

# **Recommended Practices for Shielding Gases for Welding and Cutting**



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**Key Words**—Shielding gases, gas distribution, gas safety, plasma gas, purging gas, gas mixtures, arc characteristics, dew point, gas properties

**AWS C5.10/C5.10M:2003**  
**An American National Standard**

**Approved by**  
**American National Standards Institute**  
**July 29, 2003**

# **Recommended Practices for Shielding Gases for Welding and Cutting**

**Supersedes ANSI/AWS C5.10-94**

Prepared by  
AWS C5 Committee on Arc Welding and Cutting

Under the Direction of  
AWS Safety and Health Committee

Approved by  
AWS Board of Directors

## **Abstract**

This document is concerned with six industrial gases: argon (Ar), carbon dioxide (CO<sub>2</sub>), helium (He), hydrogen (H), nitrogen (N), and oxygen (O). 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), plasma arc cutting (PAC), laser welding (LW) and laser cutting (LC). Gas purging, gas distribution and safety practices are also covered.



**American Welding Society**

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



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| <i>D. A. Fink</i>                     | The Lincoln Electric Company      |
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## AWS C5O Subcommittee on Shielding Gases

|                                  |                                   |
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| <i>*G. A. Risher</i>             | Consultant                        |
| <i>*J. M. Zawodny</i>            | Linde Gas LLC                     |

\*Advisor

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# Foreword

(This Foreword is not a part of [AWS C5.10/C5.10M:2003](#), *Recommended Practices for Shielding Gases for Welding and Cutting*, but is included for informational purposes only.)

This standard was first published in 1994 and has been recently revised to reflect advancements in the area of shielding gases and the welding processes that use them, and to more clearly and accurately depict the roles and properties of shielding gases in welding. 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.

Comments and suggestions for the improvement of this standard are welcomed. They should be sent to the Secretary, AWS C5 Committee on Arc Welding and Cutting, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

Official interpretations of any of the technical requirements of this standard may be obtained by sending a request, in writing, to the Managing Director, Technical Services Division, American Welding Society. A formal reply will be issued after it has been reviewed by the appropriate personnel following established procedures.

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# Table of Contents

|                                                                                                    | Page No. |
|----------------------------------------------------------------------------------------------------|----------|
| <i>Personnel</i> .....                                                                             | iii      |
| <i>Foreword</i> .....                                                                              | v        |
| <i>List of Tables</i> .....                                                                        | ix       |
| <i>List of Figures</i> .....                                                                       | ix       |
| 1. Scope .....                                                                                     | 1        |
| 2. Normative References .....                                                                      | 1        |
| 2.1 American Conference of Governmental Industrial Hygienists Standards .....                      | 1        |
| 2.2 ASME Standards .....                                                                           | 1        |
| 2.3 AWS Standards .....                                                                            | 1        |
| 2.4 CGA Standards .....                                                                            | 2        |
| 2.5 OSHA Standards .....                                                                           | 2        |
| 2.6 NFPA Standards .....                                                                           | 2        |
| 3. Purpose of Shielding Gas and Gas Properties .....                                               | 2        |
| 3.1 General .....                                                                                  | 2        |
| 3.2 Specific Gas Properties .....                                                                  | 2        |
| 4. Applications of Gases in Welding and Cutting .....                                              | 4        |
| 4.1 Gas Tungsten Arc Welding .....                                                                 | 4        |
| 4.2 Gas Metal Arc Welding .....                                                                    | 7        |
| 4.3 Flux Cored Arc Welding .....                                                                   | 19       |
| 4.4 Plasma Arc Welding .....                                                                       | 20       |
| 4.5 Electrode Gas Welding .....                                                                    | 21       |
| 4.6 Laser Beam Welding .....                                                                       | 22       |
| 4.7 Laser Beam Cutting .....                                                                       | 24       |
| 4.8 Plasma Arc Cutting .....                                                                       | 25       |
| 4.9 Purging and Backing Gases Used in Gas Shielded Welding .....                                   | 30       |
| 5. Gas Supply Systems .....                                                                        | 33       |
| 5.1 High-Pressure Cylinders .....                                                                  | 33       |
| 5.2 Other Supply Systems .....                                                                     | 33       |
| 5.3 Piping Systems .....                                                                           | 34       |
| 6. Shielding and Cutting Gas Safety .....                                                          | 35       |
| 6.1 Introduction .....                                                                             | 35       |
| 6.2 Safe Handling of High-Pressure and Liquid Cylinders .....                                      | 37       |
| 6.3 Safety Precautions for Specific Gases .....                                                    | 38       |
| 6.4 The Generation of Welding Fume and Pollutant Gases .....                                       | 39       |
| <i>Nonmandatory Annexes</i> .....                                                                  | 41       |
| <i>Annex A—Tables for Conversions and Gas Cylinder and Valve Data</i> .....                        | 41       |
| <i>Annex B—Supplementary Reading List</i> .....                                                    | 49       |
| <i>Annex C—Guideline for Preparation of Technical Inquiries for AWS Technical Committees</i> ..... | 51       |
| <i>List of AWS Documents on Arc Welding and Cutting</i> .....                                      | 53       |

# List of Tables

| Table                                                                                                                     | Page No. |
|---------------------------------------------------------------------------------------------------------------------------|----------|
| 1 Properties of Gases.....                                                                                                | 3        |
| 2 Gas Type, Purity and Moisture Requirements, and Dew Point Data for Shielding Gas Components.....                        | 3        |
| 3 Dew Point of Carbon Dioxide versus Percent Moisture in Carbon Dioxide .....                                             | 4        |
| 4 Recommended Types of Current, Tungsten Electrodes, and Shielding Gases for GTAW<br>of Different Metals and Alloys ..... | 6        |
| 5 Globular-to-Spray Transition Currents for Various Electrodes.....                                                       | 11       |
| 6 Gas Selection for Gas Metal Arc Welding .....                                                                           | 13       |
| 7 Shielding Gases for Electrode Gas Welding.....                                                                          | 23       |
| 8 Typical Conditions for Plasma Arc Cutting of Aluminum Alloys.....                                                       | 29       |
| 9 Typical Conditions for Plasma Arc Cutting of Stainless Steels .....                                                     | 29       |
| 10 Typical Conditions for Plasma Arc Cutting of Carbon Steel.....                                                         | 29       |
| 11 Purging Gas Recommendations .....                                                                                      | 31       |
| A1 Commonly Used Metric Conversions (Inch to Millimeter Conversions) .....                                                | 41       |
| A2 Conversions for Fahrenheit-Celsius Temperature Scales.....                                                             | 42       |
| A3 Dew Point Conversion Chart.....                                                                                        | 44       |
| A4 Liquid and Gaseous Argon, Hydrogen, Air, Nitrogen, Oxygen, and Helium.....                                             | 45       |
| A5 Gas Cylinder and Valve Data: Oxygen, Nitrogen, and Oxygen-Nitrogen Mixtures.....                                       | 46       |
| A6 Gas Cylinder and Valve Data: Shielding Gases .....                                                                     | 47       |

# List of Figures

| Figure                                                                                                                                                                    | Page No. |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| 1 The Gas Tungsten Arc Welding Process .....                                                                                                                              | 5        |
| 2 The Gas Metal Arc Welding Process .....                                                                                                                                 | 8        |
| 3a Stylized Representation of the Short-Circuiting Transfer Mode .....                                                                                                    | 9        |
| 3b Schematic Representation of the Short-Circuiting Transfer Mode .....                                                                                                   | 9        |
| 4a Stylized Representation of the Globular Transfer Mode in Argon .....                                                                                                   | 10       |
| 4b Stylized Representation of the Globular “Buried Arc” Transfer Mode in CO <sub>2</sub> .....                                                                            | 10       |
| 5 Stylized Representation of the Spray Transfer Mode .....                                                                                                                | 10       |
| 6 Stylized Representation of the Pulsed Spray Transfer Mode .....                                                                                                         | 12       |
| 7 Stylized Representation of the Rotational Spray Transfer Mode .....                                                                                                     | 12       |
| 8 Comparative Ionization Potential and Arc Columns with Argon, Carbon Dioxide, and Helium .....                                                                           | 16       |
| 9 Typical GMAW Bead and Penetration Profiles with Several Shielding Gases .....                                                                                           | 16       |
| 10 Typical Spatter Levels versus Welding Current with Three Common Shielding Gases<br>and 0.045 in. [1.2 mm] Diameter Carbon and Low Alloy Steel Welding Electrodes ..... | 17       |
| 11 The Effect of Argon and Helium Shielding Gases on Bead Profile and Penetration when<br>Welding Aluminum with GMAW .....                                                | 18       |
| 12 The Flux Cored Arc Welding Process .....                                                                                                                               | 20       |
| 13 Schematic Diagrams of Plasma Arc Welding Showing the Arc and Heat of Fusion Patterns .....                                                                             | 21       |
| 14 The Electrode Gas Welding Process .....                                                                                                                                | 23       |
| 15 Dual Flow Plasma Arc Cutting .....                                                                                                                                     | 26       |
| 16 Water Injection Plasma Arc Cutting .....                                                                                                                               | 26       |
| 17 Gas Selection Guide for Plasma Arc Cutting .....                                                                                                                       | 27       |
| 18 Pre-Purge Time for One Volume Change .....                                                                                                                             | 32       |
| 19 Manifold System .....                                                                                                                                                  | 34       |
| 20 Carbon Dioxide Gas Cylinder .....                                                                                                                                      | 35       |
| 21 Liquid Cylinders .....                                                                                                                                                 | 35       |
| 22 Bulk Storage Vessels .....                                                                                                                                             | 36       |
| 23 Tube Trailer .....                                                                                                                                                     | 36       |
| 24 Fume Generation Rates for the GMAW Process .....                                                                                                                       | 40       |

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# Recommended Practices for Shielding Gases for Welding and Cutting

## 1. Scope

This publication presents basic concepts relating to gas usage for each 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.<sup>1</sup> In addition, safe practices and specific technical data are included as guides in an effort to establish optimum operation of the selected welding or cutting process.

The reader will learn the process and specific advantages and disadvantages for each. Standard welding and cutting equipment is 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.*

This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements may not be exact equivalents; therefore each system must be used independently of the other without combining in any way. The specification with the designation C5.10 uses U.S. Customary Units. The specification C5.10M uses SI units. The latter are shown in appropriate columns in tables or within brackets [ ] when used in the text.

Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Information on safe handling of gases and cylinders can be found in Section 6. Safety and health information is available from other sources, including, but not limited to, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, applicable federal and state regulations, and local safety codes.

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

## 2. Normative References

If a code or other standard is cited without a date of publication, it is understood that the latest edition of the document referred to applies. If a code or other standard is cited with the date of publication, the citation refers to that edition only, and it is understood that any future revisions or amendments to the code or standard are not included; however, as codes and other standards undergo frequent revision, the reader is encouraged to consult the most recent edition.

### 2.1 American Conference of Governmental Industrial Hygienists Standards<sup>2</sup>

(1) ACGIH, *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*

### 2.2 ASME Standards<sup>3</sup>

(1) ASME B31.3, *Process Piping*

### 2.3 AWS Standards<sup>4</sup>

(1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

(2) AWS A1.1, *Metric Practice Guide for the Welding Industry*

(3) AWS. A3.0, *Standard Welding Terms and Definitions*

2. ACGIH standards are published by the American Conference of Governmental Industrial Hygienists, 1330 Kemper Meadow Drive, Cincinnati, OH 45240-1634.

3. ASME standards are published by the American Society of Mechanical Engineers, 3 Park Avenue, New York, NY 10017.

4. ANSI Z49.1 and AWS standards are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

(4) AWS A5.12, *Specification for Tungsten and Tungsten Alloy Electrodes for Arc Welding and Cutting*

(5) AWS A5.26, *Specification for Carbon and Low Alloy Steel Electrodes for Electrode Gas Welding*

(6) AWS A 5.32, *Specification for Welding Shielding Gases*

(7) AWS C5.1, *Recommended Practices for Plasma Arc Welding*

(8) AWS C5.2, *Recommended Practices for Plasma Arc Cutting*

(9) AWS C5.5, *Recommended Practices for Gas Tungsten Arc Welding*

(10) AWS C5.6, *Recommended Practices for Gas Metal Arc Welding*

(11) AWS C5.7, *Recommended Practices for Electrode Gas Welding*

(12) AWS C7.2, *Recommended Practices for Laser Beam Welding, Cutting, and Drilling*

(13) AWS D10.11, *Recommended Practices for Root Pass Welding of Pipe Without Backing*

(14) AWS D18.1, *Specification for Welding of Austenitic Stainless Steel Tube and Pipe Systems in Sanitary (Hygienic) Applications*

(15) AWS D1.1, *Structural Welding Code—Steel*

(16) AWS D1.2, *Structural Welding Code—Aluminum*

(17) AWS D1.3, *Structural Welding Code—Sheet Steel*

(18) AWS D1.5, *Bridge Welding Code*

(19) AWS D1.6, *Structural Welding Code—Stainless Steel*

## 2.4 CGA Standards<sup>5</sup>

(1) CGA Pamphlet, *Industrial Practices for Gaseous Transmission and Distribution Piping Systems*

## 2.5 OSHA Standards<sup>6</sup>

(1) Code of Federal Regulations (OSHA), *Title 29 Labor, Parts 1910.1 to 1910.1450*

## 2.6 NFPA Standards<sup>7</sup>

(1) NFPA 50A, *Standard for Gaseous Hydrogen Systems at Consumer Sites*

(2) NFPA 50B, *Standard for Liquefied Hydrogen Systems at Consumer Sites*

5. Available through: Compressed Gas Association, 1725 Jefferson Davis Hwy., Arlington, VA 22202-4100.

6. Available through: U.S. Government Printing Office, Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954.

7. Available through: National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269-9101.

## 3. Purpose of Shielding Gas and Gas Properties

**3.1 General.** 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. The following are specific property descriptions:

**3.1.1 Ionization Potential.** 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.

**3.1.2 Thermal Conductivity.** 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 producing a broader plasma and more even heat distribution.

**3.1.3 Reactivity.** 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:

(a) *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 hardenable steels, this shielding gas can produce some adverse effects, such as underbead or hydrogen-induced cracking.

(b) *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.

(c) *Nitrogen*, when exposed to elevated temperatures associated with welding, will react with metallic elements to form nitrides. Nitrogen will cause porosity and loss of toughness in ferritic (carbon steel, low alloy, and alloy steel) welds. Nitrogen can dissolve in nominally austenitic and duplex stainless steel weld metals, and, as an alloy element, it reduces ferrite content.

**3.2 Specific Gas Properties.** Table 2 shows the AWS and CGA classifications, purity and moisture requirements, and dew point data for shielding gas components.

**Table 1**  
**Properties of Gases**

| Properties                          | Units                                      | Argon              | Helium             | Hydrogen <sup>(1)</sup> | Carbon Dioxide                  | Nitrogen           | Oxygen             |
|-------------------------------------|--------------------------------------------|--------------------|--------------------|-------------------------|---------------------------------|--------------------|--------------------|
| Density <sup>(2)</sup>              | lb/ft <sup>3</sup><br>[kg/m <sup>3</sup> ] | 0.103<br>[1.656]   | 0.0103<br>[0.1656] | 0.0052<br>[0.0834]      | 0.114<br>[1.833]                | 0.0725<br>[1.1605] | 0.0828<br>[1.326]  |
| Liquid Density <sup>(3)</sup>       | lb/ft <sup>3</sup><br>[kg/m <sup>3</sup> ] | 86.98<br>[1394]    | 7.803<br>[125]     | 4.28<br>[68.6]          | 63.3 <sup>(4)</sup><br>[1014]   | 50.9<br>[808.8]    | 51.22<br>[820.5]   |
| Heat of Vaporization <sup>(5)</sup> | btu/lb<br>[kJ/kg]                          | 69.7<br>[162.0]    | 8.77<br>[20.4]     | 192.7<br>[448.2]        | 119.0 <sup>(6)</sup><br>[276.8] | 85.6<br>[149.1]    | 91.7<br>[213.0]    |
| Boiling Point <sup>(7)</sup>        | °F<br>[°C]                                 | −302.6<br>[−185.9] | −452.0<br>[−268.9] | −423.0<br>[−252.7]      | −109.3<br>[−78.5]               | −320.4<br>[−195.8] | −297.3<br>[−183.0] |
| Thermal Conductivity <sup>(8)</sup> | btu/hr ft °F<br>[watt/m K]                 | 0.0094<br>[0.0153] | 0.0886<br>[0.1532] | 0.1008<br>[0.175]       | 0.0093<br>[0.0162]              | 0.0147<br>[0.0254] | 0.0149<br>[0.0258] |
| Ionization Potential                | eV                                         | 15.7               | 24.5               | 13.5                    | 14.4                            | 14.5               | 13.2               |
| Molecular Weight                    |                                            | 39.94              | 4.003              | 2.016                   | 44.01                           | 28.013             | 31.99              |

Notes:

(1) Flammable limits of hydrogen:

in air: 4.1%–74.2% (vol.).

in O<sub>2</sub>: 4.7%–93.9% (vol.).

(2) At 70°F [21°C] and 1 atm.

(3) At boiling point.

(4) Saturated liquid at 1.7°F [−16.8°C].

(5) All at boiling point except CO<sub>2</sub>.

(6) Liquid CO<sub>2</sub> at 300 psi [2.07 MPa] and 1.7°F [−16.8°C].

(7) All at 1 atm. except CO<sub>2</sub> at sublimation point.

(8) All at 32°F [0°C] except CO<sub>2</sub> at 77°F [25°C].

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

| Gas            | AWS <sup>(1)</sup><br>Class | Product<br>State | Minimum<br>Purity (%) | Maximum<br>Moisture <sup>(2)</sup><br>(ppm) | Approximate Dewpoint<br>at Maximum Moisture<br>Content °F | °C  | CGA Class                |
|----------------|-----------------------------|------------------|-----------------------|---------------------------------------------|-----------------------------------------------------------|-----|--------------------------|
| Argon          | SG-A                        | Gas              | 99.997                | 10.5                                        | −76                                                       | −60 | Type I: G-II.1 Grade C   |
|                |                             | Liquid           | 99.997                | 10.5                                        | −76                                                       | −60 | Type II: G-I 1.1 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 <sup>(3)</sup> | 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 <sup>(4)</sup>  | 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:

(1) Per AWS A5.32.

(2) Moisture specifications are guaranteed at full cylinder pressure, at which the cylinder is analyzed.

(3) Including neon.

(4) Including helium.

**3.2.1 Argon.** Argon (Ar) is denser than air, is chemically inert, is colorless and odorless both as a gas and as a liquid, and constitutes slightly less than 1% 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.

**3.2.2 Helium.** Helium (He), the second least dense known element, is chemically inert, and less soluble in liquids than any other gas. Helium is used either alone or in combination with other gases for several welding, cutting and purging applications and processes.

**3.2.3 Hydrogen.** Hydrogen (H), the least dense known element, is chemically active; its high heat conductivity makes its mixtures useful in selected welding and cutting applications. See **WARNING** in 6.3.6.

**3.2.4 Nitrogen.** Nitrogen (N), which is less dense than air, accounts for 78% 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 non-welding applications.

**3.2.5 Oxygen.** Oxygen (O), which is denser than air, accounts for 50% of the earth's crust and 21%, by volume, of the atmosphere. It vigorously supports combustion and combines with practically all known elements except the inert gases. Additions of small percentages of oxygen to inert gases influence process characteristics of gas metal arc welding (GMAW) and flux cored arc welding (FCAW).

**3.2.6 Carbon Dioxide.** Carbon dioxide (CO<sub>2</sub>), which is denser than air, is a colorless gas with a faintly pungent odor and somewhat acidic taste. While most reactive gases cannot be used alone for shielding; carbon dioxide is an exception. It is extensively used alone as well as a component of gas mixtures. Carbon dioxide alone cannot produce the GMAW spray transfer mode and will exhibit only the short-circuiting or globular transfer modes. Only argon mixtures containing <20% carbon dioxide will produce GMAW spray transfer.

**3.2.6.1 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.

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 for arc welding should not exceed 50 ppm. *Note: For laser gas purity requirements consult laser manufacturer's specifications.*

**3.2.6.2 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.

**3.2.7 Air.** Air is a gaseous mixture comprised of approximately 78% nitrogen, 21% oxygen, various amounts of argon, hydrogen, carbon dioxide, and rare gases such as neon, krypton, and xenon. Air is not usually 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.

## 4. Applications of Gases in Welding and Cutting

**4.1 Gas Tungsten Arc Welding.** Gas tungsten arc welding (GTAW) is an arc welding process that uses an arc between a tungsten electrode (nonconsumable) and the weld pool (Figure 1). 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:

- (1) Can be used to weld most metals and alloys.
- (2) Is easily used in all welding positions.
- (3) Provides excellent control on thin and intricate parts.

**Table 3**  
**Dew Point of Carbon Dioxide versus**  
**Percent Moisture in Carbon Dioxide**

| Dewpoint<br>°F | Dewpoint<br>°C | % Moisture by<br>Weight | ppm Moisture<br>in CO <sub>2</sub> |
|----------------|----------------|-------------------------|------------------------------------|
| -90            | -68            | 0.000353                | 4                                  |
| -80            | -62            | 0.00078                 | 8                                  |
| -70            | -57            | 0.00166                 | 17                                 |
| -60            | -51            | 0.0034                  | 34                                 |
| -50            | -45            | 0.0067                  | 67                                 |
| -40            | -40            | 0.0128                  | 128                                |
| -30            | -34            | 0.0235                  | 235                                |
| -20            | -29            | 0.0422                  | 422                                |
| -10            | -23            | 0.074                   | 740                                |

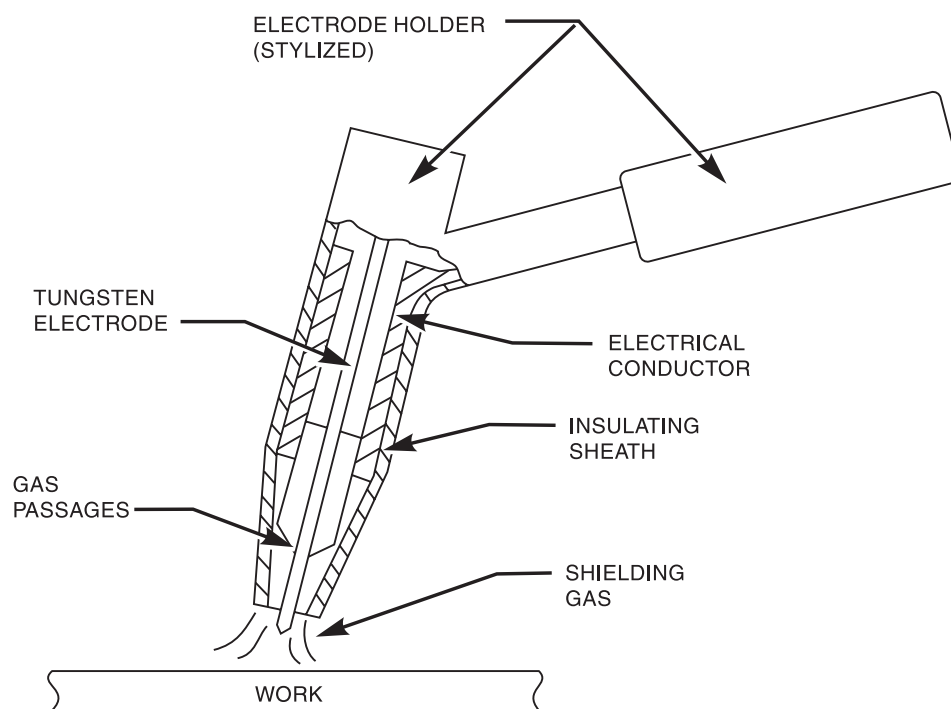


**Figure 1—The Gas Tungsten Arc Welding Process**

(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 a preferred process for critical applications with both ferrous and nonferrous materials.

#### 4.1.1 Shielding Gases (see Table 4)

**4.1.1.1 Argon (SG-A).** 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 (see 4.1.1.2 and 4.1.1.3) for alternating current (AC) welding applications because of enhanced cleaning action, arc stability, and weld appearance. Argon is denser than air, providing adequate shielding at lower flow rates than helium.

**4.1.1.2 Helium (SG-He).** 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. These attributes increase 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.

**4.1.1.3 Argon+Helium (SG-AHe).** Helium is added to argon to take advantage of the best operating characteristics of each gas. The superior arc starting and

**Table 4**  
**Recommended Types of Current, Tungsten Electrodes,**  
**and Shielding Gases for GTAW of Different Metals and Alloys**

| Metal                             | Thickness                                 | Type of Current <sup>(1), (2)</sup> | Tungsten Electrode Type <sup>(3)</sup>                       | Shielding Gases                                                      |
|-----------------------------------|-------------------------------------------|-------------------------------------|--------------------------------------------------------------|----------------------------------------------------------------------|
| Aluminum Alloys                   | All<br>>1/8 in. [3 mm]<br>≤1/8 in. [3 mm] | AC<br>DCEN<br>DCEP                  | Pure or zirconiated<br>Thoriated<br>Thoriated or zirconiated | Argon or argon-helium<br>Argon-helium or argon<br>Argon              |
| Copper and Copper Alloys          | All<br><1/8 in. [3 mm]                    | DCEN<br>AC                          | Thoriated<br>Pure or zirconiated                             | Helium or argon-helium<br>Argon                                      |
| Nickel and Nickel Alloys          | All                                       | DCEN                                | Thoriated                                                    | Argon                                                                |
| Magnesium Alloys                  | All<br><1/8 in. [3 mm]                    | AC<br>DCEP                          | Pure or zirconiated<br>Zirconiated or thoriated              | Argon<br>Argon                                                       |
| Plain Carbon and Low Alloy Steels | All<br><1/8 in. [3 mm]                    | DCEN<br>AC                          | Thoriated or zirconiated<br>Thoriated                        | Argon or argon-helium<br>Argon                                       |
| Stainless Steels                  | All                                       | DCEN                                | Thoriated or zirconiated                                     | Argon, argon-helium, argon-hydrogen (5% max) <sup>(4)</sup><br>Argon |
|                                   |                                           | AC                                  | Thoriated                                                    |                                                                      |
| Titanium Alloys                   | All                                       | DCEN                                | Thoriated <sup>(1)</sup>                                     | Argon, argon-helium                                                  |

Notes:

(1) Where AC is listed, variable polarity or pulse current could be used.

(2) AC = Alternating current; DCEP = Direct current electrode positive; DCEN = Direct current electrode negative.

(3) Where thoriated tungsten electrodes are recommended, ceriated or lanthanated electrodes may also be used.

(4) Austenitic stainless steels only.

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%.

**4.1.1.4 Argon+Hydrogen (SG-AH).** Additions of hydrogen increase the heat input, permitting faster travel, increased depth of fusion, better wetting action, and broader weld bead profile. Argon-hydrogen mixtures provide a reducing atmosphere in the arc, removing oxygen from the weld area. A typical argon-hydrogen mixture is 95% argon and 5% hydrogen. Mixtures of argon and hydrogen are frequently used to weld austenitic stainless steels, nickel, and nickel-based alloys. Argon-hydrogen mixtures should not be used to weld carbon or low alloy steels because of the potential of hydrogen-induced cracking.

Special safety precautions are required when mixing argon and hydrogen. **Users should NOT mix argon and hydrogen from separate cylinders without the use of approved mixing equipment.** See **WARNING** in 6.3.6.

**4.1.2 Shielding Gas Flow Rates.** Shielding gas flow rates are influenced by the factors listed below. For example, the type of gas affects flow rates that may be required to produce a satisfactory weld. Argon can be used for GTAW on all base metals. Typical flow rates are from 10 scfh to 35 scfh [5 L/min to 16 L/min]. Helium is less dense than argon and therefore may require higher flow rates.

- (1) Type of base metal
- (2) Type and position of joint
- (3) Torch position
- (4) Amperage
- (5) Type of gas
- (6) Gas nozzle type and size
- (7) Manual or automatic welding mode
- (8) Outdoor conditions such as wind

## 4.2 Gas Metal Arc Welding

**4.2.1 Process Description.** Gas metal arc welding (GMAW) is a welding process that uses an arc between a continuous filler metal electrode (which can be solid or metal cored) and the weld pool, as shown in Figure 2. The arc continuously melts the wire as it is fed to the weld pool, and both are protected from the atmosphere by the flow of shielding gas.

**4.2.2 Process Variations and Metal Transfer Modes.** The GMAW process includes distinctive metal transfer modes: short-circuiting transfer, globular transfer (in argon and in carbon dioxide), spray transfer, pulsed spray transfer, and high-current-density rotational

or non-rotational spray (high deposition) transfer. Factors that determine metal transfer mode are current, electrode alloy type, electrode diameter, arc length, power supply characteristics, and shielding gas.

**4.2.2.1 Short-Circuiting Transfer Mode.** The short-circuiting transfer mode occurs at low welding current and arc voltage. The arc characteristics of this transfer mode 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 thicker than 1/8 in. [3 mm], extreme care must be taken to prevent incomplete fusion. Since heat input is usually low, distortion of the work piece is minimized.

The electrode feeds at a constant speed and contacts the work piece 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 work piece. At that point in the sequence, there is no metal transfer across the arc (see Figures 3a, 3rd sketch and 3b, sketches E, F, G, H, and I).<sup>8</sup> The welding wire short-circuiting sequence repeats itself from 50 to 250 times per second.

**4.2.2.2 Globular Transfer Mode.** Globular transfer takes place when the 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 an irregular drop size approximately 2 to 4 times the diameter of the electrode (see Figures 4a and 4b). 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 droplet surface tension and 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.

**4.2.2.3 Spray Transfer Mode.** In an argon-rich shielding gas, the transfer mode 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" (see Table 5). Spray transfer in argon has a constricted arc column and pointed electrode tip (see Figure 5).

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

8. Source: AWS *Welding Handbook*, Volume 2, Eighth Edition, p. 113, Figure 4.3.

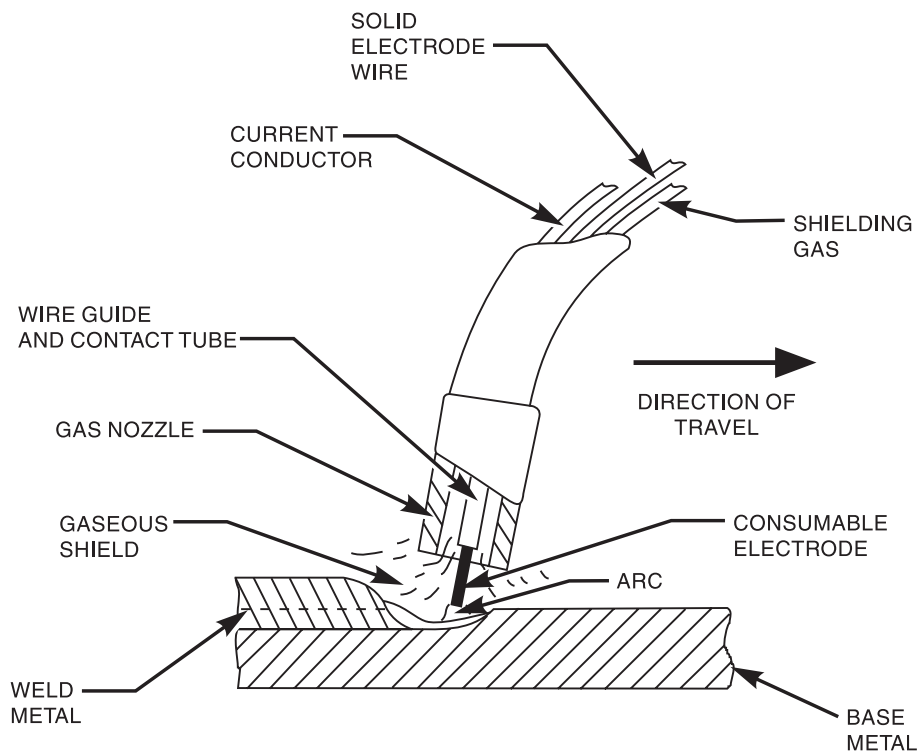


**Figure 2—The Gas Metal Arc Welding Process**

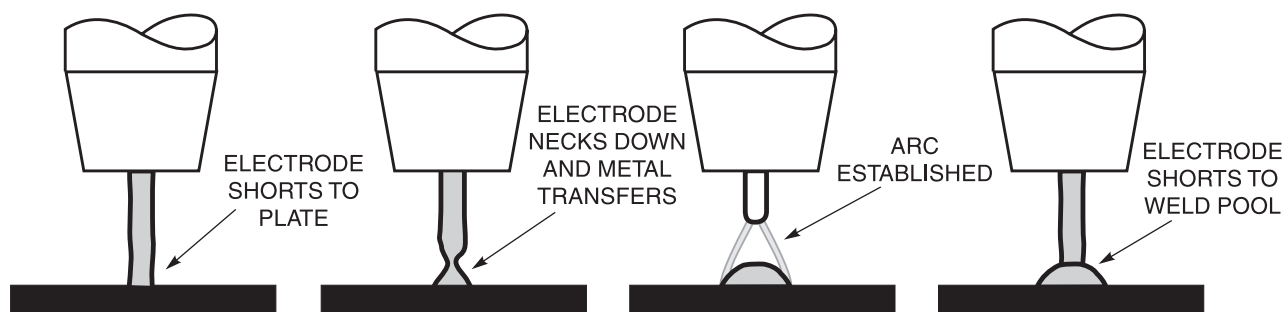


**Figure 3a—Stylized Representation of the Short-Circuiting Transfer Mode**

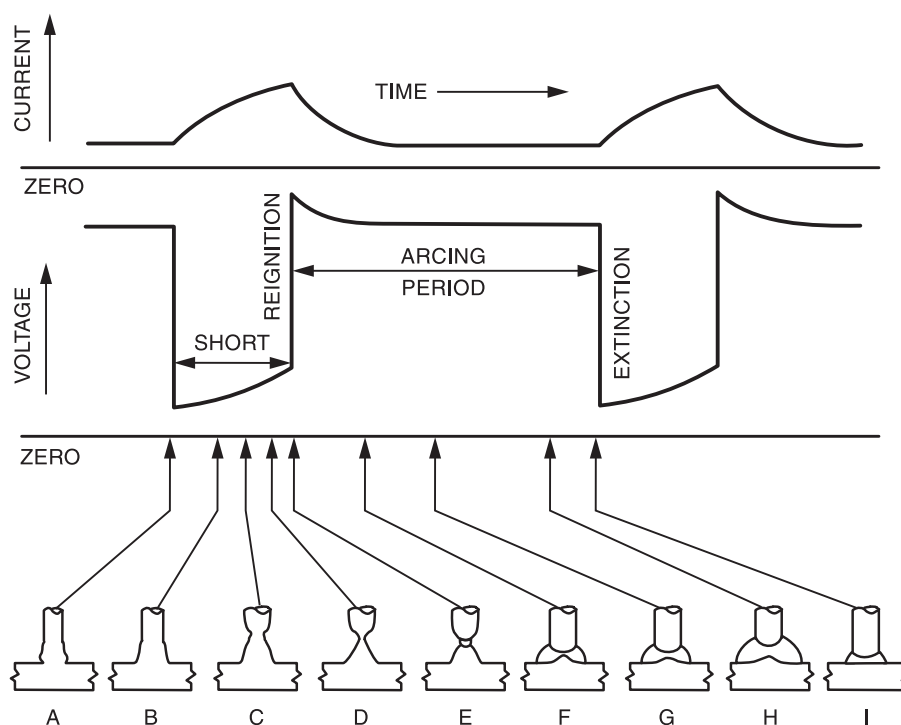


**Figure 3b—Schematic Representation of the Short-Circuiting Transfer Mode**

**4.2.2.4 Pulsed Spray Transfer Mode.** In the pulsed spray transfer mode, 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 work piece only during the high current pulse. Ideally, one small droplet is transferred during each pulse (see Figure 6).

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 and heat input allow for all-position welding of base metals less than 1/8 in. [3 mm] thick with a spray-type metal transfer mode.

**4.2.2.5 High-Current-Density Spray Transfer Mode.** High-current-density spray transfer is a name