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THE INERT GASES: ARGON, NITROGEN, AND HELIUM

SIXTH EDITION

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1 Introduction

This publication is one of a series compiled by the Compressed Gas Association (CGA) to provide information on the transportation, handling, and storage of compressed gases, cryogenic liquids, and related products.

2 Scope

The purpose of this publication is to present information regarding the characteristics and handling of the three major inert gases—argon, nitrogen, and helium. Requests for specialized technical information should be directed to any one of the manufacturers of these gases.

This publication is intended primarily for users of the inert gases. Some of the requirements do not apply to the manufacturers or distributors of these gases.

3 Definitions

For the purpose of this publication, the following definitions apply.

3.1 Publication terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

4 Argon

4.1 Properties

Argon is a colorless, odorless, and tasteless, monatomic gas that comprises approximately 1% of the atmosphere (0.934% by volume).

Argon is nontoxic, chemically inert, and only slightly soluble in water. It is nonflammable and inhibits combustion. It can act as an asphyxiant by displacing the amount of oxygen necessary to support life.

Argon gas is approximately 38% more dense than air. It can be liquefied to a colorless liquid that boils at -302.6°F (-185.9°C) at atmospheric pressure. Liquid argon at its normal boiling point is 39% heavier than water. Above its critical temperature of -188.1°F (-122.3°C), argon can exist only as a gas regardless of pressure.

Argon is classed according to type and grade (quality verification level [QVL]). Gaseous argon is denoted as Type I and liquefied argon as Type II. The grade (QVL) indicates the maximum amount of impurities that can be present. For more details, see CGA G-11.1, *Commodity Specification for Argon* [1].¹

Some of the physical constants of argon are listed in Table 1.

¹ References are shown by bracketed numbers and are listed in order of appearance in the reference section.

Table 1—Physical constants of argon [2, 3, 4]²

	U.S. Units	SI Units
Chemical symbol	Ar	Ar
Molecular weight	39.95	39.95
Density of the gas at 70 °F (21.1 °C) and 1 atm	0.103 lb/ft ³	1.650 kg/m ³
Specific gravity of the gas at 70 °F (21.1 °C) and 1 atm	1.38	1.38
Specific volume of the gas at 70 °F (21.1 °C) and 1 atm	9.71 ft ³ /lb	0.606 m ³ /kg
Boiling point at 1 atm	−302.6 °F	−185.9 °C
Density of the liquid at boiling point and 1 atm	87.02 lb/ft ³	1394 kg/m ³
Weight of the liquid at boiling point	11.63 lb/gal	1394 kg/m ³
Gas/liquid ration—Gas at 70 °F (21.1 °C) and 1 atm, liquid at boiling point vol/vol	841.2	841.2
Melting point at 1 atm	−308.6 °F	−189.2 °C
Critical temperature	−188.1 °F	−122.3 °C
Critical pressure	711.5 psia	4906 kPa, abs
Critical density	33.44 lb/ft ³	535.6 kg/m ³
Triple point	−308.8 °F at 9.99 psia	−189.3 °C at 68.9 kPa, abs
Latent heat of vaporization at boiling point and 1 atm	69.8 Btu/lb	162.3 kJ/kg
Latent heat of fusion at triple point	12.8 Btu/lb	29.6 kJ/kg
Specific heat of the gas at 70 °F (21.1 °C) and 1 atm		
C_p	0.125 Btu/(lb)(°F)	0.523 kJ/(kg)(°C)
C_v	0.075 Btu/(lb)(°F)	0.314 kJ/(kg)(°C)
Ratio of specific heats (C_p/C_v)	1.67	1.67
Solubility in water, vol/vol at 32 °F (0 °C)	0.056	0.056

4.2 Production

The most common method of producing argon is by fractional distillation of liquid air in an air separation plant. The crude liquid argon stream is purified to remove impurities consisting primarily of oxygen. The resulting argon product is 99.99%+ pure. Argon is also recovered and purified from purge gas streams of ammonia plants.

4.3 Commercial uses

The largest use of argon is in welding where it provides an inert gas shield to the arc, which prevents oxidation of the metals being welded. It also has a number of important uses in metallurgical processes. In the argon-oxygen decarburizing process, oxygen is used to remove carbon and the argon is used for “stirring” and removal of nitrogen. Basic oxygen furnaces are bottom blown with argon as a stirring medium and to lower the nitrogen content of the steel. Argon is used in continuous casting processes as an inert shield, in processes for degassing molten aluminum, and in the production of titanium sponge and alloys. In the lighting industry, it is used to fill incandescent light bulbs and used with other rare gases to fill special bulbs and display tubes for special color effects. Argon is used with other gases in Geiger counter tubes. In the electronic industry, argon is used in chemical vapor deposition and it is used in other industries for sputtering and annealing.

² kPa shall indicate gauge pressure unless otherwise noted as (kPa, abs) for absolute pressure or (kPa, differential) for differential pressure. All kPa values are rounded off per CGA P-11, *Guideline for Metric Practice in the Compressed Gas Industry* [5].

5 Nitrogen

5.1 Properties

Nitrogen is an element that at atmospheric temperatures and pressures exists as a colorless, odorless, tasteless diatomic gas. Approximately four-fifths of the atmosphere is nitrogen (78.03% by volume). Nitrogen is nontoxic and chemically inert at ordinary pressure and temperature conditions. It is nonflammable and inhibits combustion. It can act as an asphyxiant by displacing the amount of oxygen necessary to support life.

As a gas at ambient temperature, nitrogen is approximately 3% less dense than air. It can be cooled and compressed to a colorless liquid that under atmospheric pressure boils at -320.4°F (-195.8°C). As a liquid (at normal boiling point), nitrogen is approximately 81% as heavy as water. When heated above its critical temperature of -232.4°F (-146.9°C) nitrogen can exist only as a gas regardless of pressure.

Nitrogen is classed according to type and grade (QVL). Gaseous nitrogen is denoted as Type I and liquid nitrogen as Type II. The grade (QVL) indicates the maximum amount of impurities that can be present. For more details, see CGA G-10.1, *Commodity Specification for Nitrogen* [6].

Some of the physical constants of nitrogen are listed in Table 2.

Table 2—Physical constants of nitrogen [2, 3, 4]

	U.S. Units	SI Units
Chemical symbol	N ₂	N ₂
Molecular weight	28.01	28.01
Density of the gas at 70 °F (21.1 °C) and 1 atm	0.072 lb/ft ³	1.153 kg/m ³
Specific gravity of the gas at 70 °F (21.1 °C) and 1 atm (air = 1)	0.967	0.967
Specific volume of the gas at 70 °F (21.1 °C) and 1 atm	13.89 ft ³ /lb	0.867 m ³ /kg
Boiling point at 1 atm	-320.4°F	-195.8°C
Density of the liquid at boiling point and 1 atm	50.47 lb/ft ³	808.5 kg/m ³
Weight of liquid at boiling point	6.747 lb/gal	808.5 kg/m ³
Gas/liquid ratio—Gas at 70 °F (21.1 °C) and 1 atm, liquid at boiling point, vol/vol	696.5	696.5
Melting point at 1 atm	-345.8°F	-209.9°C
Critical temperature	-232.4°F	-146.9°C
Critical pressure	493 psia	3399 kPa, abs
Critical density	19.60 lb/ft ³	314.0 kg/m ³
Triple point at 1.81 psia (12.5 kPa, abs)	-346.0°F	-210.0°C
Latent heat of vaporization at boiling point	85.6 Btu/lb	199.1 kJ/kg
Latent heat of fusion at melting point	11.1 Btu/lb	25.8 kJ/kg
Specific heat of the gas at 70 °F (21.1 °C) and 1 atm		
C_p	0.249 Btu/(lb)(°F)	1.04 kJ/(kg)(°C)
C_v	0.177 Btu/(lb)(°F)	0.741 kJ/(kg)(°C)
Ratio of specific heats (C_p/C_v)	1.41	1.41
Solubility in water, vol/vol at 32 °F (0 °C)	0.023	0.023

5.2 Production

Liquid nitrogen is produced by fractional distillation of liquefied air in air separation plants. The nitrogen product obtained is 99.99%+ pure. Gaseous nitrogen is generally obtained by vaporizing liquid nitrogen.

Pressure swing absorption (PSA) and selective screen membrane technology are alternative methods of producing gaseous nitrogen on site at user locations. These prepackaged units process air and are designed to meet a wide range of flow and purity requirements.

Inert gas generators meet requirements for relatively low-purity nitrogen in medium quantities. These units are operated primarily to generate blanketing atmospheres by reacting a hydrocarbon fuel with air to produce a mixture of nitrogen, water, carbon dioxide, hydrogen, and oxides of carbon. The product stream can be purified by various methods according to process requirements.

5.3 Commercial uses

Nitrogen is widely used in the food industry to prevent oxidative deterioration, mold growth, and insect infestation. Coffee, margarine, leafy vegetables, and meat are several foods in the long list of food products using nitrogen in processing or packaging.

One of the largest uses of nitrogen is in the manufacture of ammonia where a mixture of three parts hydrogen and one part nitrogen constitutes the synthesis gas. In the chemical industry, nitrogen is used in many processes to exclude oxygen or moisture, or as a diluent. It is also widely used in polymerizations. In petroleum refining, nitrogen is used in the regeneration of spent reforming catalyst. Its uses in the semiconductor industry include purging, blanketing, pressurizing systems, and as a coolant fluid. It is also used as a carrier gas in chemical deposition.

6 Helium

6.1 Properties

Helium is an element that at atmospheric temperatures and pressures exists as a colorless, odorless, tasteless, monatomic gas.

Helium is nontoxic and chemically inert. It is nonflammable, does not present a fire hazard, and inhibits combustion. It can act as an asphyxiant by displacing the amount of oxygen necessary to support life.

As a gas at ambient temperature, helium is approximately 86% less dense than air. Helium is the only known substance that will not freeze under its vapor pressure. It has no triple point, existing only as a liquid under its vapor pressure to the absolute zero temperature. Helium gas can be liquefied after sufficient cooling and expansion. Its normal boiling point at atmospheric pressure is -452.1°F (-268.9°C). As a liquid (at normal boiling point), helium is approximately 12% as heavy as water. When heated above its critical temperature of -450.3°F (-267.9°C), helium can exist only as a gas regardless of the pressure.

Helium is classed according to type and grade (QVL). Gaseous helium is denoted as Type I and liquefied helium as Type II. The grade (QVL) indicates the maximum amount of impurities that can be present. For more details, see CGA G-9.1, *Commodity Specification for Helium* [7].

Some of the physical constants of helium are listed in Table 3.

6.2 Production

Helium is a nonrenewable natural resource extracted commercially from helium-bearing natural gas generally containing 0.3 vol % helium. According to the *Mineral Commodity Summaries Helium 2014*, the world production of helium in 2012 was 174 million cubic meters. This production was distributed among six regions as follows: Continental United States, Algeria, Australia, Russia, Qatar, and Poland.

All natural gas processed for helium recovery in the United States came from gas fields in Colorado, Kansas, Oklahoma, Texas, Utah, and Wyoming [8].