon dioxide is an active gas and produces an oxidizing effect, sound welds can be consistently achieved.

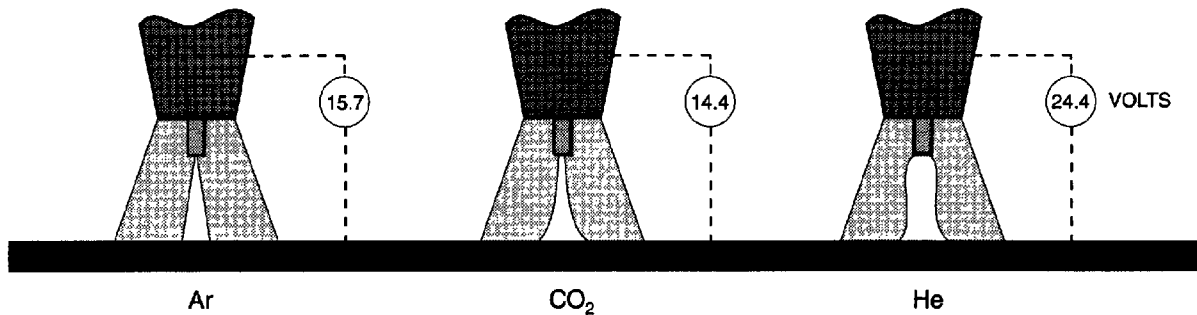


Figure 7—Comparative Ionization Potential and Arc Columns with Argon, Carbon Dioxide, and Helium

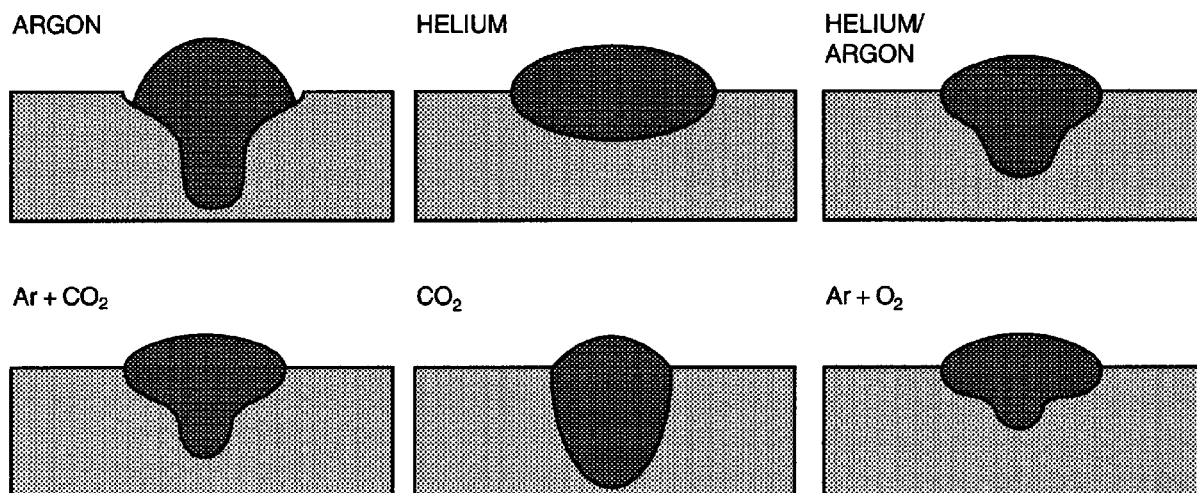


Figure 8—Gas Metal Arc Weld Bead Profiles with Several Shielding Gases

Carbon dioxide is often used for welding carbon steel. Its popularity is due to common availability, low cost, and weld performance. The low cost per unit of gas does not automatically translate to lowest cost per foot of deposited weld. Total weld cost, with carbon dioxide shielding gas, is influenced by bead contour, electrode spatter, and spatter removal.

Carbon dioxide will not support spray transfer. Metal transfer is restricted to short circuiting and globular transfer. The advantage of carbon dioxide is its increased width of fusion compared to argon. The major disadvantage of carbon dioxide is harsh globular transfer with its characteristic spatter (see Figure 9). The weld surface resulting from carbon dioxide shielding is usually heavily oxidized. A welding wire having higher amounts of deoxidizing elements may be needed to compensate for the reactive nature of the gas. Overall, good mechanical properties can be achieved with carbon dioxide.

3.2.8.4 Helium. Helium is a chemically inert gas used for welding applications requiring higher heat inputs.

Helium may improve wetting action, depth of fusion, and travel speeds. It does not produce the stable arc provided by argon. Helium has higher thermal conductivity than argon and a wider arc column. The higher voltage gradient increases heat input compared with argon, promoting increased weld pool fluidity and better wetting action. This is an advantage when welding aluminum, magnesium, and copper alloys.

Helium is often mixed with argon to obtain the advantages of both gases. Argon provides good arc stability and cleaning action, while helium promotes wetting with a broad width of fusion.

3.2.9 Binary Shielding Gas Mixtures. See Table 6.

3.2.9.1 Argon + Oxygen. The addition of small amounts of oxygen to argon greatly stabilizes the welding arc, increases the filler metal droplet rate, lowers the spray transition current, and influences bead shape. The weld pool is more fluid and stays molten longer, allowing the metal to flow out toward the toe of the weld.

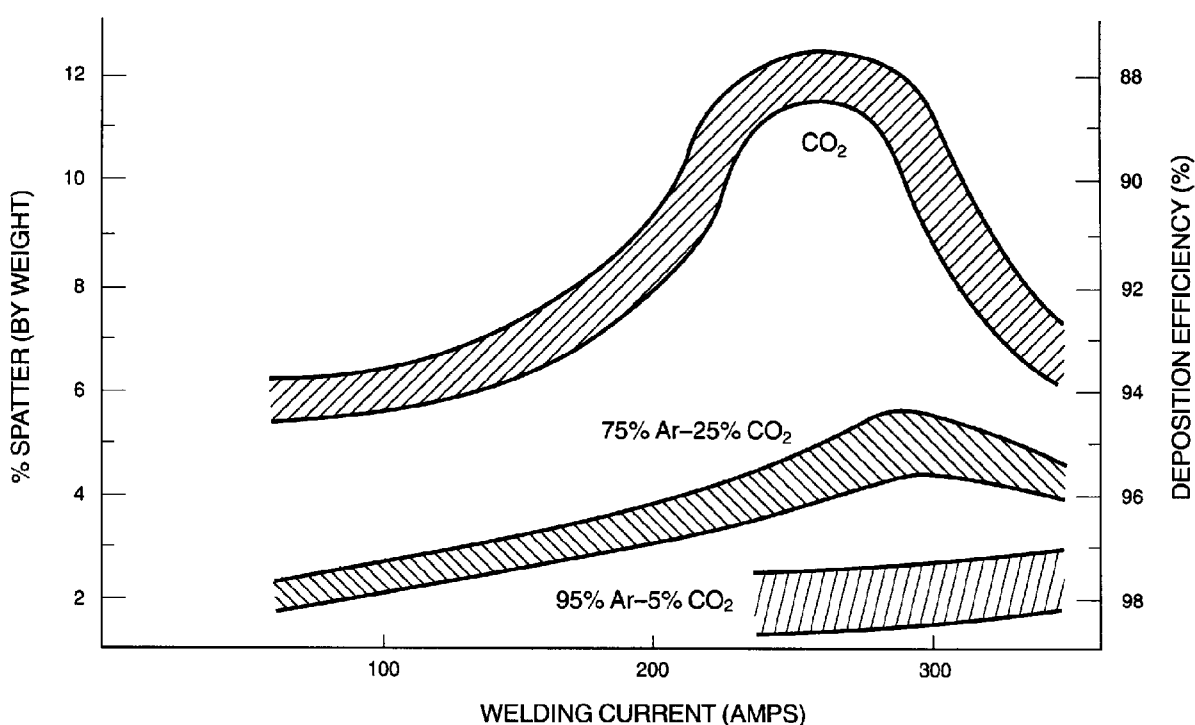


Figure 9—Typical Spatter Levels Versus Welding Current with Three Common Shielding Gases and .045 in. (1.2 mm) Diameter Carbon and Low Alloy Steel Welding Wires

Argon-oxygen shielding gas mixtures are available preblended in liquid form.

(1) **Argon + 1 Percent Oxygen.** This mixture is primarily used for spray transfer on stainless steels. One percent oxygen is usually sufficient to stabilize the arc, increase the droplet rate, and improve bead appearance.

(2) **Argon + 2 Percent Oxygen.** This mixture is used for spray arc welding on carbon steels, low alloy steels, and stainless steels. It provides additional wetting action over the 1 percent oxygen mixture. Mechanical properties and corrosion resistance of welds made with 1 and 2 percent oxygen additions are equivalent.

(3) **Argon + 5 Percent Oxygen.** This mixture provides a more fluid but still controllable weld pool and permits higher travel speeds. It is the most commonly used argon and oxygen mixture for carbon steel welding.

(4) **Argon + 8 Percent Oxygen.** This mixture provides additional depth of fusion over 5 percent oxygen. Slightly lower arc voltage or increased wire feed speed should be used. The higher weld pool fluidity and lower spray transition current of this mixture are advantageous in some applications. This mixture can be used in the short circuiting, spray, and pulsed arc modes of transfer. Greater oxidation of the weld metal, with increased loss of manganese and silicon, should be expected.

3.2.9.2 Argon + Carbon Dioxide Mixtures. The argon+carbon dioxide mixtures are used mainly on carbon and low alloy steels and have *limited* application on stainless steels. Carbon dioxide additions to argon allow increased travel speeds with greater depth and width of fusion. With these mixtures, increasing the amount of carbon dioxide will result in an increase in the level of spatter and a decrease in deposition efficiency. In GMAW with carbon dioxide additions, a slightly higher current level must be provided in order to establish and maintain stable spray transfer. Above approximately 20 percent carbon dioxide, spray transfer becomes unstable and periodic short circuiting and globular transfer occurs.

(1) **Argon + 1 to 10 Percent Carbon Dioxide.** These mixtures are used for spray transfer and short circuiting transfer on a variety of material and thicknesses. A 5 percent mixture may be used for pulsed GMAW of low alloy steels being welded in other than the flat position. With 5 to 10 percent carbon dioxide the arc column is constricted. The arc forces that develop give these mixtures more tolerance to mill scale with a controllable weld pool.

(2) **Argon + 11 to 20 Percent Carbon Dioxide.** This mixture range has been used for a variety of applications on carbon and low alloy steels. Maximum productivity on thin base metals can be achieved within this range. This is done by minimizing excessive melt-through tendency by increasing deposition rates and travel speeds. The lower carbon dioxide percentages also improve deposition efficiency by decreasing spatter loss.

(3) **Argon + 21 to 49 Percent Carbon Dioxide.** This range is commonly used for GMAW with short circuiting transfer on low-carbon steel. It was formulated to provide optimum frequency on short circuiting transfer on common size welding wires.

These mixtures operate well in high-current applications on thick base metal. They promote good arc stability, weld pool control, and weld bead appearance.

(4) **Argon + 50 Percent Carbon Dioxide.** This mixture is used where high heat inputs and increased depth of fusion are needed. Recommended base metal thicknesses are above 1/8 in. (3.2 mm). Fusion is increased in welding positions other than flat welding, utilizing short circuiting transfer. Good wetting and bead shape, without excessive fluidity, are the main advantages for pipe welding applications. Welding on thin-gauge materials has more tendency toward excessive melt-through. When welding at high current levels, the metal transfer is similar to welding in pure carbon dioxide, and unlike welding with argon+carbon dioxide mixtures. Some reduction in spatter loss can be realized due to the argon addition.

3.2.9.3 Argon + Helium. Argon and helium mixtures are used primarily for welding nonferrous base metals, such as reactive metals, aluminum, copper, nickel, magnesium, and their alloys. They are also used for welding some carbon steels. Helium is added to argon to take advantage of the best operating characteristics of each gas. Generally, the thicker the base metal, the higher the percentage of helium. Helium addition to an argon base gas will increase the heat input. (See Figures 8 and 10.) Small percentages of helium, as low as 10 percent, will affect the arc. As helium percentages increase, the arc voltage, spatter, and weld depth-to-width ratio will increase, while minimizing porosity. The argon content must be at least 45 percent when mixed with helium to produce and maintain a stable spray transfer.

(1) **Argon + 25 to 50 Percent Helium.** These mixtures are used for welding nonferrous base metals, when an increase in heat input is sought and weld bead appearance is of primary importance.

(2) **Helium + 10 to 25 Percent Argon.** These mixtures are used for welding copper over 1/2 in. (13 mm) thick and aluminum over 3 in. (75 mm) thick. Their high-heat input improves weld fusion. They may be used for short circuiting transfer with nickel filler metals.

(3) **Helium + 25 to 50 Percent Argon.** These mixtures increase heat input. They are used for welding of aluminum and magnesium greater than 1/2 in. (13 mm) thick in the flat position. They increase heat input and reduce porosity of welds in copper, aluminum, and magnesium.

3.2.10 Ternary Shielding Gas Mixtures. See Table 6.

3.2.10.1 Argon + Oxygen + Carbon Dioxide. Mixtures containing these three components are versatile

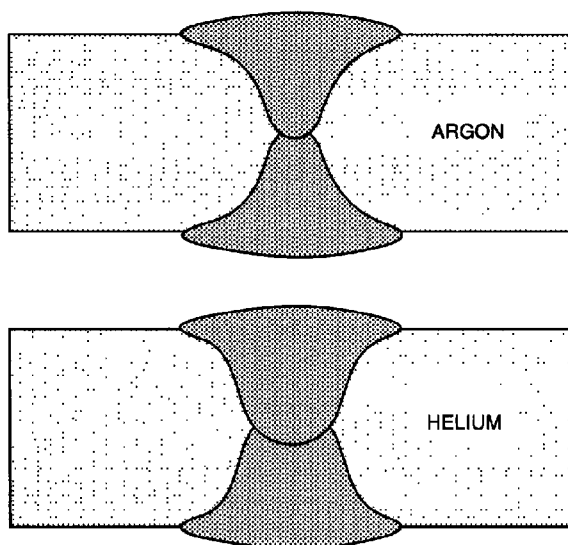


Figure 10—Effect of Argon and Helium Shielding Gases on Gas Metal Arc Weld Profile When Welding Aluminum

due to their ability to function with processes using short circuiting, globular, spray, pulsed, and high-current-density spray transfer. Several ternary compositions are available, and their application will depend on the desired metal transfer methods. The advantage of these mixtures is their ability to shield carbon steel and low alloy steel of all thicknesses using any type of metal transfer. These mixtures produce good welding characteristics and mechanical properties on carbon and low alloy steels. On thin-gauge base metals, the oxygen constituent improves arc stability at low-current levels (30 to 60 amps) permitting the arc to be kept short and controllable. This helps minimize excessive melt-through and distortion by lowering the total heat input into the weld zone.

3.2.10.2 Argon + Helium + Carbon Dioxide. Helium and carbon dioxide additions to argon increase the heat input to the weld, increasing bead wetting and fluidity. The weld bead profile becomes flatter and wider.

(1) Argon + 10 to 40 Percent Helium + 1 to 15 Percent Carbon Dioxide. Mixtures in this range have been developed for pulse spray arc welding of carbon, low alloy, and stainless steels. These mixtures are most often used on thick sections, in positions other than flat. Good mechanical properties and weld pool control are characteristic of these mixtures.

(2) Helium + 25 to 35 Percent Argon and 1 to 5 Percent Carbon Dioxide. These mixtures are used for short circuiting transfer welding of high strength and

stainless steels, especially for welding positions other than flat. The carbon dioxide content is kept low to insure good weld metal toughness. The helium provides the heat necessary for good weld pool fluidity.

(3) Helium + 7.5 Percent Argon + 2.5 Percent Carbon Dioxide. This mixture is widely used for short circuiting transfer welding of stainless steel in all welding positions. The carbon dioxide content is kept low to minimize carbon absorption and assure good corrosion resistance, especially in multipass welds. The argon+carbon dioxide additions provide good arc stability and increased depth of fusion. The high helium content provides significant heat input to overcome the sluggish nature of the stainless steel weld pool.

3.2.10.3 Argon + Helium + Oxygen. Just as helium addition to argon increases the arc energy when welding nonferrous metals, oxygen affects the arc with the GMAW process on ferrous metals. Argon-helium-oxygen mixtures have been used occasionally with spray transfer to increase weld pool fluidity, control bead shape, and reduce porosity.

3.2.10.4 Argon + Nitrogen + Oxygen. Small amounts of nitrogen (1.0 to 3.0 percent) have been added to argon+1 percent oxygen to achieve a completely austenitic microstructure in welds made with Type 347 stainless steel filler metal.

3.2.11 Quaternary Shielding Gas Mixtures. See Table 6.

3.2.11.1 Argon + Helium + Carbon Dioxide + Oxygen. Commonly known as a "quad mix," this combination is most popular for high deposition GMAW using the high-current-density metal-transfer arc. This mixture will give good mechanical properties and operability throughout a wide range of deposition rates. Its major application is welding low alloy, high tensile strength base materials, but it has been used on mild steel for high-productivity welding. Weld economics are an important consideration in using this gas for welding mild steel.

3.3 Flux Cored Arc Welding

3.3.1 Process Description. Flux cored arc welding (FCAW) is an arc welding process that produces coalescence of metals by heating them with an arc between a continuous flux cored metal electrode and the weld pool. Shielding is provided by either the decomposition of flux contained within the electrode or externally supplied gas or both (see Figure 11).

3.3.2 Shielding Gases

3.3.2.1 Carbon Dioxide. Welding with carbon dioxide shielding gas is generally characterized by a globular type of metal transfer and broad depth of fusion.

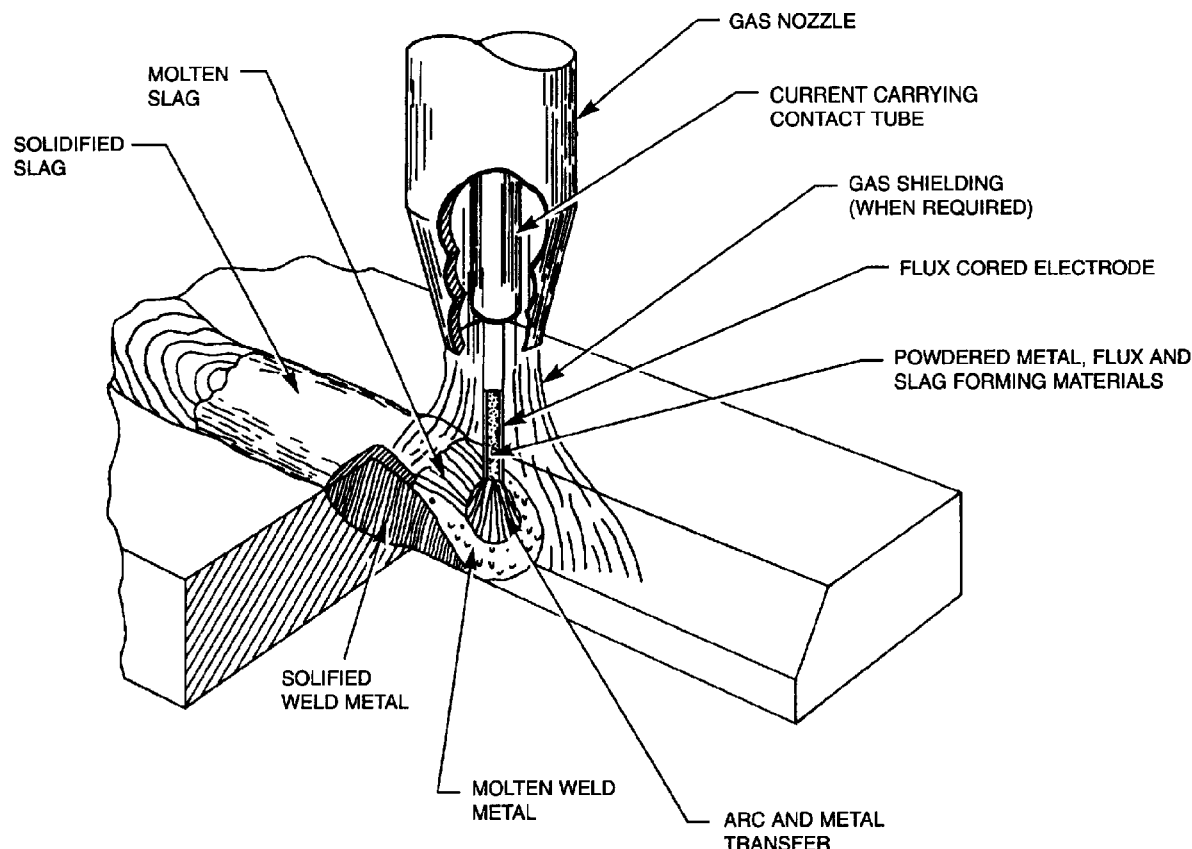


Figure 11—Flux Cored Arc Welding Process

The oxidizing characteristic of carbon dioxide is well known to the developers and manufacturers of flux cored electrodes. Deoxidizing materials are added to the core of the electrode to compensate for the oxidizing effect of the carbon dioxide. The deoxidizing elements have a great affinity for oxygen and readily combine with it.

3.3.2.2 Gas Mixtures. The trend toward using smaller diameter welding electrodes to obtain greater versatility has resulted in the use of more gas mixtures. The most common mixture for FCAW is argon + 25 percent carbon dioxide.

Because of the poor transfer of deoxidizing elements in FCAW when using carbon dioxide, all electrodes designed for use with carbon dioxide are heavily deoxidized. When these same electrodes are used with gas mixtures utilizing argon based gases, a buildup of manganese, silicon, and other deoxidizing elements may occur.

Welds produced using these mixtures generally have higher strengths but slightly lower ductility than welds made under the same conditions with carbon dioxide.

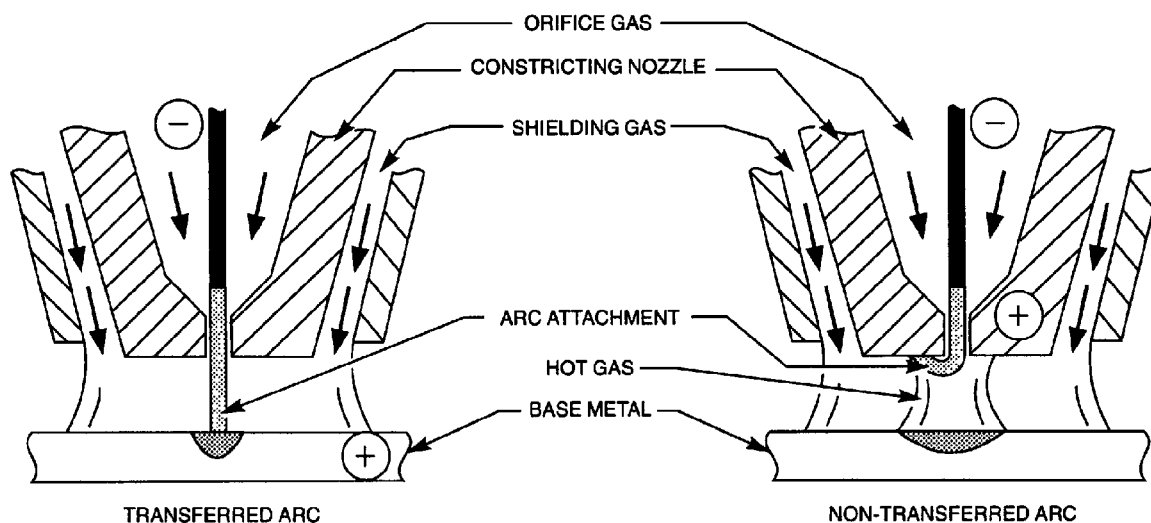
Many manufacturers provide different FCAW electrodes for use in either 100% carbon dioxide or argon based mixtures.

Ternary mixtures such as argon + oxygen + carbon dioxide have been used with good results with certain HSLA materials.

Mixtures such as argon + 2 percent oxygen are used for shielding with stainless steel electrodes designated EXXXT-2.

3.4 Plasma Arc Welding

3.4.1 Process Description. Plasma arc welding (PAW) is a process similar to gas tungsten arc welding (GTAW) wherein weld coalescence is produced by heating with a constricted arc between a nonconsumable electrode and the workpiece (transferred arc) or between the electrode and constricting nozzle (nontransferred arc). See Figure 12. Shielding of the weld fusion zone is provided by the use of an inert gas or a gas mixture. Transferred plasma arc welds are produced with either a melt-through keyhole or a conventional fusion technique.



**Figure 12—Schematic Diagrams of Plasma Arc Welding
Showing the Arc and Heat of Fusion Patterns**

PAW can be used over a wide range of heat inputs and is usually referenced by the current range and fusion technique being employed. For thin base metal 1/16 in. (1.6 mm) and under, low current PAW (1 to 50 amperes) is utilized. For thicker base metal, higher currents (50 to 400 amperes) are used.

Single-pass butt welds can be made on most base metals up to 1/4 in. (6.3 mm) thick, using a square groove and keyhole welding technique. An inert underside root shielding gas² may be required for high quality welds. Thicker base metals may require multiple-pass welds, where the subsequent passes utilize a conventional fusion technique with filler metal additions. PAW produces high-quality welds and offers the following specific advantages over GTAW:

- (1) The arc length is less critical, particularly when manually welding thin base metals.
- (2) Since the plasma arc torch electrode is recessed inside the arc constricting nozzle, it is not possible to touch the electrode to the work, minimizing the possibility of contaminating the weld with tungsten.
- (3) Single-pass keyhole welding produces a narrow weld bead and heat-affected zone, resulting in less distortion and improvement in transverse weld strength.
- (4) Travel speeds are higher.

2. Underside root shielding gas is commonly referred to as *backing gas*.

PAW is a low deposition rate process and is not used for thick base metal. It is used primarily for joining components fabricated of stainless steel, nickel, copper, aluminum, titanium, and zirconium alloys. Tables 7 through 10 list some AWS recommended practices for plasma arc welding.

Additional tables of welding conditions for various base metals and thicknesses are listed in the *AWS Welding Handbook*, current edition.

3.4.2 Shielding Gases

3.4.2.1 Argon. Argon is the principal gas used for PAW and may be both the orifice gas and shielding gas, or may be used in combination with other gases. (See equipment manufacturers for gas recommendations). Argon has a low ionization potential and provides easy arc starting.

3.4.2.2 Helium. Helium is generally used in a mixture with argon for PAW. Its higher ionization potential produces a higher temperature plasma arc for a given welding current. Helium may increase joint penetration and travel speed. The low density of helium requires a higher shielding gas flow rate than argon to provide adequate coverage of the weld fusion and heat-affected zones. The higher ionization potential of helium may cause some difficulty with arc starting.

3.4.2.3 Helium + Argon. When helium is mixed with argon for PAW, mixtures of 65 to 75 percent helium are most common.

Table 7
Typical Plasma Arc Welding Conditions for Butt Joints in Titanium

Thickness		Travel Speed		Current DCEN	Arc Voltage	Orifice Size		Gas Flow				Remarks ^{a,b}
								Orifice		Shield		
in.	mm	in./min	mm/s	A	V	in.	mm	scfh	lpm	scfh	lpm	
0.125	3.2	20	8.5	185	21	0.111	3.0	8 ^c	4.0	60 ^c	30	Keyhole, square-groove weld
0.187	4.8	13	5.5	175	25	0.136	3.5	18 ^c	8.5	60 ^c	30	Keyhole, square-groove weld
0.390	10	10	4.2	225	38	0.136	3.5	32 ^d	15.0	60 ^d	30	Keyhole, square-groove weld
0.500	13	10	4.2	270	36	0.136	3.5	27 ^e	15.0	60 ^e	30	Keyhole, square-groove weld

Notes:

- a. A backing gas is required for all welds.
b. Torch standoff: 3/16 in. (4.8 mm)
c. Gas used: argon
d. Gas used: 75% He + 25% Ar.
e. Gas used: 50% He + 50% Ar.

Table 8
Typical Plasma Arc Welding Conditions for Welding Stainless Steels—Low Amperage

Thickness		Type of Weld	Travel Speed		Current DCEN	Orifice Size		Gas Flow ^a Orifice		Torch Standoff		Electrode Diameter		Remarks ^{b,c}
in.	mm		in./min	mm/s		in.	mm	scfh	lpm	in.	mm	in.	mm	
0.030	0.8	Square-groove weld, butt joint	5	2	11	0.030	0.8	0.6	0.3	0.250	6.4	0.0	1	Mechanized
0.060	1.6	Square-groove weld, butt joint	5	2	28	0.047	1.2	0.8	0.4	0.250	6.4	0.0	1.6	Mechanized
0.030	0.8	Fillet weld, T-joint	—	—	8	0.030	0.8	0.6	0.3	0.250	6.4	0.0	1.0	Manual, filler metal ^d
0.060	1.6	Fillet weld, T-joint	—	—	22	0.047	1.2	0.8	0.4	0.250	6.4	0.0	1.6	Manual, filler metal ^d
0.030	0.8	Fillet weld, lap joint	—	—	9	0.030	0.8	0.6	0.3	0.375	9.5	0.0	1.0	Manual, filler metal ^d
0.060	1.6	Fillet weld, T-joint	—	—	22	0.047	1.2	0.8	0.4	0.375	9.5	0.0	1.6	Manual, filler metal ^d

Notes:

- a. Orifice gas: argon.
b. Shielding gas: 95% Ar + 5% H₂ at 20 scfh (9 lpm).
c. Backing gas: argon at 10 scfh (5 lpm).
d. Filler metal: 0.045 in. (1.2 mm) dia.

Table 9
Typical Plasma Arc Welding Conditions for Butt Joints in Stainless Steel

Thickness		Travel Speed		Current DCEN	Arc Voltage	Orifice Size		Gas Flow				Remarks ^{a,c}
in.	mm	in./min	mm/s			A	V	in.	mm	Orifice ^a		
								scfh	lpm	scfh	lpm	
0.092	2.3	24	10	115	30	0.111	2.8	6	3	35	16	Keyhole, square-groove weld
0.125	3.2	30	13	145	32	0.111	2.8	10	5	35	16	Keyhole, square-groove weld
0.187	4.8	16	7	165	36	0.136	3.5	13	6	45	21	Keyhole, square-groove weld
0.250	6.4	14	6	240	38	0.136	3.5	18	8	50	24	Keyhole, square-groove weld

Notes:

- a. Gas used: 95% Ar + 5% H₂
b. A backing gas is required for all welds.
c. Torch standoff: 3/16 in. (4.8 mm)

Table 10
Typical Plasma Arc Welding Conditions for Butt Joints in Carbon and Low Alloy Steels

Metal	Thickness		Travel Speed		Current DCEN A	Arc Voltage V	Orifice Size		Gas Flow ^a				Remarks ^{b,c}
	in.	mm	in./min.	mm/s			in.	mm	Orifice scfh	lpm	Shield scfh	lpm	
Mild steel	0.125	3.2	12	5	185	28	0.111	2.8	13	6	60	30	Keyhole, square-butt weld
4130 steel	0.170	4.4	10	4	200	29	0.136	3.5	12	6	60	30	Keyhole, square groove weld, 3/64 in. dia. (1.2 mm) filler metal added at 30 in./min. (13 mm/s)
D6AC steel	0.250	6.4	14	6	275	33	0.136	3.5	15	7	60	30	Keyhole, square groove weld, 600°F (315°C) preheat

Notes:

a. Gas used: argon

b. A backing gas is required for all welds.

c. Torch standoff: 3/16 in. (4.8 mm) for all welds.

3.4.2.4 Argon + Hydrogen. Mixtures of argon + hydrogen are used as the orifice and shielding gases for keyhole welding stainless steel. Permissible hydrogen percentages vary from 1 to 15 percent, depending on base metal thicknesses and travel speed requirements. See hydrogen caution in 3.1.2(4). Hydrogen additions in any quantity may be detrimental to weld properties on base metals other than nickel, copper-nickel, or austenitic stainless steels.

3.4.2.5 Nitrogen. Because of its low cost, relatively inert behavior, and greater thermal conductivity, attempts have been made to utilize nitrogen as a shielding gas. Most success has been achieved in Europe where nitrogen has been used as a shielding gas for welding of copper and copper alloys. Mixtures of argon and up to 20 percent nitrogen have been used successfully on austenitic stainless steel, but argon or argon + hydrogen mixtures are preferred. Nitrogen should not be used to shield carbon or low alloy steels, since it produces undesirable iron nitrides in the weld.

3.5 Electrode Gas Welding

3.5.1 Process Description. Electrode gas welding (EGW) is similar to both GMAW and FCAW, but uses molded shoes to confine the molten weld metal for uphill position welding. Although the axis of the weld is vertical, the process is in the flat position with vertical travel. A consumable electrode, either solid or tubular, is fed downward into a cavity formed by the joint members and

the molded shoes. Heat from the arc melts the base metal and the continuously fed electrode. Melted electrode and base metal collect in a pool beneath the arc and solidify to form the weld metal. Shielding may or may not be obtained from an externally supplied gas or gas mixture. As the cavity fills, one or both shoes move upward (see Figure 13).

EGW of carbon and low alloy steels, using a solid electrode, is normally done with carbon dioxide or argon+carbon dioxide shielding. Recommended gas flow rates range from 40 to 140 scfh (20 to 65 lpm). Gas flow rates depend on the equipment design, and manufacturer recommendations should be followed. Solid electrodes have also been used for EGW of aluminum. Shielding gas should be argon, helium, or mixtures of argon+helium. Typical shielding gases for electrode gas welding are listed in Table 11.

Tubular electrodes, used with EGW of steel, are specifically designed for EGW. The flux produces a thin layer of slag between the weld metal and shoes, without accumulating excessive slag above the weld pool. EGW with a flux cored tubular electrode requires gas shielding or a self-shielded electrode. Shielding gases for welding carbon and high strength, low alloy steels are normally carbon dioxide or argon + carbon dioxide mixtures. Recommended gas flow rates range from 30 to 140 scfh (15 to 65 lpm).

ANSI/AWS A5.26, *Specification for Carbon and Low Alloy Steel Electrodes for Electrode Gas Welding*, classifies tubular electrodes on the basis of (1) whether a separate

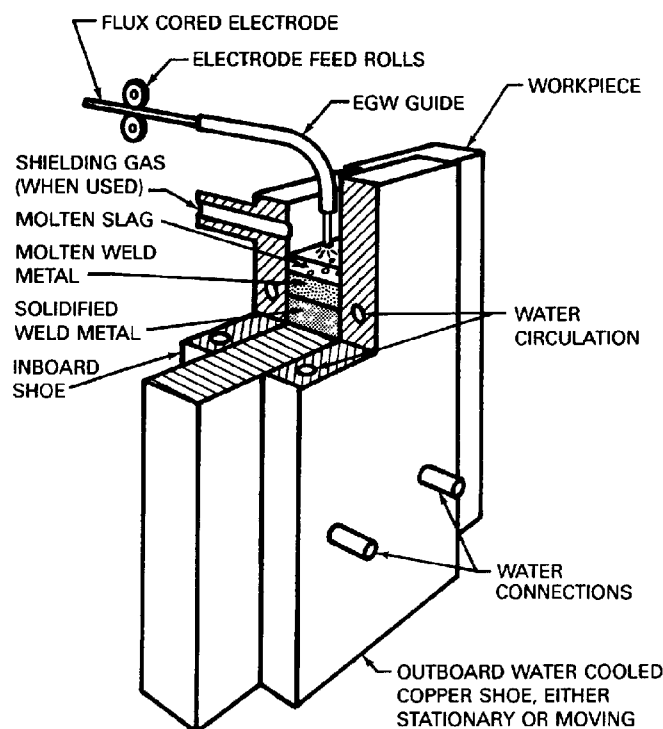


Figure 13—Electrogas Welding Process

shielding gas is required, and (2) on the chemical composition and as-welded mechanical properties of the weld metal. The solid electrodes are classified on the basis of (1) their chemical composition and on (2) the as-welded mechanical properties of the weld metal (using CO_2 gas shielding). The mechanical properties of a weld metal will vary with chemical composition, and this chemical composition can be altered by changing the gas shielding. Therefore, mechanical properties expected in production must be determined by making test welds. A written welding procedure that identifies the essential variables (including gas shielding) to be used in EGW should always be prepared and followed.

3.6 Plasma Arc Cutting

3.6.1 Process Description. Plasma arc cutting (PAC) is an arc cutting process that uses a constricted arc and removes the molten metal with a high-velocity jet of ionized gas issuing from the constricted orifice.

In the early 1950's it was discovered that the properties of the open arc, as used in GTAW, could be greatly altered. The arc was constricted by directing it through a water cooled copper nozzle located between an electrode (cathode) and the work (anode). Instead of diverging into an

open arc, such an arc is constricted by the nozzle into a small cross section. This action greatly increases the power density of the arc. Both the arc temperature and the voltage are raised.

The characteristics of the plasma jet can be altered greatly by changing the gas type, flow rate, arc current, and nozzle size. For example, if low gas flow rates are used, the jet momentum is reduced. The plasma jet forms a highly concentrated heat source that is ideal for welding. Conversely, if the gas flow rate is increased sufficiently, the momentum of the plasma jet will be high enough to expel the molten metal created by the heat of the plasma arc, resulting in gouging or cutting. Figures 14 and 15 are schematic diagrams of two basic types of PAC torches.

PAC utilizes a transferred arc between the electrode and the work after the arc is initiated by the pilot arc or high-frequency discharge between the electrode and constricting nozzle. The selection of gas for PAC is determined by base metal, thickness, and equipment type.

For manual PAC, air, nitrogen, argon+hydrogen, and nitrogen+hydrogen mixtures are most frequently employed as the plasma gas. Argon, nitrogen, carbon dioxide, air, or oxygen are used with PAC equipment requiring a secondary or cooling gas.

Table 11
Shielding Gases For Electrogas Welding

Metal	Thickness		Welding Wire	Shielding Gas
	in.	mm		
AISI 1018	3/8 to 4	10 to 100	EG70S-3	80% Ar + 20% CO ₂
AISI 1018	3/8 to 4	10 to 100	EG70T-2	CO ₂
ASTM A36	1	25	EG72T-4	CO ₂
ASTM A36	3	75	EG72T-4	CO ₂
ASTM A36	3	75	EG72T-4	80% Ar + 20% CO ₂ ^a
ASTM A131	1-1/2	28	EG72T-3	CO ₂
ASTM A203	1-5/8	28	EG72T-4	80% Ar + 20% CO ₂
ASTM A242	3/8 to 4	10 to 100	EG72T-4	CO ₂
ASTM A516	1-1/2	28	EG72T-4	80% Ar + 20% CO ₂
ASTM A537	1-1/2	25	EG72T-4	CO ₂
ASTM A537	1-1/8	28	EG72T-4	80% Ar + 20% CO ₂ ^a
ASTM A572	1	25	EG72T-4	80% Ar + 20% CO ₂
ASTM A558	3	75	EG72T-4	CO ₂
Aluminum	2 to 3	50 to 75	Aluminum	He + 25% Ar ^b

Notes:

a. Improved impact properties compared to CO₂.

b. Increased weld speeds.

Mechanized PAC cutting utilizes nitrogen, air, or oxygen as the orifice gas and water injection to further restrict the arc. For base metal over 3 in. (75 mm) argon+hydrogen gas is frequently used. Mechanized cutting can be used for low-carbon steel, stainless steel, and some nickel alloys while submerged in water. This has the advantage of reducing noise, smoke, and ultraviolet radiation from the arc. Great care has to be taken if aluminum is cut underwater, as hydrogen is generated and can become entrapped under the plate, providing an explosion potential. Underwater cutting is generally limited to base metals under 2 in. (51 mm) thick.

Tables 12 through 14 list the combinations of orifice and auxiliary gases that may be employed in PAC.

3.6.2 Gas Flow. The orifice gas will have a lower flow rate than the auxiliary gas, but both will vary as changes

in cutting current are made to accommodate different base metals and thicknesses.

Gas flow in most PAC equipment is controlled by a gas pressure regulator and a flowmeter. Because PAC equipment design can vary significantly between models, no specific flow rates are listed herein. Tables 15 through 17 list some AWS recommended practices for PAC.

The range of gas flow can vary between 1 and 100 scfh (0.5 and 50 lpm) for orifice gas and 8 to 200 scfh (5 to 95 lpm) for auxiliary gas, as determined by cutting requirements. Very high current automated equipment may use up to 300 scfh (140 lpm) gas flow rates. Refer to equipment manufacturer's recommendation for correct flow rates.

3.6.3 Gas Mixtures and Purity Levels. PAC equipment suppliers will specify exact mixtures to be used with

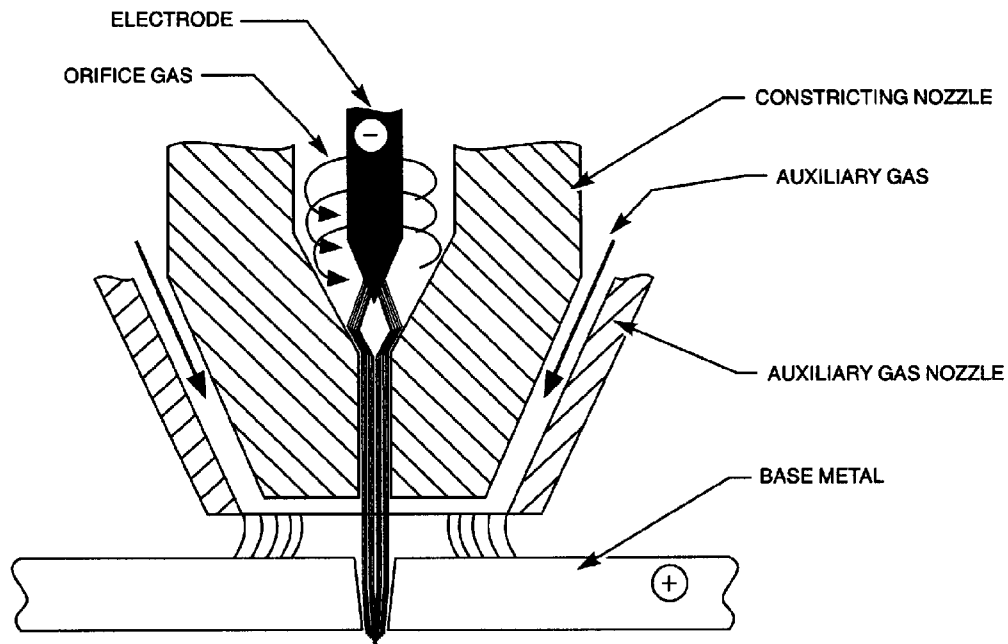


Figure 14—Dual Flow Plasma Arc Cutting

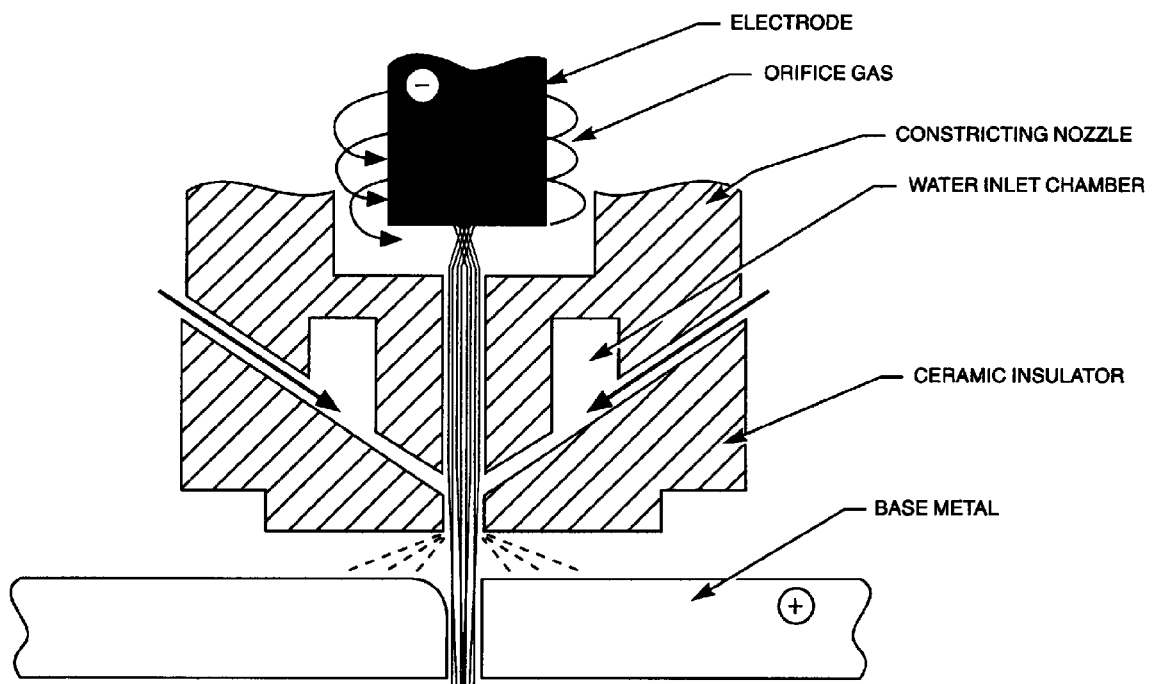


Figure 15—Water Injection Plasma Arc Cutting

Table 12
Orifice and Auxiliary Gases For Plasma Arc Cutting of Aluminum^{1,2,3,4}

Thickness		Orifice Gas				Auxiliary Gas				Water Injection
in	mm	Air	Argon + Hydrogen	Argon + Nitrogen	Nitrogen	Nitrogen	Carbon Dioxide	Air	Oxygen	
1/8	3.2	X	X		X	X	X	X	X	
					X	X	X	X		
					X					X
1/4	6.4	X	X			X	X	X		
			X		X	X	X	X	X	
				X						X
1/2	13	X			X	X	X	X	X	
				X	X					
					X					X
1	25		X		X	X	X	X	X	
				X	X					
					X					X
2	50		X		X	X	X	X		
				X	X					
					X					X
3	75		X		X	X	X			
4	100		X		X	X	X	X	X	
5	125		X							
6	150		X							

Notes:

Depending upon equipment type, the following applies:

1. An orifice gas is often used with no auxiliary gas.
2. When multiple auxiliary gases are shown for a single orifice gas, only one auxiliary gas applies for a given application.
3. Cutting speed and quality can vary with gas selection.
4. This table is a composite based on gas requirements for currently available PAC equipment. Use manufacturer's recommendations for selecting gases.

Table 13
Orifice and Auxillary Gases for Plasma Arc Cutting of Carbon Steel^{1,2,3,4}

Thickness		Orifice Gas					Auxiliary Gas					Under-water
in	mm	Air	Argon + Hydrogen	Argon + Nitrogen	Nitrogen	Oxygen	Nitrogen	Carbon Dioxide	Air	Oxygen	Water Injection	
1/16	1.6	X		X	X		X	X	X	X		
					X						X	X
						X						X
1/8	3.2	X	X	X	X		X		X			
					X		X	X	X	X		X
						X					X	X
1/4	6.4	X	X	X	X		X		X			
					X		X	X	X	X		X
						X					X	X
1/2	13	X		X	X		X		X			
					X		X	X	X	X		X
						X					X	X
1	25	X		X	X		X		X			
					X		X	X	X	X		X
						X						X
2	50		X	X	X		X		X	X		
					X							X
3	75		X	X	X				X			
					X							X
4	100		X		X				X			
5	125		X		X				X			

Notes:

Depending upon equipment type, the following applies:

1. An orifice gas is often used with no auxiliary gas.
2. When multiple auxiliary gases are shown for a single orifice gas, only one auxiliary gas applies for a given application.
3. Cutting speed and quality can vary with gas selection.
4. This table is a composite based on gas requirements for currently available PAC equipment. Use manufacturer's recommendations for selecting gases.

Table 14
Orifice and Auxillary Gases for Plasma Arc Cutting of Stainless Steel and Nickel Alloys*

Thickness		Orifice Gas				Auxiliary Gas					
in	mm	Air	Argon + Hydrogen	Argon + Nitrogen	Nitrogen	Nitrogen	Carbon Dioxide	Air	Oxygen	Water Injection	Under-water
1/16	1.6	X			X X	X	X	X X	X	X	X
1/8	3.2	X	X		X X	X X	X	X X	X	X	X
1/4	6.4	X	X		X X	X X	X	X X	X	X	X
1/2	13		X		X X	X X	X	X X	X	X	X
1	25		X		X X	X X	X	X X	X	X	X
2	50		X		X X	X X	X	X X	X	X	X
3	75		X		X X		X	X		X	
4	100		X		X		X	X			
5	125		X				X	X			
6	150		X				X	X			

*All footnotes listed in Table 12 apply.

Table 15
Typical Conditions for Plasma Arc Cutting of Aluminum Alloys

Base Metal Thickness		Cutting Speed		Orifice Diam*		Current DCEN
in.	mm	in/min	mm/sec	in.	mm	A
1/4	6.4	300	130	1/8	3.2	300
1/2	13	200	85	1/8	3.2	250
1	25	90	40	5/32	4	400
2	50	20	9	5/32	4	400
3	75	15	6	3/16	4.8	450
4	100	12	5	3/16	4.8	450
6	150	8	3	1/4	6.4	750

* Orifice gas flow rates vary with orifice diameter and gas used from about 100 scfh (50 lpm) for a 1/8 in. (3.2 mm) orifice to about 250 SCFH (120 lpm) for a 1/4 in. (6.4 mm) orifice. The gases are nitrogen and argon with hydrogen additions up to 35%. The equipment manufacturer should be consulted for each application. See caution note in 3.1.2(4).

Table 16
Typical Conditions for Plasma Arc Cutting of Stainless Steels

Base Metal Thickness		Cutting Speed		Orifice Diam*		Current DCEN
in.	mm	in/min	mm/sec	in.	mm	A
1/4	6.4	200	85	1/8	3.2	300
1/2	13	100	42	1/8	3.2	300
1	25	50	20	5/32	4	400
2	50	20	8	3/16	4.8	500
3	75	16	7	3/16	4.8	500
4	100	8	3	3/16	4.8	500

* Orifice gas flow rates vary with orifice diameter and gas used from about 100 scfh (50 lpm) for a 1/8 in. (3.2 mm) orifice to about 200 scfh (100 lpm) for a 3/16 in. (4.8 mm) orifice. The gases are nitrogen and argon with hydrogen additions from 0 to 35%. The equipment manufacturer should be consulted for each application.

Table 17
Typical Conditions for Plasma Arc Cutting of Carbon Steel

Base Metal Thickness		Cutting Speed		Orifice Diam*		Current DCEN
in.	mm	in/min	mm/sec	in.	mm	A
1/4	6.4	200	85	1/8	3.2	275
1/2	13	100	42	1/8	3.2	275
1	25	50	21	5/32	4	425
2	50	25	11	3/16	4.8	550

* Orifice gas flow rates vary with orifice diameter and gas used from about 200 scfh (95 lpm) for a 1/8 in. (3.2 mm) orifice to about 300 scfh (140 lpm) for a 3/16 in. (4.8 mm) dual flow orifice. The gases are usually compressed air, nitrogen with up to 10% hydrogen additions, or nitrogen with oxygen added downstream from the electrode (dual flow). The equipment manufacturer should be consulted for each application.

their equipment. Industry acceptable gas purity levels for most welding and cutting applications are listed in Table 2.

3.7 Purging and Backing Gases Used in Gas Shielded Welding

3.7.1 Introduction. The international welding industry uses the terms "purging gas," "forming gas," and "backing gas" interchangeably. The American Welding Society endorses the term *purging gas* as the proper designation of a method by which unwanted air is replaced from the weld root by a gas that prevents oxidation during welding. This oxidation can produce a variety of problems such as root porosity, incomplete fusion, and changes in weld metal chemistry that can affect weld metal mechanical properties. The purging gas replaces the air in the weld root zone and provides an atmosphere that will not react with the weld metal.

The process of purging is a common procedure for pipe and tube welding. Purging is also used in welding reactive metals such as titanium, where welding is sometimes accomplished in a chamber or other containment device. On some welded assemblies, the fixture used to align the parts also introduces root purging gas. The following will provide some general guidelines for purging techniques, gas selection, and suggested equipment.

3.7.1.1 When to Consider Purging. Purging should be considered on any joint design sensitive to oxidation that leaves the weld root exposed to the atmosphere. When consumable inserts are used in pipe welding, purging is specified to prevent oxidation and improve root fusion. Purging is a recommended practice for welding stainless steel, low alloy steel, and most nonferrous base metals. Purging is not usually needed when welding carbon steels and some low alloy steels. A weld procedure specification should indicate if purging is required.

3.7.1.2 Gases Used for Purging (see Table 18). Argon, helium, nitrogen, hydrogen, and mixtures of these gases are most commonly used for purging. Argon + helium, being chemically inert, can be used as a purging gas with all gas-shielded welding processes and base metals.

Helium is not commonly used for purging due to its low density. Combinations of argon + helium are used in selected applications. Argon is commonly used in the United States due to its lower cost and ample supply.

Nitrogen is not a chemically inert gas but has been used with success in purging austenitic stainless steel. Nitrogen is used for some carbon and low alloy steel purging where large volumes must be evacuated and require high gas volume.

Hydrogen is most commonly used as a purging gas in combination with nitrogen or argon to improve the wetting characteristics of the weld pool under bead by reducing the surface tension of the weld metal. At high

Table 18
Purging Gas Recommendations

Base Metal	Ar	Ar/He	N ₂	N ₂ /H ₂ ^a	Ar/H ₂ ^a
Carbon Steel	x				
Alloy Steel	x	x			
High-Alloy Steel	x	x			x
Stainless Steel	x	x	x	x	x
Copper	x		x		
Titanium	x		x		
Aluminum	x		x		x ^b

Notes:

a. H₂ 4% max. [See warning 5.3(4)].

b. When welding aluminum, it is recommended that the nitrogen purge be replaced with argon before welding.

temperatures, hydrogen can combine with oxygen in metal oxides, causing the metal oxide to be reduced to pure metal. Up to 4 percent hydrogen addition to either argon or nitrogen is most common. See **WARNING 5.3(4)**.

3.7.1.3 Equipment Used for Purging. The following equipment is recommended for proper purging depending on the application or purge procedure being used:

- (1) Oxygen analyzer
- (2) Dew point analyzer
- (3) Purge dams
 - (a) inflatable bladder
 - (b) water soluble paper
 - (c) wood or plastic gasketed disks
 - (d) expandable plugs
 - (e) end caps
 - (f) copper backup material
- (4) Suitable gas pressure regulator/flowmeter

Purge dams are defined as any material of any shape that is used to isolate the weld root area to be purged. Dams are used primarily in pipe welding where they are placed on the inside of the pipe between 6 and 24 in. (150 and 600 mm) on each side of the joint to be welded. Dam placement should be such that the heat of welding does not damage the dams.

3.7.2 Preparation for Purging. The weld root should be isolated by means of dams or other suitable containment devices. Purging requires entrance and exit openings through which the purging gas can enter and leave the weld joint area at controlled rates. When argon or nitrogen is used, the gas inlet should be located lower than the exit opening to prevent entrapment of air. When lighter-than-air gases are used for purging, such as mixtures in which helium is the major component, the inlet gas opening should be higher than the exit. The size of the exit port

should be equal to or greater than the entry to prevent pressure increase. Special precautions must be taken to ensure that all leak paths are blocked and that areas where air may be entrapped are well vented. Where open root weld joints are used, it is good practice to tape over the joint to eliminate air from reentering the purged system and to reduce purging gas losses. The tape is removed just prior to welding (refer to 5.3).

3.7.3 Purging Prior to Welding. The purging gas is introduced at relatively high flow rates, 20 to 50 scfh (10 to 25 lpm), for a period of time that is determined by the volume being purged. Figure 16 plots purge time as a function of system volume. The time required for the first stage of purging depends on the maximum oxygen level permitted by the welding procedure, the volume of the system being purged, and the purging gas flow rate. The relationship between purging gas flow rate and time is not linear. An increase in the purge flow rate increases the turbulence within the system. This results in an increase in the mixing of air and purging gas. Additional volume changes of gas within the system will be required to achieve the desired level of purity. An oxygen level of less than 1% should generally be achieved before welding begins.

Reasonable purge flow rates and times can be estimated from calculations of the system volume and by applying time factors. The time for one system volume change is found by dividing the system volume by the purging gas

flow rate. For example, the purge time for one volume change in a 20 ft (6 m) length of 18 in. (457 mm) diameter pipe purged at 50 scfh (25 lpm) would be

$$\begin{aligned}\text{Volume} &= 0.785 \times (\text{pipe diameter})^2 \times \text{Length} \\ &= 0.785 \times (1.5 \text{ ft})^2 \times 20 \text{ ft} \\ &= 35.3 \text{ ft}^3\end{aligned}$$

$$35.3 \text{ ft}^3 / 50 \text{ scfh} = .70 \text{ hours or 42 minutes}$$

A general rule is to purge at flow rates and times that will produce five to six system volume changes. In the example above, volume changes take place every 42 minutes.

The calculations above are guides to help estimate the purge time; but it is recommended that residual oxygen measurements, using an oxygen analyzer, be taken prior to welding to ensure purge purity.

3.7.4 Purging Gas Flow During Welding. Once the required purge has been achieved, the flow rate should be reduced before root pass welding begins to avoid pressure increase in the system. Excessive pressure can cause root concavity and porosity of the root pass. The correct flow rate during welding is one that is barely detectable at the exit port. A pressure gauge, or U-tube manometer graduated in inches of water, can be used in selecting the optimum flow. Such devices are generally installed at the purge exit port.

When welding with consumable inserts, where the unfused insert seals the joint root and prevents the escape

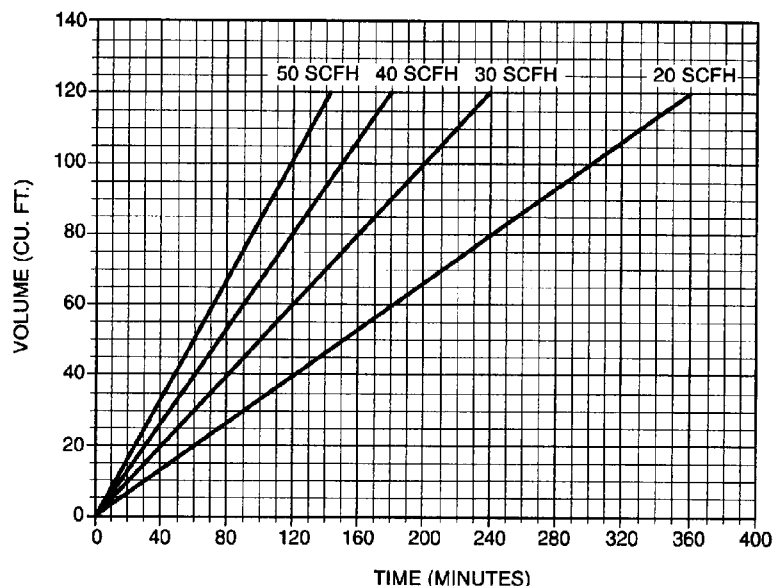


Figure 16—Prepurge Time for One Volume Change

of purging gas, flow rates on the order of 8 to 12 scfh (4 to 6 lpm) are typical. Flow rates of 15 to 18 scfh (7 to 9 lpm) are typical for joints having open roots. For smaller diameter pipe and tubing, it may be necessary to reduce the flow rates below the stated values. On applications where the joints are taped closed during the purge procedure, it is common for the welder to remove only enough tape to permit access for welding relatively short lengths of the joint at a time.

3.7.5 Additional Information. Refer to AWS publication ANSI/AWS D10.11, *Recommended Practices for Root Pass Welding of Pipe Without Backing*, for more detailed information on purging of piping systems.

4. Gas Supply Systems

4.1 High-Pressure Cylinders. Since gases have a relatively low density, the volume of gas at atmospheric pressure can be considerably reduced by compressing it into a cylinder under greater pressure. These cylinders must be constructed to withstand the high pressures and meet Department of Transportation (DOT) standards.

4.1.1 Identification of Gases in Cylinders. Identification of the gas content of compressed gas cylinders is established by means of the *chemical* or *trade name* of the gas marked on the cylinder.

This accepted means of identification is used by the industry in general in conformance with the methods established by the American National Standards Institute (ANSI) under its General Acceptance Method. The provisions apply as set forth in the American Standard Method of Marking Compressed Gas Cylinders to Identify Gas Content, published by ANSI.

While cylinders are painted in various colors and combinations of colors, these colors do not provide identification of gas contents and should not be used for that purpose. Suppliers do not intend that users rely on cylinder color to identify gas content.

4.2 Other Supply Systems. Gases come in several forms and with several methods of delivery and storage.

The user need only select the type of gas needed, know the volume requirement, and know the storage location. The gas supplier will determine the best methods of supply and distribution.

The user has the option of using compressed gas cylinders, a manifold (which has two or more gas cylinders connected), or a liquid system, which converts liquid product to gas on demand. An additional requirement will occur when the user needs a gas mixture. Mixtures can be purchased premixed in cylinders or can be mixed at the user's location with the use of approved mixing equipment. For safety reasons, it is recommended that argon+hydrogen mixtures be purchased already mixed.

4.2.1 Single Cylinder. Normally, single cylinders are located at the welding station. A regulator/flowmeter and hose assembly must be used to connect the cylinder to the welding equipment.

4.2.2 Multiple Cylinder Manifolds or Cradles. Manifolds can be used to provide a single or mixed gas. They are generally used with a piping system to supply multiple welding stations.

Simplex manifolds provide a means of connecting two or more cylinders or banks of cylinders to provide greater storage capacity or higher flow rates than can be obtained from a single cylinder. Duplex manifold systems transfer to the full cylinder bank when the first bank of cylinders is empty, and sound an alarm or light an indicator that the first bank needs to be changed. Each manifold system should have its own pressure regulator, as shown in Figure 17, and piping to the stations is at reduced pressure. A cluster is a quantity of cylinders tied together on a skid to deliver a greater quantity of gas.

4.2.3 Gas Mixers. Gas mixers may be used to blend gases at the user's location to meet standard or custom shielding gas requirements.

4.2.4 Carbon Dioxide Gas Containers. Welding grade carbon dioxide is available to the user in either cylinders or in bulk containers. The most widely used container is the high-pressure steel cylinder, approved by the DOT. Cylinders containing carbon dioxide are always labeled as carbon dioxide, and may be labeled "Welding Grade."

Figure 18 shows a standard cylinder of welding grade carbon dioxide. As shown, the content of a full carbon dioxide gas cylinder at 70°F (21°C) is both liquid and gas. Liquid carbon dioxide takes up approximately two-thirds of the space in the cylinder. Above the liquid level, the carbon dioxide exists as a gas.

4.2.5 Portable Liquid Containers. Portable liquid containers (Figure 19) or liquefied gas cylinders are available for use at one or more welding stations, or can be used at a remote location with the gas dispensed through a piping system.

4.2.6 Bulk Liquid Containers. Bulk liquid containers are located permanently at a given location. The benefits of such containers are a large, uninterrupted source of supply, high purity, and lower costs (see Figure 20).

4.2.7 Tube Trailers. An individual gas or gas mixture is transported to the user in tube trailers as a high-pressure gas and connected to the user's piping system (see Figure 21).

4.3 Piping Systems. Gas distribution piping systems are complicated systems and are outside the scope of this document.

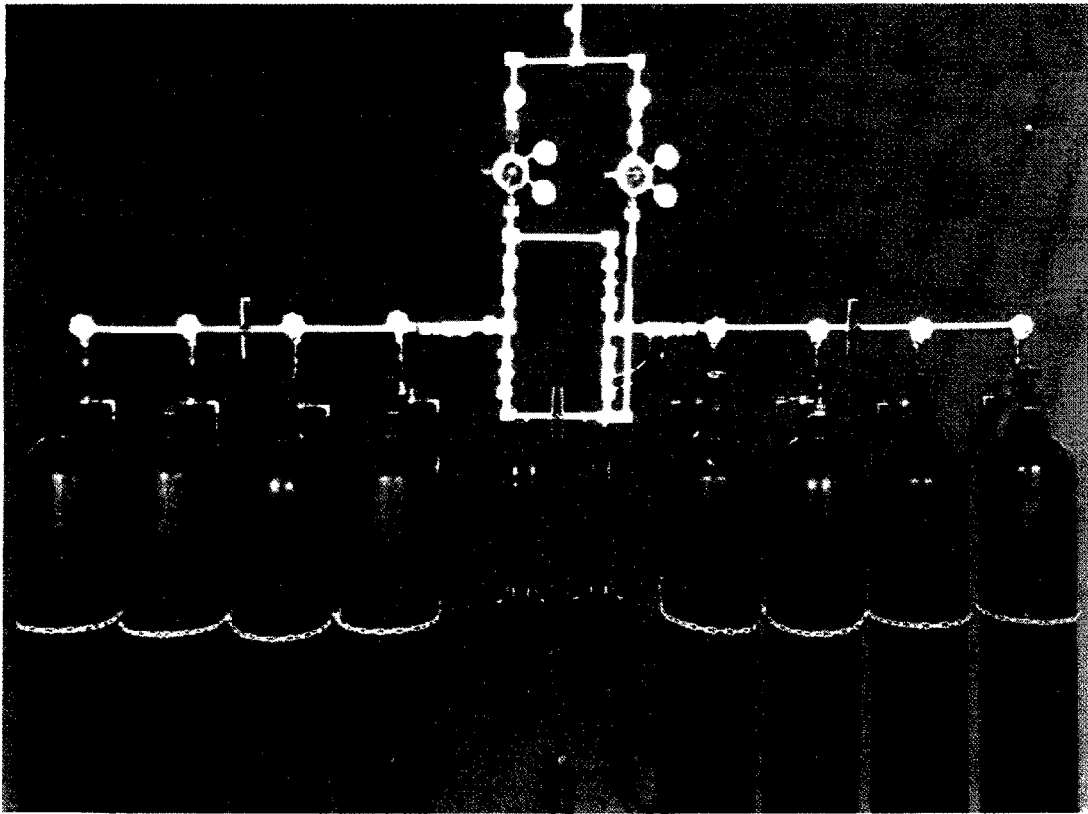


Figure 17—Manifold System

The source of the gas is assumed to be from the manifold connected to either high-pressure cylinders or to a liquid storage unit having suitable pressure regulators for the intended service. If not superseded by local, state, or federal requirements [including the Office of Safety and Health Administration (OSHA)], it is recommended that the design, material, fabrication, inspection, and tests meet the requirements of ANSI/ASME B31.3, *Petroleum Refinery Piping*. The designer is cautioned that the Code is not a design handbook. The Code does not do away with a need for the engineer or competent engineering judgment.

The Compressed Gas Association (CGA) pamphlet "Industrial Practices for Gaseous Transmission and Distribution Piping Systems" furnishes additional information pertinent to pipelines.

5. Safe Handling of Gases and Cylinders

OBTAIN, READ, AND UNDERSTAND:

(1) American National Standard Z49.1, *Safety in Welding and Cutting* published by the American Weld-

ing Society, 550 N.W. LeJeune Road, Miami, Florida 33126

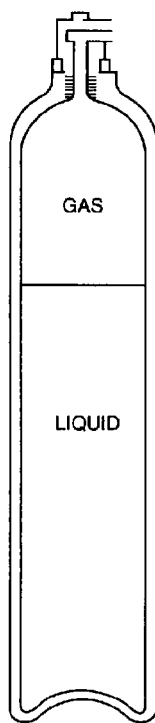
(2) *OSHA Safety and Health Standards*, 29 CFR 1910, available from the U.S. Government Printing Office, Washington D.C. 20402

(3) Manufacturers Material Safety Data Sheet (MSDS)

(4) AWS, A5.32, *Specification for Shielding Gases for Welding*

5.1 Introduction. High pressure and liquefied gas cylinders are constructed and maintained in accordance with the regulations of the DOT. High-pressure cylinders normally have maximum filling pressures below 3000 psig (21 MPa). There are, however, some cylinders with filling pressures of 6000 psig (42 MPa). The sudden release of high pressure, due to the rupture of a cylinder or the accidental damage of a cylinder valve, can result in severe or fatal injury.

Liquefied argon, nitrogen, carbon dioxide, and oxygen can have temperatures as low as -320°F (-195°C). At these extremely low temperatures, the liquid, the gases evaporated from them, and other materials chilled by them may cause frostbite to exposed body parts, especially to the eyes. Safety glasses and face shields should be worn,



NOTE: AT 70 DEGREES F.
THERE ARE 8.76 CUBIC FEET OF
CARBON DIOXIDE PER POUND.

Figure 18—Carbon Dioxide Gas Cylinder

and boiling or splashing liquid should be avoided. Delicate eye tissue can be damaged by an exposure to cryogenic gases which would not normally affect the skin of the hands or face. If exposure to these cryogenic liquids or cold gases does occur, a physician should be immediately contacted or other first aid sought. As quickly as possible, the affected area should be restored to normal body temperature. This is most efficiently accomplished by using water at 108°F (42°C) (lukewarm). The affected area should not be rubbed either before or after warming. Any unprotected part of the body should never be allowed to come in contact with uninsulated pipes or vessels containing liquified gases. Body tissue may stick to the cold metal and be damaged as an attempt is made to withdraw from it.

5.2 Safe Handling of High-Pressure and Liquid Cylinders. Before any high-pressure cylinder is moved, the cylinder cap should be checked to ensure that it is properly secured to the cylinder. When moving cylinders, an approved cylinder cart should always be used to avoid upset during transport. Chains, or other devices provided, should be utilized for securing the cylinder to the cart.

Separate storage areas should be available for full and empty cylinders. One should make certain that all local

fire codes are complied with for the storage of flammable gases and other high-pressure gases.

When a high-pressure cylinder is moved into a work station, the cylinder should be secured before removing the cylinder cap. The contents of a cylinder should never be used without a pressure regulator.

Before a regulator is connected to a cylinder, the regulator connection nut and the cylinder valve threads should be checked to ensure that both are the same CGA standard. A regulator nut should never be forced onto a cylinder valve; an adaptor should never be used; *only a regulator connector designed for a specific cylinder and gas should be used.* Before a regulator is connected to a cylinder, the cylinder valve should be opened momentarily. **WARNING:** (except hydrogen and hydrogen mixtures) **While standing to the side or rear of the cylinder valve outlet, the cylinder valve should be opened slightly for an instant, then closed quickly. This will clean the valve of any accumulation of dust or dirt.**

After a regulator is connected to a cylinder, and before the cylinder valve is opened, the pressure adjusting screw should be checked to ensure that it is disengaged or rotated counterclockwise until it turns freely. The operator should be careful not to be standing in line with the pressure adjusting screw. The valve should be opened very slowly so there is not a sudden surge of pressure into the regulator.

When a cylinder is not in use, the cylinder valve should be closed. The regulator should never be permitted to be substituted for the cylinder valve as the closing device. If a small leak occurs at the regulator seat, cylinder pressure can increase on the low-pressure side of the regulator, possibly causing a rupture of the regulator diaphragm.

High-pressure cylinder valves are normally supplied with pressure-relief devices. The purpose of these devices is to provide a discharge of excess pressure before an increase capable of rupturing a cylinder is realized. Pressure-relief devices shall not be tampered with, modified, or obstructed in any manner.

Before empty high-pressure cylinders are moved, valves should be closed tightly and cylinder caps secured. Empty cylinders should be stored separately from full cylinders. Arrangements should be made for the prompt return of empty cylinders. It is advisable to tag all empty cylinders before returning them to the supplier.

Cylinders that have been damaged by fire shall not be shipped if they still contain gas. Under these circumstances, the gas supplier shall be promptly contacted.

If a high-pressure cylinder is dented or has arc strikes, it shall be tagged with the damage and location noted, and removed from service. If a valve leaks and the leak cannot be remedied by tightening the valve gland, the valve shall be closed and a tag attached stating that the cylinder is unserviceable. If the contents are flammable (hydrogen or hydrogen mixture), the cylinder should be kept away from ignition sources. The leaking cylinder should be moved

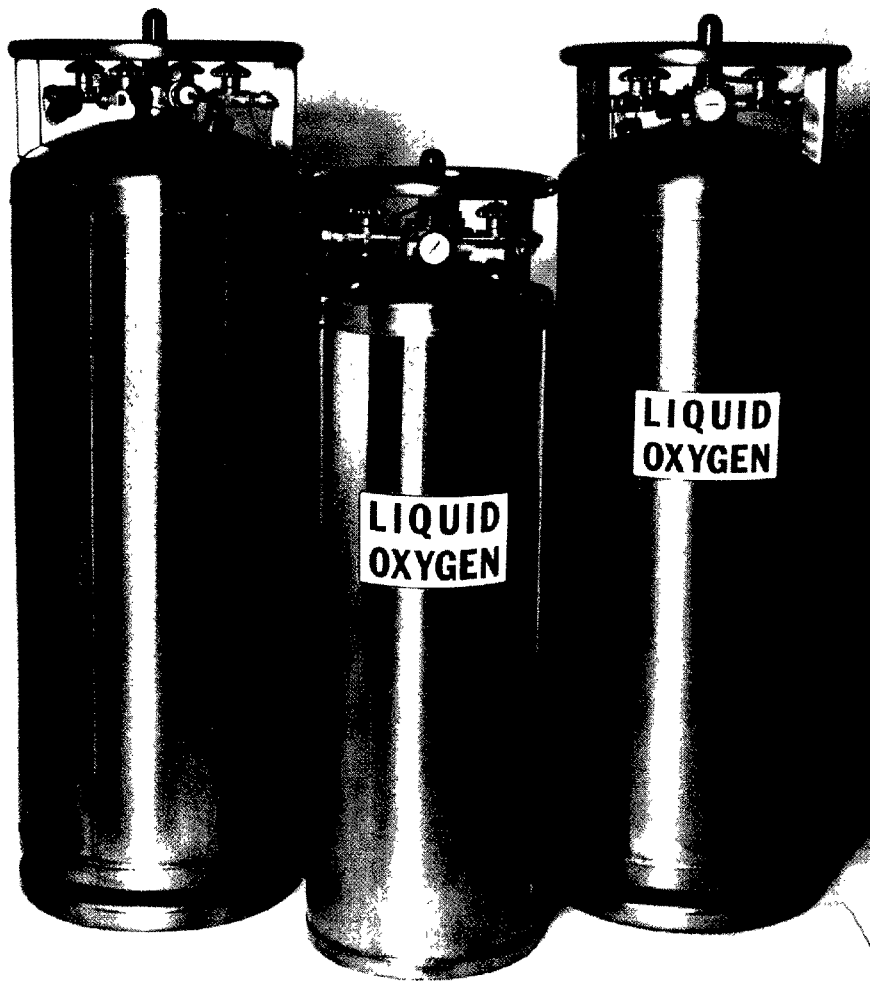


Figure 19—Liquid Cylinders

outdoors to a well-ventilated location (or place under a suitable exhaust ventilating system). An appropriate sign should be placed on the cylinder warning of the hazard. The gas supplier shall be notified and the supplier's instructions followed as to the return or disposition of the cylinder. Liquid cylinders are designed to vent from the external relief valve to maintain internal pressures, and should not be considered a safety hazard.

Storage areas should be maintained in a dry area, free of litter and rubbish. Preferably, cylinders should be stored in a secured fenced-in area with an overhead covering to protect them from direct sunlight as well as rain or snow.

5.3 Safety Precautions. The information noted above is general and applicable to all gas and liquid cylinders.

Listed below are some specific instructions for various gases.

IMPORTANT NOTE! If a person accidentally enters an enclosed area and becomes dizzy or unconscious, do not enter the area to render aid unless equipped with an oxygen breathing apparatus or mask with a fresh air supply. Rescue attempts should be conducted only by a team of a minimum of two persons. The backup person should not enter the area, but remain outside to provide assistance in removing the victim.

When a question arises about the proper handling or storage of a gas, the safety department or the supplier of the gas cylinders should be contacted.

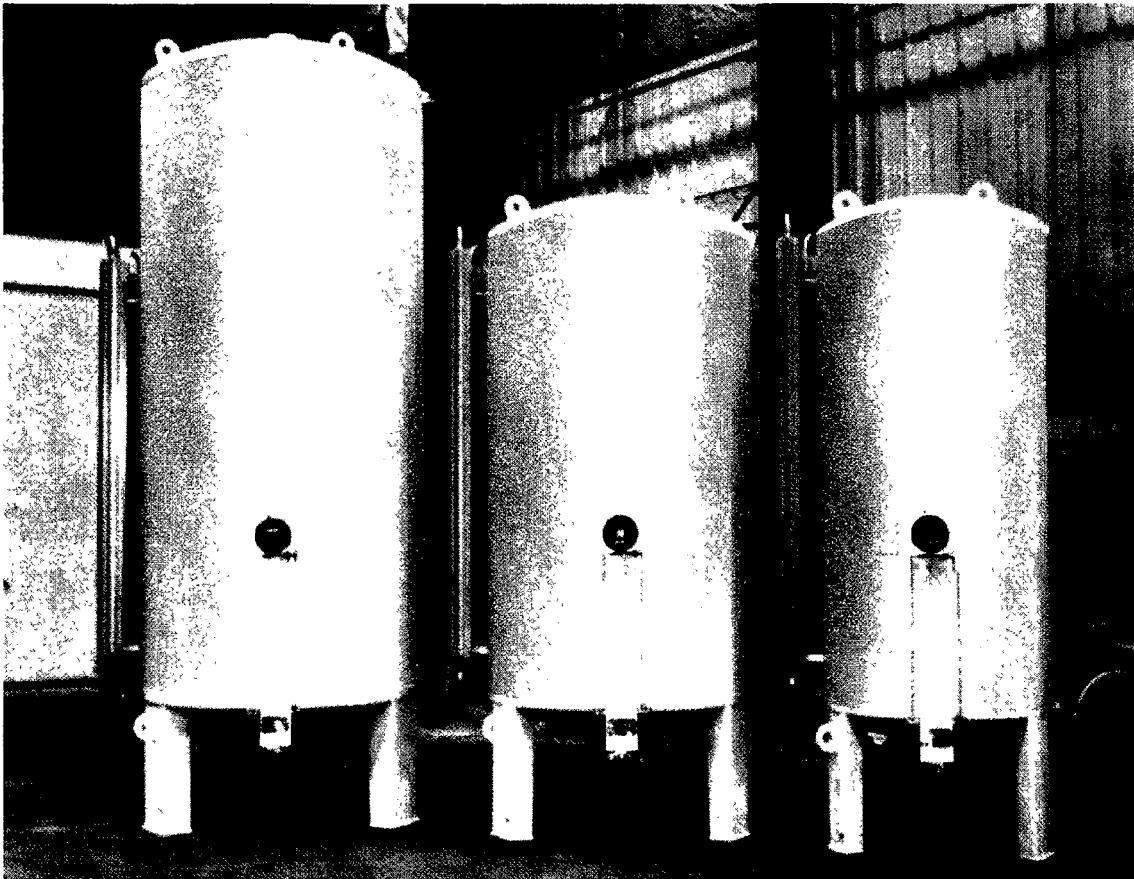


Figure 20—Bulk Storage Vessels

A gas should never be identified by the color of the cylinder, since there is no standard code on cylinder colors and some cylinder paints change colors when exposed to light. **ALWAYS READ THE CYLINDER LABEL.**

Gases should always be referred to by their proper names. For example, *oxygen* should not be referred to as “air”; compressed air is a specific product.

(1) Argon, Helium, and Nitrogen. All are inert gases and are odorless, colorless, and tasteless. All can cause rapid asphyxiation and death in confined, poorly ventilated areas. Any atmosphere containing less than 18 percent oxygen will cause dizziness, unconsciousness, or possibly death. If there is doubt about the adequacy of oxygen in a room, tank, or enclosed area, an oxygen analyzer with an adequate scale range should be used to check for oxygen.

(2) Carbon Dioxide. Similar to argon, helium, and nitrogen, carbon dioxide will also cause rapid asphyxiation in confined and poorly ventilated areas. In addition,

carbon dioxide affects the acid-base balance in the body. Carbon dioxide is formed in normal functions within the body. Increased concentrations, however, can be tolerated only in limited amounts. OSHA standards have adopted a threshold limit value (TLV) of 5000 parts per million (0.5 percent concentration). For safety, concentrations above this level should not be permitted. Higher concentrations can cause bodily harm or death.

All carbon dioxide cylinders are filled by weight, since the product is liquid in the cylinder. Rapid withdrawal will result in a frost buildup on the regulator. It is also possible for the seat in the regulator to freeze. If the withdrawal rates for a specific application are sufficient to cause a freeze-up, it is recommended that these cylinders be manifolded or a special electric heater be installed between the cylinder valve and regulator inlet. There are also regulators available with the heater as an integral part of the unit.

Some carbon dioxide cylinders are equipped with an eductor (dip) tube that permits only liquid carbon dioxide

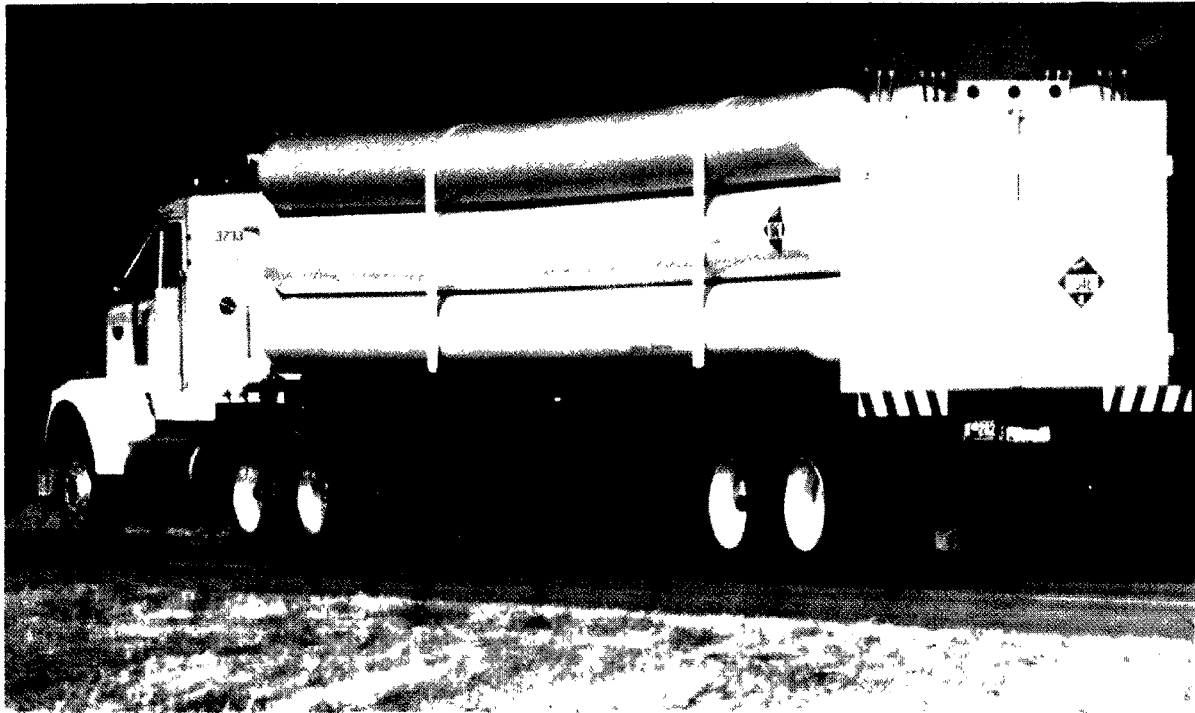


Figure 21—Tube Trailer

to be withdrawn from the cylinder. A special notation or marking is placed on cylinders containing eductor tubes. Special care should be taken to ensure that only vapor withdrawal cylinders are used for welding or cutting.

(3) Oxygen. Oxygen is an odorless, colorless, tasteless gas. Oxygen is an oxidizer and supports combustion. At concentrations above the normal 21 percent occurring in the atmosphere, combustion can be greatly accelerated. Specifically, oil, grease, kerosene, paint, tar, coal dust, dirt, and wood or cloth impregnated with any of these materials must not come in contact with oxygen. Care should be taken to prevent any spills of liquid oxygen. Should liquid oxygen be accidentally spilled, preclude any possibility of equipment rolling through or anyone walking over the spill.

Special care should be taken when connecting regulators to oxygen cylinders. Prior to connecting the regulator, a careful visual inspection should be made to ensure that the regulator and cylinder valve are free of oil, grease, or any other contaminants. Hydrocarbon contaminants can be ignited when the cylinder valve is opened and will burn violently in an enriched oxygen atmosphere.

At no time should oxygen be used to blow dust or dirt from clothing or machinery. Clothing saturated with pure

oxygen will burn with explosive violence if any source of ignition, such as a spark, is present.

(4) Hydrogen. Hydrogen is an odorless, colorless, tasteless gas. Being the lightest element, escaping hydrogen tends to rise to the highest elevation in an enclosed area. It is a flammable gas, and burns with a nearly invisible flame. Mixtures of hydrogen with oxygen or air in an enclosed room or area will explode if exposed to any source of ignition, spark, or flame. Since the gas is odorless, a concentration of hydrogen cannot be detected by smell. All areas where hydrogen is used should be kept well ventilated.

WARNING:

Hydrogen is a highly flammable gas. A mixture of hydrogen with oxygen or air in a confined area will explode when brought in contact with a flame or other source of ignition. Concentrations of hydrogen between 4 percent and 75 percent by volume in air are relatively easy to ignite by a low-energy spark and may cause an explosion. Smoking, open flames, unapproved electrical equipment, and other ignition sources must not be permitted in hydrogen areas. Store containers outdoors or in other well-ventilated areas.

Before making any installation, one should become thoroughly familiar with NFPA (National Fire Protection Association) Standards No. 50-A, *Standard for Gaseous Hydrogen Systems at Consumer Sites*, and 50-B, *Standard for Liquefied Hydrogen Systems at Consumer Sites*, and with all local safety codes. For further safety information, refer to supplier MSDS sheets on hydrogen safety.

Every precaution against hydrogen leaks should be taken. Escaping hydrogen cannot be detected by sight, smell, or taste. Since it is lighter than air, Hydrogen has a tendency to accumulate beneath roofs and in the upper portions of other confined areas.

(5) **Gas Mixtures.** It is not possible to list each gas mixture that may be encountered. In general, the labels should be checked to identify those that are classified as flammable or as oxidizers. Mixtures of inert gases should be handled with the same precautions as argon, carbon dioxide, helium, and nitrogen.

References

- AGA Gas, Inc. "Shielding gases for welding — theory and application," Report 1983, p. 10. Lidingo, Sweden: AGA Gas, Inc., 1983.
- American Society of Mechanical Engineers. ANSI B31.3, *Petroleum refining piping*. New York: American Society of Mechanical Engineers.
- ASM. *ASM Metals handbook*, Vol. 6, 8th Ed., p. 214–224 and 915–917. Metals Park, OH: ASM, 1983.
- American Welding Society. D10.11-87, *Recommended practices for root pass welding and gas purging*. Miami, FL: American Welding Society, 1987.
- . A3.0-89, *Standard welding terms and definitions*. Miami, FL: American Welding Society, 1989.
- . *Welding handbook*, 6th Edition, p. 85.27. Miami, FL: American Welding Society.
- . *Welding handbook*, Vol. 2, 7th Ed., p. 296–310. Miami, FL: American Welding Society.
- . C5.1-73, *Recommended practices for plasma arc welding*. Miami, FL: American Welding Society, 1973.
- . C5.2-83, *Recommended practices for plasma arc cutting*. Miami, FL: American Welding Society, 1983.
- . C5.5-80, *Recommended practices for gas tungsten arc welding*. Miami, FL: American Welding Society, 1980.
- . C5.6-89, *Recommended practices for gas metal arc welding*. Miami, FL: American Welding Society, 1989.
- . ANSI/ASC Z49.1-88, *Safety in welding and cutting*. Miami, FL: American Welding Society, 1988.
- Burkle, W. S. and Lighfoot, J. O. "Practical guidelines for pipe purging." *Welding Journal*, p. 34–37, May 1980.
- Cary, H. B. *Modern welding technology*, p. 107–115 and 250–251. Troy, OH: Prentice Hall, Inc., 1979.
- E. Pierre Bungess Publishing Company. *Welding processes and power sources*, 3rd Ed. Minneapolis, MN: E. Pierre Bungess Publishing Company.
- Farwer, A. (Messer-Griesheim), Schweissen Schneiden (ESAB). *Forming gases — gases for root protection in inert welding*. Lidingo: Sweden, December 1983.
- Shirwaikar, C. V. and Reddy, G. P. "Purging with nitrogen in the welding of austenitic stainless steel." *Welding Journal*, p. 12s–15s, January 1975.
- Union Carbide Corporation. *Guidelines for design and installation of industrial gaseous (nitrogen/argon) distribution piping system*, Form L-14-003. Danbury: Linde Division, Union Carbide Corporation, 1982.
- . Union Carbide. *Shielding gases, a guide to their properties, selection, and application*. Danbury: Union Carbide, 1991.
- Wolff, L. and Komers, M. "Considerations on the use of gas mixtures in the shielded arc welding with consumable electrodes." *Welding Journal*, p. 536s–539s, December 1962.

Annex A

(This Annex is not part of ANSI/AWS C5.10-94, *Recommended Practices for Shielding Gases for Welding and Plasma Arc Cutting*.)

FOR INFORMATION ONLY

Table A1
Commonly Used Metric Conversions
(Inch – Millimeter Conversions)

1 in. = 25.4 mm exactly					
To convert inches to millimeters, multiply the inch value by 25.4.			To convert millimeters to inches, divide the millimeter value by 25.4.		
Inch			Inch		
Fraction	Decimal	Millimeter	Fraction	Decimal	Millimeter
1/64	0.015	0.396	33/64	0.515	13.096
1/32	0.031	0.793	17/32	0.531	13.493
3/64	0.046	1.190	35/64	0.546	13.890
1/16	0.062	1.587	9/16	0.562	14.287
5/64	0.078	1.984	37/64	0.578	14.684
3/32	0.093	2.381	19/32	0.593	15.081
7/64	0.109	2.778	39/64	0.609	15.478
1/8	0.125	3.175	5/8	0.625	15.875
9/64	0.140	3.571	41/64	0.640	16.271
5/32	0.156	3.968	21/32	0.656	16.668
11/64	0.171	4.365	43/64	0.671	17.065
3/16	0.187	4.762	11/16	0.687	17.462
13/64	0.203	5.159	45/64	0.703	17.859
7/32	0.218	5.556	23/32	0.718	18.256
15/64	0.234	5.953	47/64	0.734	18.653
1/4	0.250	6.350	3/4	0.750	19.050
17/64	0.265	6.746	49/64	0.765	19.446
9/32	0.281	7.143	25/32	0.781	19.843
19/64	0.296	7.540	51/64	0.796	20.240
5/16	0.312	7.937	13/16	0.812	20.637
21/64	0.328	8.334	53/64	0.828	21.034
11/32	0.343	8.731	27/32	0.843	21.431
23/64	0.359	9.128	55/64	0.859	21.828
3/8	0.375	9.525	7/8	0.875	22.225
25/64	0.390	9.921	57/64	0.890	22.621
13/32	0.406	10.318	29/32	0.906	23.018
27/64	0.421	10.715	59/64	0.921	23.415
7/16	0.437	11.112	15/16	0.937	23.812
29/64	0.453	11.509	61/64	0.953	24.209
15/32	0.468	11.906	31/32	0.968	24.606
31/64	0.484	12.303	63/64	0.984	25.003
1/2	0.500	12.700	1	1.000	25.400

Table A2
Conversion for Fahrenheit – Celsius Temperature Scales

Find the number to be converted in the center (**boldface**) column. If converting Fahrenheit degrees, read the Celsius equivalent in the column headed “°C”. If converting Celsius degrees, read the column headed “°F”. If converting Celsius degrees, read the Fahrenheit equivalent in the column headed “°F”.

°C	°F	°C	°F	°C	°F	°C	°F
-273	-459	-16.7	2	35.6	96	204.8	540
-268	-450	-15.6	4	39.2	98	208.4	550
-262	-440	-14.4	6	42.8	100	212.0	560
-257	-430	-13.3	8	46.4	110	230	570
-251	-420	-12.2	10	50.0	120	248	580
-246	-410	-11.1	12	53.6	130	266	590
-240	-400	-10.0	14	57.2	140	284	600
-234	-390	-8.9	16	60.8	150	302	610
-229	-380	-7.8	18	64.4	160	320	620
-223	-370	-6.7	20	68.0	170	338	630
-218	-360	-5.6	22	71.6	180	356	640
-212	-350	-4.4	24	75.2	190	374	650
-207	-340	-3.3	26	78.7	200	392	660
-201	-330	-2.2	28	82.4	210	410	670
-196	-320	-1.1	30	86.0	212	414	680
-190	-310	0.0	32	89.6	220	428	690
-184	-300	1.1	34	93.2	230	446	700
-179	-290	2.2	36	96.8	240	464	710
-173	-280	3.3	38	100.4	250	482	720
-166	-270	4.4	40	104.0	260	500	730
-162	-260	5.6	42	107.6	270	518	740
-157	-250	6.7	44	111.2	280	536	750
-151	-240	7.8	46	114.8	290	554	760
-146	-230	8.9	48	118.4	300	572	770
-140	-220	10.0	50	122.0	310	590	780
-134	-210	11.1	52	125.6	320	608	790
-129	-200	12.2	54	129.2	330	626	800
-123	-190	13.3	56	132.8	340	644	810
-118	-180	14.4	58	136.4	350	662	820
-112	-170	15.6	60	140.0	360	680	830
-107	-160	16.7	62	143.6	370	698	840
-101	-150	17.8	64	147.2	380	716	850
-96	-140	18.9	66	150.8	390	734	860
-90	-130	20.0	68	154.4	400	752	870
-84	-120	21.1	70	158.0	410	770	880
-79	-110	22.2	72	161.6	420	788	890
-73	-100	23.3	74	165.2	430	806	900
-68	-90	24.4	76	168.8	440	824	910
-62	-80	25.6	78	172.4	450	842	920
-57	-70	26.7	80	176.0	460	860	930
-51	-60	27.8	82	179.6	470	878	940
-46	-50	28.9	84	183.2	480	896	950
-40	-40	30.0	86	186.8	490	914	960
-34	-30	31.1	88	190.4	500	932	970
-29	-20	32.2	90	194.0	510	950	980
-23	-10	33.3	92	197.6	520	968	990
-17.8	0	34.4	94	201.2	530	986	1000

(continued)

Table A2 (Continued)

°C	°F	°C	°F	°C	°F	°C	°F
543	1010	1850	821	1510	2750	1099	2010
549	1020	1868	827	1520	2768	1104	2020
554	1030	1886	832	1530	2786	1110	2030
560	1040	1904	838	1540	2804	1116	2040
566	1050	1922	843	1550	2822	1121	2050
571	1060	1940	849	1560	2840	1127	2060
577	1070	1958	854	1570	2858	1132	2070
582	1080	1976	860	1580	2876	1138	2080
588	1090	1994	866	1590	2894	1143	2090
593	1100	2012	871	1600	2912	1149	2100
599	1110	2030	877	1610	2930	1154	2110
604	1120	2048	882	1620	2948	1160	2120
610	1130	2066	888	1630	2966	1166	2130
616	1140	2084	893	1640	2984	1171	2140
621	1150	2102	899	1650	3002	1177	2150
627	1160	2120	904	1660	3020	1182	2160
632	1170	2138	910	1670	3038	1188	2170
638	1180	2156	916	1680	3056	1193	2180
643	1190	2174	921	1690	3074	1199	2190
649	1200	2192	927	1700	3092	1204	2200
654	1210	2210	932	1710	3110	1210	2210
660	1220	2228	938	1720	3128	1216	2220
666	1230	2246	943	1730	3146	1221	2230
671	1240	2264	949	1740	3164	1227	2240
677	1250	2282	954	1750	3182	1232	2250
682	1260	2300	960	1760	3200	1238	2260
688	1270	2318	966	1770	3218	1243	2270
693	1280	2336	971	1780	3236	1249	2280
699	1290	2354	977	1790	3254	1254	2290
704	1300	2372	982	1800	3272	1260	2300
710	1310	2390	988	1810	3290	1266	2310
716	1320	2408	993	1820	3308	1271	2320
721	1330	2426	999	1830	3326	1277	2330
727	1340	2444	1004	1840	3344	1282	2340
732	1350	2462	1010	1850	3362	1288	2350
738	1360	2480	1016	1860	3380	1293	2360
743	1370	2498	1021	1870	3398	1299	2370
749	1380	2516	1027	1880	3416	1304	2380
754	1390	2534	1032	1890	3434	1310	2390
760	1400	2552	1038	1900	3452	1316	2400
766	1410	2570	1043	1910	3470	1321	2410
771	1420	2588	1049	1920	3488	1327	2420
777	1430	2606	1054	1930	3506	1332	2430
782	1440	2624	1060	1940	3524	1338	2440
788	1450	2642	1066	1950	3542	1343	2450
793	1460	2660	1071	1960	3560	1349	2460
799	1470	2678	1077	1970	3578	1354	2470
804	1480	2696	1082	1980	3596	1360	2480
810	1490	2714	1088	1990	3614	1366	2490
816	1500	2732	1093	2000	3632	1371	2500

°C = 5/9 (°F - 32)

°F = 9/5 (°C + 32)

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Table A3
Dew Point Conversion Chart

D.P. (°F)	D.P. (°C)	ppm	D.P. (°F)	D.P. (°C)	ppm	D.P. (°F)	D.P. (°C)	ppm
-130	-90.0	0.1	-73	-58.3	13.3	-38	-38.9	144
-120	-84.4	0.25	-72	-57.8	14.3	-37	-38.3	153
-110	-78.9	0.63	-71	-57.2	15.4	-36	-37.8	164
-105	-76.1	1.00	-70	-56.7	16.6	-35	-37.2	174
-104	-75.6	1.08	-69	-56.1	17.9	-34	-37.7	185
-103	-75.0	1.18	-68	-55.6	19.2	-33	-36.1	196
-102	-74.4	1.29	-67	-55.0	20.6	-32	-35.6	210
-101	-73.9	1.40	-66	-54.4	22.1	-31	-35.0	222
-100	-73.3	1.53	-65	-53.9	23.6	-30	-34.4	235
-99	-72.8	1.66	-64	-53.3	25.6	-29	-33.9	250
-98	-72.2	1.81	-63	-52.8	27.5	-28	-33.3	265
-97	-71.7	1.96	-62	-52.2	29.4	-27	-32.8	283
-96	-71.1	2.15	-61	-51.7	31.7	-26	-32.2	300
-95	-70.6	2.35	-60	-51.1	34.0	-25	-31.7	317
-94	-70.0	2.54	-59	-50.6	36.5	-24	-31.1	338
-93	-69.4	2.76	-58	-50.0	39.0	-23	-30.6	358
-92	-68.9	3.00	-57	-49.4	41.8	-22	-30.0	378
-91	-68.3	3.28	-56	-48.9	44.6	-21	-29.4	400
-90	-67.8	3.53	-55	-48.3	48.0	-20	-28.9	422
-89	-67.2	3.84	-54	-47.8	51	-19	-28.3	448
-88	-66.7	4.15	-53	-47.2	55	-18	-27.8	475
-87	-66.1	4.50	-52	-46.7	59	-17	-27.2	500
-86	-65.6	4.78	-51	-46.1	62	-16	-26.7	530
-85	-65.0	5.3	-50	-45.6	67	-15	-26.1	560
-84	-64.4	5.7	-49	-45.0	72	-14	-25.6	590
-83	-63.9	6.2	-48	-44.4	76	-13	-25.0	630
-82	-63.3	6.6	-47	-43.9	82	-12	-24.4	660
-81	-62.8	7.2	-46	-43.3	87	-11	-23.9	700
-80	-62.2	7.8	-45	-42.8	92	-10	-23.3	740
-79	-61.7	8.4	-44	-42.2	98	-9	-22.8	780
-78	-61.1	9.1	-43	-41.7	105	-8	-22.2	820
-77	-60.6	9.8	-42	-41.1	113	-7	-21.7	870
-76	-60.0	10.5	-41	-40.6	119	-6	-21.1	920
-75	-59.4	11.4	-40	-40.0	128	-5	-20.6	970
-74	-58.9	12.3	-39	-39.4	136	-4	-20.0	1020

Table A4
Liquid and Gaseous Argon, Hydrogen, Air, Nitrogen, Oxygen, and Helium

Argon						
	Weight		Gas		Liquid	
	Pounds lb	Kilograms kg	Cubic Feet scf	Cubic Meters nm³	Gallons gal	Liters L
1 lb	1.0	0.4536	9.67	0.274	0.086	0.326
1 kg	2.205	1.0	21.32	0.604	0.190	0.718
100 scf gas	10.34	4.690	100.0	2.832	0.889	3.557
1 nm ³ gas	3.652	1.656	35.31	1.0	0.314	1.189
1 gal liquid	11.628	5.274	112.45	3.184	1.0	3.785
1 L liquid	3.072	1.393	29.71	0.841	0.2642	1.0

Scf (standard cubic foot) gas measured at 1 atm and 70°F. Nm³ (normal cubic meter) gas measured at 1 atm and 0°C. Liquid measured at 1 atm and boiling temperature. All values to nearest 4/5 significant numbers.

Hydrogen						
	Weight		Gas		Liquid	
	Pounds lb	Kilograms kg	Cubic Feet scf	Cubic Meters nm³	Gallons gal	Liters L
1 lb	1.0	0.4536	191.96	5.436	1.693	6.409
1 kg	2.205	1.0	423.20	11.984	3.733	14.130
100 scf gas	0.521	0.236	100.0	2.832	0.882	3.339
1 nm ³ gas	0.184	0.083	35.31	1.0	0.311	1.179
1 gal liquid	0.591	0.268	113.37	3.210	1.0	3.785
1 L liquid	0.156	0.071	29.95	0.348	0.264	1.0

Scf (standard cubic foot) gas measured at 1 atm and 70°F. Nm³ (normal cubic meter) gas measured at 1 atm and 0°C. Liquid measured at 1 atm and boiling temperature. All values to nearest 4/5 significant numbers.

Air						
	Weight		Gas		Liquid	
	Pounds lb	Kilograms kg	Cubic Feet scf	Cubic Meters nm³	Gallons gal	Liters L
1 lb	1.0	0.4536	13.35	0.351	0.1371	0.5190
1 kg	2.205	1.0	29.42	0.773	0.3023	1.144
100 scf gas	7.493	3.399	100.0	2.628	1.027	3.889
1 nm ³ gas	2.850	1.293	38.04	1.0	0.3911	1.4804
1 gal liquid	7.294	3.306	97.34	2.573	1.0	3.785
1 L liquid	1.927	0.8740	25.71	0.6796	0.2642	1.0

Scf (standard cubic foot) gas measured at 1 atm and 70°F. Nm³ (normal cubic meter) gas measured at 1 atm and 0°C. Liquid measured at 1 atm and boiling temperature. All values to nearest 4/5 significant numbers.

Table A4 (Continued)

Nitrogen						
	Weight		Gas		Liquid	
	Pounds lb	Kilograms kg	Cubic Feet scf	Cubic Meters nm³	Gallons gal	Liters L
1 lb	1.0	0.4536	13.80	0.391	0.148	0.561
1 kg	2.205	1.0	30.43	0.862	0.327	1.237
100 scf gas	7.245	3.286	100.0	2.832	1.074	4.296
1 nm ³ gas	2.558	1.160	35.31	1.0	0.379	1.436
1 gal liquid	6.746	3.060	93.11	2.637	1.0	3.785
1 L liquid	1.782	0.808	24.60	0.697	0.2642	1.0

Scf (standard cubic foot) gas measured at 1 atm and 70°F. Nm³ (normal cubic meter) gas measured at 1 atm and 0°C. Liquid measured at 1 atm and boiling temperature. All values to nearest 4/5 significant numbers.

Oxygen						
	Weight		Gas		Liquid	
	Pounds lb	Kilograms kg	Cubic Feet scf	Cubic Meters nm³	Gallons gal	Liters L
1 lb	1.0	0.4536	12.08	0.342	0.105	0.397
1 kg	2.205	1.0	26.62	0.754	0.231	0.876
100 scf gas	8.281	3.756	100.0	2.832	0.869	3.290
1 nm ³ gas	2.924	1.327	35.31	1.0	0.307	1.162
1 gal liquid	9.527	4.321	115.05	3.258	1.0	3.785
1 L liquid	2.517	1.142	30.39	0.861	0.2642	1.0

Scf (standard cubic foot) gas measured at 1 atm and 70°F. Nm³ (normal cubic meter) gas measured at 1 atm and 0°C. Liquid measured at 1 atm and boiling temperature. All values to nearest 4/5 significant numbers.

Helium						
	Weight		Gas		Liquid	
	Pounds lb	Kilograms kg	Cubic Feet scf	Cubic Meters nm³	Gallons gal	Liters L
1 lb	1.0	0.4536	96.72	2.739	0.959	3.631
1 kg	2.205	1.0	213.23	6.038	2.115	8.006
100 scf gas	1.042	0.473	100.0	2.855	1.000	3.785
1 nm ³ gas	0.365	0.166	35.31	1.0	0.350	1.326
1 gal liquid	1.042	0.473	100.00	2.855	1.0	3.785
1 L liquid	0.275	0.125	26.63	0.734	0.264	1.0

Scf (standard cubic foot) gas measured at 1 atm and 70°F. Nm³ (normal cubic meter) gas measured at 1 atm and 0°C. Liquid measured at 1 atm and boiling temperature. All values to nearest 4/5 significant numbers.

Table A5
Cylinder and Valve Data: Oxygen, Nitrogen, and Oxygen-Nitrogen Mixtures

Gas	Contents (cf)	Full Cyl. Pressure at 70°F (psi)	Height Incl. Cap (in)	Outside Diameter (in)	Approximate Weight		Cylinder Valve Outlet Connection CGA No.
					Full (lb)	Empty (lb)	
Oxygen	337	2,640	60	9-1/4	172	146	540
	251	2,200	51	9	153	133	540
	125	2,200	43	7	92	82	540
Liquid	3,350	—	58	20	517	240	—
Oxygen	4,200	—	62	20	572	224	—
	3,000	—	57	20	468	220	540
	4,500	—	62-1/4	20	623	250	540
Oxygen + Nitrogen	*	2,200	56	9	*	133	540 ^a
Nitrogen	304	2,640	55	9-1/4	165	143	580
	230	2,200	51	9	149	133	580
	115	2,200	43	7	124	116	580
Nitrogen	2,700	—	58	20	435	240	—
	3,410	—	62	20	471	224	—
	3,930	—	58	20	503	218	—
	2,440	—	58	20	399	220	580
	3,640	—	62-1/4	20	514	250	580
Nitrogen + Hydrogen	*	2,000	56	9	*	133	350

*Dependent on relative proportions of component gases.

a. Less than 5% oxygen, CGA 580; 5–23% oxygen, CGA 590; over 23% oxygen, CGA 296.

Table A6
Shielding Gas, Cylinder, and Valve Data

Gas	Contents (cf)	Full Cyl. Pressure at 70°F (psi)	Height Incl. Cap (in)	Outside Diameter (in)	Approximate Weight		Cylinder Valve Outlet Connection CGA No.
					Full (lb)	Empty (lb)	
Argon	336	2,640	60	9-1/4	177	143	580
	280	2,200	56	9	158	133	580
	150	2,200	43	7	95	80	580
Liquid	3,290	—	58	20	580	240	—
Argon	4,035	—	62	20	641	224	—
	2,900	—	58	20	519	220	580
	4,320	—	62-1/4	20	697	250	580
Argon + Oxygen	*	2,640	60	9-1/4	*	143	580
Argon + Hydrogen	*	2,000	56	9	*	133	350
Argon + Carbon Dioxide	*	2,640	60	9-1/4	*	143	580
Argon + Nitrogen	*	2,640	60	9-1/4	*	143	580
Helium	291	2,640	55	9-1/4	146	143	580
	219	2,200	51	9	135	133	580
	110	2,200	43	7-3/8	82	80	580
Liquid	800	—	44-1/4	18-3/4	91-1/2	83	—
Helium	2,663	—	62	20	272*	200	—
Argon + Helium	* *	2,640 2,200	60 56	9-1/4 9	* *	143 143	580 580
Helium + Argon + Oxygen	214	2,200	56	9	135	133	580
Helium + Argon Carbon + Dioxide	213	2,200	56	9	135	133	580
Carbon Dioxide	437 (50 lb)	1,000	51	9	183	133	320

*Dependent on relative proportions of component gases.

a. Includes shipping skid.

AWS Arc Welding and Cutting Document List

AWS Designation	Title
C5.1	Recommended Practices for Plasma Arc Welding
C5.2	Recommended Practices for Plasma Arc Welding
C5.3	Recommended Practices for Air Carbon Arc Gouging and Cutting
C5.4	Recommended Practices for Stud Welding
C5.5	Recommended Practices for Gas Tungsten Arc Welding
C5.6	Recommended Practices for Gas Metal Arc Welding
C5.7	Recommended Practices for Electrode Gas Welding
C5.10	Recommended Practices for Shielding Gases for Welding and Plasma Arc Cutting

For ordering information, contact the Order Department, American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126. Phone: 1-800-443-9353.