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NOTE—Technical changes from the previous edition are underlined.

NOTE—No technical information has been changed from the 2015 edition. This reaffirmed edition may include minor editorial changes.

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1 Introduction

This publication is one of a series of publications compiled by the Compressed Gas Association, Inc. (CGA) to satisfy the demand for information concerning the transportation, handling, and storage of compressed gases.

2 Scope

This publication provides information regarding the characteristics and safe handling of oxygen. Requests for specialized technical information should be directed to any one of the manufacturers of this gas. This publication is intended primarily for users of oxygen and some of the requirements do not apply to manufacturers or distributors of this gas.

3 What is oxygen?

3.1 Physical and chemical properties

Oxygen (O_2) is a molecule that exists at atmospheric temperatures and pressures as a colorless, odorless, tasteless gas. About one-fifth of the atmosphere is oxygen (20.95% by volume).

The outstanding property of oxygen is its ability to sustain life and to support combustion. Although oxygen is nonflammable, materials that normally do not burn in air can burn in an oxygen-enriched atmosphere. Materials that burn in air will burn more vigorously and at a higher temperature in an oxygen-enriched atmosphere. Some combustibles such as oil burn in oxygen with near explosive violence if ignited by flame, impact, or some other energy source. As a result of these properties, caution shall be exercised and precautions taken when entering areas or confined spaces where an oxygen-enriched atmosphere can exist. See CGA P-45, *Fire Hazards of Oxygen and Oxygen-Enriched Atmospheres* and National Fire Protection Association (NFPA) 53, *Recommended Practice on Materials, Equipment and Systems Used in Oxygen-Enriched Atmospheres* for more information regarding the hazards of oxygen-enriched atmospheres [1, 2].¹

As a gas, oxygen is 1.1 times heavier than air. It can be compressed and cooled to a pale blue liquid that, under atmospheric pressure, boils at $-297.3\text{ }^{\circ}\text{F}$ ($-182.9\text{ }^{\circ}\text{C}$). As a liquid (at normal boiling point), oxygen is 1.14 times heavier than water. When heated above its critical temperature of $-181.4\text{ }^{\circ}\text{F}$ ($-118.6\text{ }^{\circ}\text{C}$), oxygen can exist only as a gas, regardless of the pressure that is exerted upon it.

Oxygen is denoted according to type and grade or quality verification level (QVL). Gaseous oxygen is denoted as Type I and liquefied oxygen as Type II. The QVLs specify the maximum amount of various impurities (also termed limiting characteristics) that can be present. Further details are given in CGA G-4.3, *Commodity Specification for Oxygen* [3].

Physical constants of oxygen are listed in Table 1.

3.2 Manufacture

The primary method of manufacturing oxygen is by fractional distillation after the liquefaction of air. Improved efficiency in utilization has led to a generally recognized industry standard of purity, which exceeds the 99% required by the *United States Pharmacopeia* and *National Formulary (USP-NF)* [4]. Oxygen of lower purity can be used in some chemical and metallurgical processes. Other methods of manufacturing oxygen include pressure swing adsorption, vacuum swing adsorption, membrane separation, electrolysis, and chemical reaction. These processes produce oxygen at lower purities than that obtained by fractional distillation at cryogenic temperatures.

For more information on the manufacture of oxygen, see CGA P-8, *Safe Practices Guide for Cryogenic Air Separation Plants* and CGA P-8.1, *Safe Installation and Operation of PSA and Membrane Oxygen and Nitrogen Generators* [5, 6].

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

3.3 Commercial uses

The principal uses of oxygen stem from the life-sustaining and combustion-supporting properties of the gas.

Oxygen and oxygen mixtures (e.g., oxygen-helium, oxygen-carbon dioxide) are used extensively for medical purposes. For further information on the medical applications of oxygen, oxygen mixtures, and other gases, see CGA P-2, *Guideline for Characteristics and Safe Handling of Medical Gases* [8].

Oxygen is also used to sustain life in high altitude aviation, deep sea diving, and similar applications.

The industrial uses of oxygen include its use with acetylene or other fuel gases in such processes as metal cutting, welding, hardening, scarfing, cleaning, and dehydrating. Oxygen is also used in the manufacture of steel and in various chemical processes and as an oxidizer for fuels in rockets and missiles.

Table 1—Physical constants of oxygen ²

	U.S. Units	SI Units
International symbol ¹⁾	O ₂	O ₂
Molecular weight ¹⁾	31.9988	31.9988
At 70 °F (21.1 °C) and 1 atm: ²⁾		
Density of gas	0.083 lb/ft ³	1.329 kg/m ³
Specific gravity of gas	1.10	1.10
Specific volume of gas	12.05 ft ³ /lb	0.752 m ³ /kg
At 59 °F (15 °C) and 1 atm (101.325 kPa, abs): ²⁾		
Density of gas	0.085 lb/ft ³	1.362 kg/m ³
Specific gravity of gas	1.10	1.10
Specific volume of gas	12.05 ft ³ /lb	0.752 m ³ /kg
Boiling point at 1 atm ²⁾	−297.3 °F	−182.9 °C
Freezing point at 1 atm ²⁾	−361.1 °F	−218.4 °C
Critical temperature ²⁾	−181.4 °F	−118.6 °C
Critical pressure ²⁾	731.4 psia	5043 kPa, abs
Critical density ²⁾	27.23 lb/ft ³	436.1 kg/m ³
Triple point ³⁾	−361.8 °F at 0.0216 psia	−218.8 °C at 0.1489 kPa, abs
Latent heat of vaporization at boiling point and 1 atm ⁴⁾	91.7 Btu/lb	213 kJ/kg
Specific heat of gas at 70 °F (21.1 °C) and 1 atm: ²⁾		
C _p	0.220 Btu/lb (°F)	0.919 kJ/kg (°C)
C _v	0.157 Btu/lb (°F)	0.657 kJ/kg (°C)
Ratio of specific heat	1.40	1.40
Solubility in water, vol/vol at 32 °F (0 °C) ¹⁾	0.0489	0.0489
Weight of liquid at boiling point ²⁾	9.52 lb/gal	1141 kg/m ³
¹⁾ Weast, R.C., Editor, <i>CRC Handbook of Chemistry and Physics</i> . 66th Edition, p. B-121. ²⁾ Younglove, B.A., "Interactive Fortran Program to Calculate Thermophysical Properties of Six Fluids." National Bureau of Standards (U.S.), Tech. Note 1048 (July 1982). ³⁾ McCarty, R.D., "Interactive Fortran IV Computer Programs for the Thermodynamic and Transport Properties of Selected Cryogenics (Fluid Pack)." National Bureau of Standards (U.S.), Tech. Note 1025 (October 1980). ⁴⁾ Snell, F.D. and Ettre, L.S., <i>Encyclopedia of Industrial Chemical Analysis</i> . Vol. 16, Table 3, page 517 (1972).		

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].

4 Oxygen containers

4.1 Federal regulations applying to containers

Oxygen is classified by the U.S. Department of Transportation (DOT) and by Transport Canada (TC) as a non-flammable, oxidizing gas. If it is shipped in containers at a pressure exceeding 40.6 psia (280 kPa, abs) at 68 °F (20 °C), it shall be shipped in containers that meet DOT or TC specifications. DOT regulations are contained in Title 49 of the U.S. *Code of Federal Regulations* (49 CFR), Parts 100-180 [9]. TC regulations are contained in the *Transportation of Dangerous Goods Regulations* that refers to Canadian Standards Association (CSA) B339, *Cylinders, spheres, and tubes for the transportation of dangerous goods* and CSA B340, *Selection and use of cylinders, spheres, tubes, and other containers for the transportation of dangerous goods, Class 2* [10, 11, 12]. Current authorizing agencies are DOT and TC while previous authorizing agencies included the Interstate Commerce Commission (ICC) in the United States and the Canadian Transport Commission (CTC), the Board of Trade Commissioners for Canada (BTC), and the Canadian Railway Commission (CRC) in Canada.

Cylinders stamped with current or previous authorizing agency stampings may continue to be used provided they otherwise meet all qualifications for continued service.

Cylinder specifications in the United States and Canada require, among other things, that the metal used in oxygen containers meets certain chemical and physical requirements, that the containers pass certain periodic requalification tests, and that the containers are protected by appropriate pressure relief devices (PRDs). For more information on PRDs, see CGA S-1.1, Pressure Relief Device Standards—Part 1—Cylinders for Compressed Gases [13]. For oxygen containers authorized under DOT special permits/TC equivalency certificates, the manufacturing, periodic requalifications, and PRD requirements are specified in the special permit/equivalency certificate paperwork. Specifications, as well as regulations governing maintenance, requalification, and testing are published by federal authorities of the DOT and TC.

DOT specifications and regulations applying to the shipment of compressed gases are published in 49 CFR [9]. Canadian cylinder specifications and regulations applying to the shipment of compressed gases are published in *Transportation of Dangerous Goods Regulations*, which in turn refer to CSA B339 and CSA B340 [10, 11, 12].

4.2 Cylinders and containers

4.2.1 General

Gaseous oxygen is commonly shipped in seamless steel cylinders constructed to TC/DOT Specifications 3A or 3AA cylinders or UN pressure receptacles, with nominal capacities of up to 330 scf (9.34 m³).³ Higher pressure steel cylinders with greater capacities are also available. Oxygen may also be shipped in disposable (Specification 39) or aluminum (Specification 3AL) cylinders.

Liquid oxygen may be shipped in TC/DOT-4L insulated cylinders (commonly called liquid cylinders). A commonly used Specification 4L cylinder has an approximate equivalent capacity of 5000 scf (142 m³) of gaseous oxygen. Specification 4L cylinders having greater capacity are available.

Liquid oxygen for home care medical applications is also shipped in smaller liquid containers. If the pressure during transportation does not exceed 25.3 psi (174 kPa), they are not required to meet DOT/TC specifications. See 49 CFR 173.320 for specific exceptions [9].

In addition, oxygen may be shipped in cylinders made to a DOT special permit or TC equivalency certificate, if allowed.

4.2.2 Valve outlet connections

Container valve connections that do not fit shall not be used. Threads on regulator connections or other auxiliary requirements shall match those on the container valve outlet. The valve outlet connection shall conform to recognized standards. For more information on cylinder valve outlet connections, see CGA V-1, Standard for

³ A standard cubic foot (scf) is defined as volume of gas at 70 °F (21.1 °C) and 14.696 psia (1 atm).

Compressed Gas Cylinder Valve Outlet and Inlet Connections [14]. Connections other than those found in CGA V-1 exist. If a user chooses such a connection, they shall ensure that such connections do not cross-connect with existing connections in CGA V-1 and that they have been engineered for the intended gas service and pressure. The threads on a cylinder valve outlet, as well as on regulators and other ancillary equipment, shall be examined prior to connection to ensure they are clean and undamaged.

4.2.3 Pressure relief devices

With few exceptions, oxygen cylinders are required by federal regulations to be equipped with PRDs. These devices consist of a frangible disk designed to burst under excessive pressure, or a combination disk backed with fusible metal with a low melting point designed to melt and release the gas in case of fire. Cryogenic vessels may be equipped with spring-loaded pressure relief valves that reseal when the pressure drops to a pre-selected value. These devices are approved with respect to type and location by the federal authorities. See CGA S-1.1 [13].

4.2.4 Filling limits

Because of the characteristics of any gas confined in a closed container to increase in pressure with rising temperature, the possibility always exists that a cylinder charged with gas at a safe pressure at normal temperature could reach a dangerously high pressure at high temperatures. To prevent this with normal usage, federal regulations limit the amount of gas that may be charged into a cylinder.

TC/DOT-3A, TC/DOT-3AA, TC/DOT-3AL, and TC/DOT-39 cylinders shall not be filled to a pressure greater than the stamped service pressure at 70 °F (21.1 °C). TC/DOT-3A and TC/DOT-3AA cylinders stamped with a plus mark (+) after the last test date may be filled to a pressure 10% greater than the stamped service pressure under conditions described in 49 CFR 173.302a [9]. This also applies to cylinders stamped ICC, CTC, BTC, and RTC.

Metricated TC-3A and TC-3AA cylinders, identified by the letter *M* stamped at the end of the specification designation and not stamped with a *K* after the service pressure, have the 10% overfill included in the stamped service pressure and may be filled to that pressure at 59 °F (15 °C), if equipped with a PRD(s) of the rupture disk type without fusible metal backing. If a *K* is stamped after the service pressure, the cylinder shall be filled to a maximum of 90% of the stamped service pressure, see CSA B340 [12].

NOTE—Metricated TC cylinders have their service pressure stamped in bar. One bar is equal to 100 kPa, or approximately 14.5 psi.

If the liquid container pressure is equal to or less than 25.3 psi (174 kPa), TC/DOT-4L container filling operation is not regulated (see 49 CFR 173.320). At pressures greater than 25.3 psi (174 kPa), TC/DOT-4L cylinders shall be filled by weight in accordance with regulations. DOT and TC regulations prescribe permissible fill rates in 49 CFR 173.316 and CSA B340 [9, 112].

4.2.5 Retesting

In addition to the hydrostatic testing of cylinders at the time of manufacture, federal regulations provide that Specification 3A, 3AA, and 3AL cylinders shall be periodically retested. When using hydrostatic testing methods for retesting, DOT, CTC, ICC, BTC, and CRC cylinders are tested at 5/3 of their stamped service pressure, while metricated TC cylinders are tested at 3/2 of their stamped service pressure. See 49 CFR Part 180 Subpart C [9]. Specification 3A, 3AA and 3AL cylinders shall be hydrostatically retested at 5-year intervals. Under certain conditions prescribed in federal regulations, the interval may be a maximum of 10 years for 3A and 3AA cylinders. Such cylinders are stamped with a 5-pointed star following the last test date. Periodic retesting of Specification 4L welded insulated liquid cylinders is not required. Specification 39 cylinders shall not be refilled and hence require no retest. Retesting of 3E cylinders is not required.

In the United States, Specification 3A and 3AA cylinders that have been in a fire shall be removed from service and shall not be returned to service until they meet the requirements of 49 CFR 180.212. Specification 3AL cylinders that are exposed to fire or temperatures in excess of 350 °F (177 °C) shall be removed from service and condemned. Specification 4L cylinders that are in a fire shall be removed from service until they meet the requirements of 49 CFR 180.211 [9].