SECOND EDITION

Equipment for Respiratory Care

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Dedication

I dedicate this book to the respiratory students whose quest for knowledge inspired me to find new and innovative ways to maximize their educational experience and to my family, whose love and support allowed me to pursue my dreams!

Teresa A. Volsko

Learning and teaching are fundamental to existence. I dedicate this book to all those who understand that to achieve extraordinary results you must live an uncommon life.

Robert L. Chatburn

To Mayssa, Farouk, Dina, and Manar—thanks for your love and support. You are the joy of my life.

To my mother, Souad, and to the soul of my father.

Mohamad F. El-Khatib

Brief Contents

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Foreword

Throughout my career, I have found that airway management is the major role of the respiratory therapist, whether opening and maintaining a closed airway or sustaining breathing through mechanical ventilation. With this role comes an expectation of being the expert on all the equipment that is needed to maintain an airway and provide ventilation. This expertise is what sets respiratory therapists apart from other hospital personnel. Biomedical engineers know how equipment works by its mechanical design, and anesthesia personnel know how to ventilate patients in the controlled environment of the operating room. But troubleshooting skills and knowledge of airway and ventilation equipment separate the respiratory care professional from these other professionals.

Troubleshooting is an important skill for any respiratory therapy student to learn and for all practicing respiratory therapists to maintain. Troubleshooting involves locating and correcting technical problems related to the machinery used in patient care. Under most circumstances, this requires logical reasoning, as opposed to problem posing and problem solving. Troubleshooting is always essential in clinical practice because members of the medical team in the ICU rely on respiratory therapists' technical expertise to advise, explain, and troubleshoot equipment used for airway management and mechanical ventilation. Respiratory therapists work in teams, but there are times when they must work without assistance. It is in such circumstances that troubleshooting respiratory care equipment is most crucial. The topic of troubleshooting in respiratory therapy is taught at a level that cannot be found in the core curriculum of medical or nursing schools. Thus, it is a unique skill of respiratory therapists that is not shared by other allied health clinicians, nurses, and physicians.

This new text covers most equipment topics addressed in respiratory therapy education. Respiratory therapy equipment courses are usually among the first courses in most respiratory therapy programs of study. Teresa A. Volsko, Robert L. Chatburn, and Mohamad F. El-Khatib bring their expertise and insights to the operation and indications for use of equipment used in respiratory care practice. The text provides information that builds on the respiratory therapist's knowledge of the physiology of the respiratory system as well as the electronic functionality of the equipment used while experience is gained in the laboratory setting and on the job. I hope that students and practitioners alike will use this information and ask themselves, "How well do I use my troubleshooting skills when I work without assistance in my practice, for instance, when I make a home visit to a patient receiving mechanical ventilation?" Our future patients are depending on us to be able to answer this question!

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Preface

Technological advances have made a significant impact on our profession. The equipment used to treat disorders of the respiratory tract are no longer simple machines. Many of the devices respiratory therapists use are governed by sophisticated operating systems.

In this new edition, the authors recognize that it is not just about the technology; it's about sharing knowledge and the key elements of information that will enable respiratory care professionals to distinguish between equipment malfunction and patient intolerance in order to effectively communicate recommendations for therapy or changes to the plan of care. The authors embraced this work as a mechanism to build a learning community and create a culture of professionalism.

The layout of each chapter is standardized, much like the format for a scientific research paper. Just as scientific papers commence with a thorough review of the literature, each chapter provides the reader with a purpose for the particular topic. The information from a variety of sources is summarized in a logical and uniform fashion to provide equipment specifications, routine use, and limitations. Rather than outlines of manufacturer specifications, the authors provide fundamental theoretical constructs for the categories of equipment described in each chapter.

Finally, there is an in-depth discussion that ties in the clinical significance of the equipment presented. Similar to the discussion section of a scientific manuscript, this portion of the chapter establishes the practical relevance of the equipment discussed. The equipment selection and troubleshooting guides provide practical solutions to complex problems. These sections are presented in an easy-to-follow manner and provide the theoretical constructs, practical applications, and algorithms to provide respiratory care students and professionals with the tools to distinguish equipment malfunction from patient intolerance. Understanding this difference is an essential critical thinking skill and instrumental when communicating with the interdisciplinary team. These skills are necessary to clearly articulate the need to initiate therapy or a rationale for recommending modifications to the patient plan of care.

Chapter-by-Chapter Overview

The text is written in a clear and concise manner. Illustrations, tables, and figures are provided to enhance the learning experience.

Chapter 1, Introduction to Medical Gases, introduces the learner to the essential role medical gases play along the continuum of care. Essential elements in the selection, distribution, storage, and safe handling of medical gases are presented. This chapter also highlights the safety standards required by credentialing bodies, such as the Joint Commission and the National Fire Protection Agency, that impact our clinical practice.

Chapter 2, Administering Medical Gases, provides clinically relevant information on the delivery systems and devices used to administer medical gas therapy. This chapter provides a comprehensive review of the different delivery devices that are used to administer medical gases along the continuum of care. It also explores the ongoing debate regarding the best methods to safely deliver medical gases. Practical information, rooted in the evidence available in the literature, is presented to facilitate a systematic thinking approach to device selection.

Chapter 3, Hyperbaric Oxygen Therapy, explores the fascinating and rapidly expanding field of hyperbaric oxygen therapy. Because application of this therapeutic modality requires knowledge of the physics of gases, gas laws as well as different oxygen delivery systems are presented. This chapter also discusses the physiologic principles of hyperbaric oxygen as well as its indications, contraindications, complications, and hazards. A discussion of the different chambers, equipment, and monitoring used to evaluate oxygenation and ventilation as well as the use of concurrent mechanical ventilation is presented.

Chapter 4, Humidity and Aerosol Therapy, presents the principles of humidity and aerosol therapy. This chapter describes the various devices that are currently used in the clinical practice of providing humidity and aerosol therapies in spontaneously breathing and mechanically ventilated patients. Information is provided to enable the learner to gain a firm understanding of the rationale, physiologic basis, indications, and contraindications for humidity and aerosol therapies. Additionally, this chapter provides information in a manner that facilitates comprehension of the technical considerations germane to the multitude of devices available for clinical use.

Chapter 5, Medicated Aerosol Delivery Devices, details the operational characteristics of a variety of

devices used to deliver medication to the lung. This chapter also provides information on devices designed specifically for certain medications. An understanding of the function and limitations of medicated aerosol delivery devices will enable respiratory therapists to appropriately select the device or devices that can make a positive clinical impact.

Chapter 6, Airway Management and Emergency Resuscitation Equipment, provides a clinical approach to the devices used to secure and maintain a patent airway. Because any device has the potential to help as well as cause harm, this chapter is designed to familiarize the learner with the indications, proper use, and limitations of airway management equipment. A practical approach to evaluating the plethora of equipment used in the routine and emergency care of the airway is also provided.

Chapter 7, Blood Gas and Critical Care Analyte Analysis, focuses on the equipment used for blood gas and analyte analysis. The types of equipment available in core labs and point-of-care testing are highlighted. The importance of implementing a quality management system to maintain the integrity of a sample and assure accuracy of results is detailed. Regulatory requirements from agencies such as the College of American Pathology and the Joint Commission as well as federal requirements, such as the Clinical Laboratory Improvement Amendments of 1988, are detailed.

Chapter 8, Patient Monitors, provides relevant information on noninvasive equipment used to measure and monitor clinical parameters important to the diagnosis and retreatment of cardiorespiratory system disorders. The appendices provide a unique way to compare performance characteristics and evaluate the utility and limitations of noninvasive monitors used for monitoring oxygen saturation and expired carbon dioxide concentrations as well as mechanisms for identifying and quantifying hemoglobin disorders. This chapter also provides a comprehensive review of equipment available for the evaluation and monitoring of lung mechanics.

Chapter 9, Measuring and Monitoring Pulmonary Function, describes types of devices used to evaluate and monitor pulmonary health. Stationary instruments used in a laboratory as well as portable devices and those used at the bedside and in ambulatory and home care settings are characterized by their measurement methods. A comparison of methods to select devices that are useful in detecting airflow limitations, gas transfer impairment, volume limitations, and respiratory muscle weakness is provided. This chapter also highlights how a quality management system can improve performance standards and comply with regulatory requirements for training personnel and performing quality control procedures.

Chapter 10, Mechanical Ventilation, presents a unique and systematic approach to a complicated subject. The fundamental theory for understanding ventilator terminology is presented in a way that leads to a practical taxonomy for modes of ventilation. This approach facilitates the understanding of ventilator operation that transcends a mere proliferation of the trade names of the modes, minimizing confusion and the propensity for user error. Through the use of this taxonomy, the learner is able to classify, compare, and contrast the functional differences of the nearly 300 modes currently available on mechanical ventilators.

Chapter 11, Sleep Apnea Devices, provides clinically relevant information on the devices available for the treatment of sleep-disordered breathing. The principles of operation, safety, and technical considerations used for patient selection are provided. Key aspects of cleaning and maintenance as they relate to the safe and effective operation of these devices in the long-term care and home care environment are detailed.

Chapter 12, Cardiovascular Monitoring, focuses on the equipment used to monitor and assess the function of the cardiovascular system. The variety of devices used for cardiovascular monitoring, from the electrocardiogram to the devices that measure intravascular pressures and cardiac output, are discussed. The clinical relevance of hemodynamic monitoring for mechanically ventilated patients is highlighted. In addition to the theory of operation, this chapter familiarizes the learner with techniques used to troubleshoot technological problems.

Chapter 13, Hyperinflation Therapy, describes the devices used to perform lung expansion maneuvers, which are those that subject the lungs to volumes greater than normal in order to reinflate areas of collapse and improve gas exchange. Incentive spirometers; intermittent positive pressure breathing devices; and positive airway pressure devices, including positive expiratory pressure devices used to accomplish hyperinflation therapy goals, are detailed.

Chapter 14, Airway Clearance, focuses on the mechanical devices used to clear airway secretions. Mechanical devices that assist with the cephalad mobilization of secretions in airways as well as those that assist with expectoration are discussed. Although some of the devices that are described in this chapter are also found in Chapter 12, the dual function of these devices and their operational characteristics that enable them to generate volumes greater than normal and expiratory flow rates that can move airway secretions cephalad are explored.

Chapter 15, Manual and Automatic Resuscitators, differentiates automatic resuscitators from mechanical ventilators and provides clinically relevant information on the different types of resuscitators available for manual ventilation. Key aspects for device use and selection are provided.

The authors of this textbook are distinguished educators, practicing clinicians, researchers, and internationally recognized experts in both pediatric and adult

respiratory care. These authors have a passion for educating respiratory therapists, from the novice to the advanced practitioner, in order to optimize care, improve outcomes, and advance the practice of our profession. Their contributions will serve respiratory care students as well as credentialed practicing clinicians.

What's New to This Edition

- Expanded descriptions of interfaces used for oxygen delivery (i.e., Oxymask) as well as devices used to administer heated high-flow oxygen therapy
- A schematic breakdown of the control panel and injector used to deliver inhaled nitric oxide
- A comprehensive description of the heated pass-over and wick humidifiers
- Expanded use of illustrations for tracheal tubes and more detailed product descriptions
- Additional illustrations and product descriptions of various devices available for point-of-care blood gas and analyte testing
- A description of brain tissue oxygen monitoring systems
- Comprehensive details on the type of pulmonary function equipment, capabilities, and software and quality control used in the lab, in the ambulatory setting, or at the bedside

How to Use This Book

Chapter Features

- Each chapter of the book begins with a list of **Objectives** to help you focus on the most important concepts in that chapter.

OBJECTIVES

1. Define a medical gas.
2. Describe the types of gases used in respiratory care.
3. Explain how medical gases are delivered to the patient.
4. Describe how liquid oxygen is formed.
5. Describe how liquid oxygen is delivered to the patient.
6. Differentiate between liquid and compressed gas.
7. Describe the piping system used in acute care facilities.
8. Discuss the use of station outlets and the types of connectors used.
9. Explain the various methods of testing the hospital gas distribution system.
10. Identify problems with a hospital piping system.
11. Discuss how medical gases are stored and transported.
12. Identify the various cylinder sizes and colors and how they relate to the particular medical gas contents.
13. Discuss how oxygen concentrators work.

- Each chapter contains **Tables** that highlight important information, such as **Table 6-20** Endotracheal Tube Exchangers.

TABLE 6-20
Endotracheal Tube Exchangers

Brand	OD (mm)	ETT Range (ID, mm)	Length (cm)	Use
Sheridan TTX	2.0 3.3 4.8 5.8	2.5–4 4–6 6–8.5 7.5–10	56 81 81 81	Regular tube exchange
Sheridan ETX		35–41 Fr	100	Double lumen tubes
Sheridan JETTX		6.5–10	100	Provide jet ventilation or oxygen delivery
Cook Airway Exchanger Soft Tip and Extra Firm	11 Fr 14 Fr	≥4 ≥5	100 100	Provide jet ventilation or oxygen delivery; extra firm is for double lumen tubes
Cook Airway Exchange Catheter Regular	8 11 14 19	≥3 ≥4 ≥5 ≥7	45 83 83 83	
Aintree Intubation Catheter	19	≥7	56	

OD, outer diameter; ETT, endotracheal tube; ID, inner diameter.

- This text is **highly illustrated** with diagrams and photos demonstrating a variety of concepts, including **Figure 5-24** **A.** Aerosolization of dry powder. **B.** Component parts of Flexhaler. **C.** Component parts of Diskus.

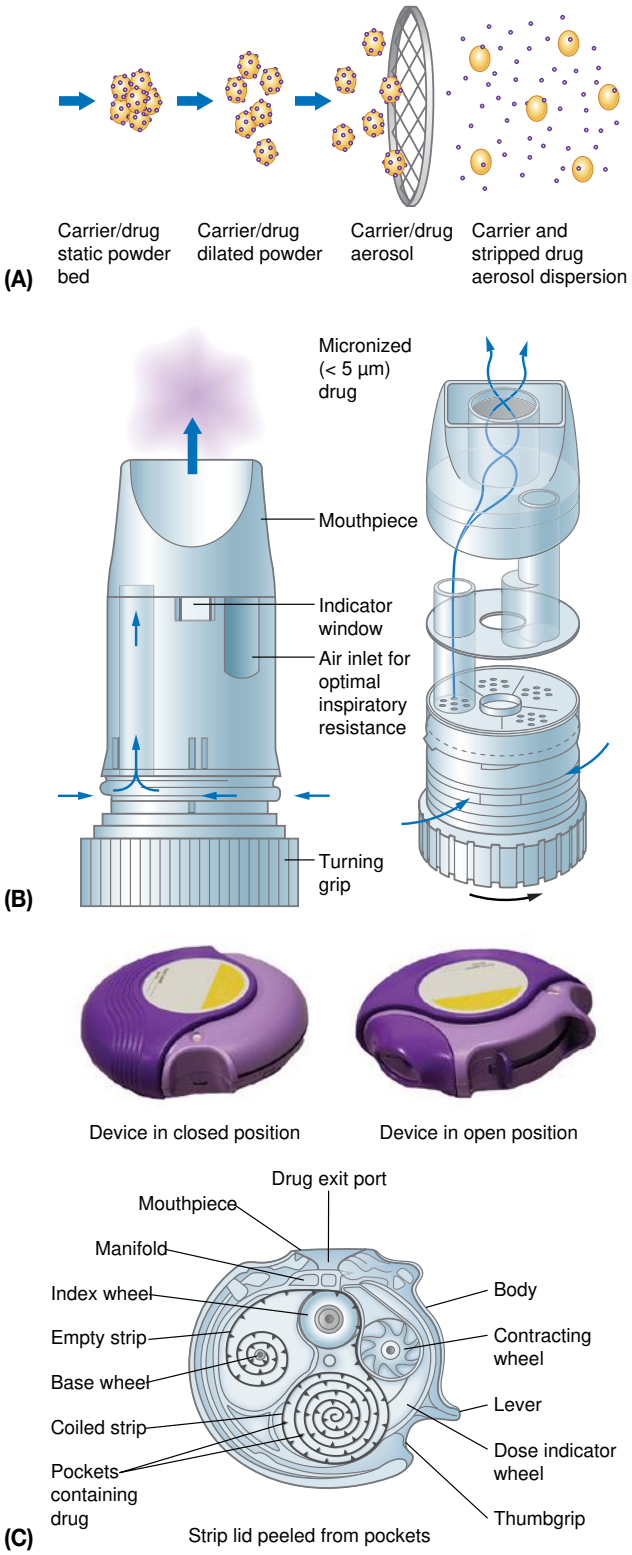

FIGURE 5-24 **A.** Aerosolization of dry powder. **B.** Component parts of Flexhaler. **C.** Component parts of Diskus.

A. Modified from Dhand R, Fink JB. Dry powder inhalers. Respir Care 1999;44:940-951. **B.** Reproduced with permission from Crompton GK. Delivery systems. In: Kay AB, editor. Allergy and allergic diseases. London: Blackwell Science; 1997:1440-1450; permission conveyed through Copyright Clearance Center, Inc.

Instructor and Student Resources

For the Instructor

As a benefit of using this textbook and to save you valuable time in the preparation and instruction of this course, you will receive access to

- Slides in PowerPoint format
- Image bank
- Test bank
- Prepopulated midterm and final exams
- Sample syllabus
- Answer key to student activities
- Web links to computer-aided instructional materials to enhance the learning experience and ensure that the content is current and relevant to clinical practice as well as online resources for students and faculty, which include:
  - AARC expert panel and evidence-based clinical practice guidelines
  - Comprehensive resources for medicated aerosol delivery
  - Practice guidelines from professional organizations

For the Students

- Laboratory exercises were designed to complement didactic instruction by providing reinforcement and opportunities to realistically simulate clinical scenarios and interdisciplinary team rounds.
- Case studies present scenarios and assessment items so students can apply their knowledge to real-life situations.
- Access to our interactive Equipment Simulator allows students to realistically simulate clinical scenarios and interdisciplinary team rounds.

About the Authors

Teresa A. Volsko, MHHS, RRT, FAARC, is adjunct graduate faculty for Rush University and Northeastern Medical College of Ohio and a fellow of the American Association for Respiratory Care. Currently, Terry is the director of Respiratory Care, Transport, and the Communication Center for Akron Children's Hospital. Before joining the Akron Children's Hospital, Terry was an associate professor of health professions in the Bitonte College of Health and Human Services at Youngstown State University. She served as the program director for the Respiratory Care and Polysomnography programs for several years. Terry is the author of 3 textbooks, more than 40 manuscript publications in peer-reviewed medical journals and several book chapters. She has served the profession in many capacities and is currently a member of the Board of Trustees for the National Board for Respiratory Care, Board of Trustees for the American Respiratory Care Foundation, Board of Directors for Lambda Beta, the American Association for Respiratory Care Evidence-Based Clinical Guidelines Committee. Terry is also a member of the Editorial Boards of *Respiratory Care Journal* and the *Canadian Journal for Respiratory Therapy*.

Terry was born and raised in the Youngstown, Ohio, area. She received her associate degree in respiratory therapy technology, her Bachelor of Science, Master of Health and Human Services and Master of Business Administration from Youngstown State University. Terry's passion for the respiratory care profession and dedication to mentoring respiratory care students and professionals span nearly four decades.

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Rob, a native of Niles, Ohio, spent his career in the Cleveland, Ohio, area. He received an associate degree from Cuyahoga Community College and Bachelor of Science and Master of Health and Human Services degrees from Youngstown State University. He started his career at Rainbow Babies and Children's Hospital in 1977. In 1979, he was promoted to research coordinator. In 1986, he took the position of technical director of pediatric respiratory care and, in 1995, annexed the adult division as well. In 1997, he became assistant professor of pediatrics at Case Western Reserve University and was promoted to associate professor in 1998. In 2006, Rob became clinical research manager, Section of Respiratory Therapy, at the Cleveland Clinic. Rob became a fellow of the American Association for Respiratory Care in 1998 and was a recipient of the Forrest M. Bird Lifetime Scientific Achievement Award and Jimmy Young Medal.

Mohamad F. El-Khatib, MD, PhD, MBA, RRT, is a professor of anesthesiology and the director of the Respiratory Therapy Department at the American University of Beirut Medical Center. Dr. El-Khatib has published more than 115 peer-reviewed articles and abstracts in the fields of anesthesiology, critical care medicine, and respiratory care. Dr. El-Khatib's main area of interest is optimization of mechanical ventilation, including newer and nonconventional modes of ventilatory support and strategies for liberation from mechanical ventilation. Dr. El-Khatib has lectured at many international and regional meetings. He is currently the managing editor of the *Middle East Journal of Anesthesiology* and a reviewer for the journals of *Critical Care Medicine*, *Respiratory Care*, *Critical Care*, *American Journal of Respiratory and Critical Care Medicine*, *Lung*, and *Saudi Journal of Anesthesia*.

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CHAPTER

1

Introduction to Medical Gases

Teresa Volsko
Keith Hirst

OBJECTIVES

1. Define a medical gas.
2. Describe the types of gases used in respiratory care.
3. Explain how medical gases are delivered to the patient.
4. Describe how liquid oxygen is formed.
5. Describe how liquid oxygen is delivered to the patient.
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9. Explain the various methods of testing the hospital gas distribution system.
10. Identify problems with a hospital piping system.
11. Discuss how medical gases are stored and transported.
12. Identify the various cylinder sizes and colors and how they relate to the particular medical gas contents.
13. Discuss how oxygen concentrators work.

KEY TERMS

American National Standards Institute (ANSI)
American Standard Safety System (ASSS)
Diameter Index Safety System (DISS)
diaphragm compressor
direct-acting valve
fractional distillation
fusible plug
indirect-acting valve
Pin Index Safety System (PISS)
piston compressor
pressure-relief valve
quick-connect adapter
rotary compressor
rupture disk
spring-loaded device
terminal unit
Wood's metal
zone valve

Introduction

Respiratory therapists have a wide range of medical gases at their disposal. Gases designated for therapeutic or diagnostic purposes must undergo rigorous testing and meet standards before use. The U.S. Pharmacopeia (USP) provides the purification specifications manufacturers must abide by to distribute their products for human use. Therapeutic gases include oxygen, air, nitric oxide, and mixtures of helium and oxygen and oxygen and carbon dioxide. Gases may also be used to perform diagnostic tests or to calibrate the machines used to perform diagnostic testing. Helium, nitrogen, and carbon monoxide are commonly used for this purpose.

Medical-grade gases play an important role across the continuum of care. It is essential for the respiratory therapist to be knowledgeable not only of the types of gas used but also how they are composed, manufactured, transported, and stored until needed. This chapter presents the principles of medical gas manufacturing, storage, transport, and use in a variety of healthcare settings.

Medical Gases

Oxygen

Oxygen (O_2) is an elemental gas that is colorless, odorless, and tasteless at normal pressures and temperatures. It also supports life because oxygen makes up roughly 20.9% of the Earth's atmosphere by volume. It has a molecular weight of 31.9988 and a density of 1.326 kg/m^3 at standard temperature and pressure, dry (STPD).[1] When oxygen is in liquid form, it has a pale bluish tint and is slightly heavier than water. A common misconception is that oxygen is flammable. Oxygen is not flammable, but it will support combustion. Oxygen will accelerate combustion, causing the materials to burn at a higher temperature and more vigorously in its presence.[2] Substances that are combustible, such as oil, petroleum, and grease, will ignite more easily in an oxygen-enriched environment. Therefore, in the presence of oxygen, a small spark created by impact or friction can ignite these highly combustible products very easily.[1] The risk of fire in the operating room is of concern because of the extensive use of lasers, especially during head and neck surgeries.[3,4]

Oxygen has a unique molecular bonding. When oxygen is added to certain elements and/or compounds, oxidation, or the breakdown of that substance, will occur. The rate of oxidation will vary, depending on the substance, the temperature, and the amount of oxygen available.

Uses in Respiratory Care

Oxygen is used for diagnostic and therapeutic purposes. Diagnostically, it is used as a source gas to calibrate respiratory care monitoring equipment, such as gas analyzers. It can also be used as a mixture for device calibration; for example, oxygen mixtures are used in the calibration of gas cylinders for transcutaneous oxygen monitors.

Because of its life-sustaining properties, oxygen is used in concentrations greater than ambient air to treat and/or prevent the manifestations or symptoms of hypoxia.[5] In the acute care setting, oxygen may be used when hypoxemia is suspected, such as during resuscitative efforts in response to trauma[6] or during cardiac arrest.[7] Oxygen also may be used in the acute care setting to prevent or treat the manifestations or symptoms associated with tissue hypoxemia.[8] It may also be used to provide long-term therapy to individuals with chronic illness.[9] Oxygen may also be administered to prevent or treat hypoxemia during surgical procedures[10] or when recovering from anesthesia.[11] It is used in a variety of patient populations, from premature infants to adults. In some cases, supplemental oxygen may be needed for long-term use to treat hypoxemia associated with chronic lung conditions, such as chronic obstructive pulmonary disease (COPD) or cystic fibrosis.[12]

Oxygen therapy is not without risk. There are detrimental effects from the delivery of high concentrations of oxygen and/or the presence of hyperoxia for prolonged periods of time. In premature infants, the inability to regulate blood flow caused by the vasodilation effects of oxygen and fluctuations in P_aO_2 can alter cerebral blood flow and contribute to the development of intraventricular hemorrhages as well as alter retinal blood flow and contribute to retinopathy of prematurity[13,14] In adults, prolonged use at high concentrations ($F_IO_2 > 0.50$) may lead to oxygen toxicity, absorption atelectasis, and depression of ciliary and/or leukocyte function.[15-17]

Manufacturing

Oxygen is produced naturally by chlorophyll-containing plants through a process known as photosynthesis. Sunlight facilitates the production of glucose and oxygen when carbon dioxide and water combine within the chlorophyll-containing plants. Once transformed by this biological process, oxygen is released into the atmosphere.

Oxygen can also be produced commercially by **fractional distillation** of liquefied air. This process for bulk production relies on a method known as the Joule-Kelvin principle, which states that, when gases under pressure are released into a vacuum, the gas molecules will tend to lose their kinetic energy. The reduction of kinetic energy within the vacuum causes the temperature and the cohesive forces between molecules to decrease. This process is divided into three stages: (1) purification, (2) liquefaction, and (3) distillation.

During the purification stage, air is subjected to a series of compression and cooling cycles. At the beginning of this process, air is compressed to 1500 pounds per square inch (psi). Subjecting air to this increase in

pressure also causes an increase in temperature. The conditioned gas is then passed through a water-cooled heat exchanger, which dissipates excess heat. The air is then compressed a second time at a higher pressure, 2000 psi, after which the gas is passed through an aftercooler and delivered to a countercurrent heat exchanger at room temperature. Once this process is complete, the air is then cooled to −50° F (−45.6° C). This is the final cooling process in the purification phase. Waste nitrogen is used during this cooling process to freeze the water vapor and make it easier to remove.

Liquefaction is the next phase in the process. The gas passes through a series of heat exchangers and is cooled to extreme temperatures. This process eliminates any remaining water vapor. The initial pass through the first heat exchanger cools the air to −40° F (−40° C). The next pass through a third heat exchanger subjects the gas to a pressure of 200 psi and cools it to −265° F (−165° C). Liquefaction then takes place when the air is released into a separator and expanded to 90 psi. This release of pressure causes a further drop in temperature[1] and partial liquefaction of oxygen.

Distillation is the final stage of the process. In the separator, gas and liquid are pumped through separate streams into the distillation column. The liquid portion enters the top and passes through a series of cylindrical shells that contain metal trays. Vapor from the separator passes through the liquid as it travels across and through the metal trays. The liquid becomes richer in oxygen because this process enables nitrogen to be boiled off. As a result, the vapor that rises becomes very rich in nitrogen. Liquid oxygen forms at the bottom of the column; however, this oxygen is not free from impurities. The liquid oxygen may still contain krypton and argon. To remove any remaining impurities the oxygen is boiled again at a precise temperature and pressure. As the boiling points of these remaining gases are reached, they evaporate. The oxygen that is left through this process is 99.9% pure oxygen.[1]

Carbon Dioxide

Carbon dioxide (CO_2) is a chemical compound composed of two oxygen atoms covalently bonded to a single carbon atom. Its molecular weight is 44.01, and it has a density of 1.833 kg/m^3 at STPD.[1] Carbon is 27.3% and oxygen 72.7% of the total molecular weight of this compound. Carbon dioxide is a trace gas, comprising 0.039% of the atmosphere. It is colorless and, at low concentrations, also odorless. At higher concentrations, this gas has a sharp, acidic odor and can cause a sour taste in the mouth and irritation or stinging to the upper respiratory tract. Studies have demonstrated that inhalation of high concentrations of carbon dioxide (7.5%) were associated with increased heart rate and blood pressure and increased subjective scores of panic, anxiety, and fear[18,19] or even asphyxiation. This gas is heavier and denser than both air and oxygen and is nonflammable and cannot support life. Because of these properties, carbon dioxide in its liquid form is sometimes used in fire suppression units in areas where water may damage sensitive equipment.[20] Solid carbon dioxide, or dry ice, can be used to ship medical and nonmedical items that would perish at normal temperatures.

Uses in Respiratory Care

Carbon dioxide has a limited role as a therapeutic gas. In lieu of adding mechanical dead space to a ventilator circuit, carbon dioxide has been titrated in small amounts to correct respiratory alkalosis for patients requiring full ventilator support. Typically, carbon dioxide is added to oxygen in concentrations of 5% or 10% carbon dioxide, yielding 95% or 90% oxygen, respectively, to form "carbogen." Inhaled carbogen (5% carbon dioxide, 95% oxygen) has been used to promote vasodilation and increase cerebral perfusion in patients with occlusive carotid artery disease.[21] When it is used therapeutically, the duration of therapy is relatively short, 10 minutes or less, and close patient monitoring is warranted. Pediatric cardiac patients have been given carbon dioxide postoperatively to manipulate pulmonary vascular resistance and thus reapportion pulmonary and peripheral blood flow.[22]

Carbon dioxide is most useful as a diagnostic or calibration gas in the clinical laboratory setting. It is also used for calibration of blood gas analyzers and transcutaneous partial pressure of carbon dioxide electrodes and capnographs. Carbon dioxide is added to membrane oxygenators for devices that bypass the heart and lungs, such as extracorporeal membrane oxygenation (ECMO) and cardiopulmonary bypass (CPB) machines. It has also been used as a shuttle gas for intra-aortic balloon pumps (IABPs); however, most IABPs now use helium.[23]

Manufacturing

Unrefined carbon dioxide is obtained either from geological reserves or as a by-product from the combustion of coal, coke, natural gas, and oil. It can also be obtained as a by-product from the fermentation of sugar during the production of alcohol.

Atmospheric carbon dioxide is refined for medical use. The refinement process removes impurities, such as pollutants, water, and gas mixtures (e.g., carbon monoxide, hydrogen sulfide, and nitric acid). The purity of medical-grade carbon dioxide must be at least 99.5%.

Helium

Helium (He) may be the lightest gas used in respiratory care. Its molecular weight is 4 with a density at STPD of 0.165 kg/m^3.[1] It is a rare gas found in the Earth's atmosphere at a concentration of 5 parts per million (ppm). Helium is colorless, odorless, and tasteless. This

nonflammable gas does not react with biological membranes. It has excellent thermal conductivity and a high rate of permeability and is only slightly soluble in the bloodstream. It cannot support life because it is both chemically and physiologically inert.

Uses in Respiratory Care

Helium has a very low density—0.18 g/L compared to 1.29 g/L for air and 1.43 g/L for oxygen (STPD). Because of this low density, helium is used extensively to promote less-turbulent gas flow and improve the distribution of gas in conditions where the airways are narrowed. Helium cannot support life and can be used for inhalation only as part of a gas mixture with oxygen. The helium/oxygen blend is often called "heliox." The literature reports the use of heliox decreases the work of breathing in conditions associated with increased airway resistance.[24-26] Because helium is so light, it diffuses approximately four times faster than a mixture of nitrogen and oxygen, enhancing the effect on carbon dioxide elimination.[27]

Heliox is commercially available in $He:O_2$ concentrations of 80:20 and 70:30. Typically, it is distributed in high-pressure medical gas cylinders in the H, G, or E size. Because the gas density of heliox mixtures is less than that of air or oxygen, clinicians should be aware of the effect heliox may have on the functions of medical devices. Air and oxygen flowmeters, for example, are affected by gas density and will not correctly measure heliox flow. In this instance, a formula can be used to calculate the predicted heliox flow, which is calculated by multiplying the diffusible factor for helium by the flow of gas set on the standard flowmeter. The conversion factor is 1.6 for 70:30 and 1.8 for 80:20.

If a 70:30 mixture were used for a patient and the flow on a standard air/oxygen flowmeter were set to 10 L/min, the predicted flow of heliox could be calculated as:

$$\text{Predicted flow of heliox} = \text{Conversion factor} \times \text{Flow set on the flowmeter}$$

$$\text{Predicted flow of heliox} = 1.6 \times 10 \text{ L/min}$$

$$\text{Predicted flow of heliox} = 16 \text{ L/min}$$

Care should be taken when using heliox to power standard jet or vibrating mesh during medicated aerosol therapy. Heliox can negatively affect nebulizer function if the predicted flow does not match the manufacturer's recommended flow. Depending on the total predicted flow, a smaller particle size, altered nebulizer output, and/or longer nebulization time can result.[28-30]

The density, viscosity, and thermal conductivity of heliox may interfere with ventilator function. It is essential for the clinician to know whether a ventilator is calibrated to deliver helium/oxygen mixtures before use. The literature reports that alterations in delivered and measured exhaled tidal volumes can occur when heliox is delivered through a ventilator that is not calibrated for use with gases other than air and oxygen.[31-33] To minimize the risks associated with ventilator malfunction, it is imperative for clinicians to consult the ventilator's operation manual and verify safe use of heliox.

Helium is an inert gas and will not interfere with human metabolism. This physical property facilitates the use of this medical gas with other medical devices and therapeutic interventions. Helium is used during surgical procedures to help expand patients' abdominal contents and make it easier for the surgeons to operate.[34] Helium is also used as a shuttle gas in IABPs to inflate the balloon. When used for this purpose, there is no risk of emboli or patient harm if the balloon were to rupture.[13]

Helium is also used diagnostically. It is used during pulmonary function testing to measure lung volumes and determine diffusion capacity.

Manufacturing

A small quantity of helium is naturally present in the atmosphere and can be obtained by fractionation. Most helium used is extracted from natural gas wells. It is obtained cryogenically and refined through a process of liquefaction and purification.

Compressed Air

Air is a mixture of several gases; the most prominent are nitrogen and oxygen along with many other trace gases that support the atmosphere of Earth. The oxygen in air is needed to sustain most life forms because it is vital to the metabolic process in our bodies. Medical-grade air is colorless, odorless, and tasteless. It is also considered nonflammable, but, like oxygen, it can support combustion. It can have a blue tint if cooled and may have a milky appearance if it contains high levels of carbon dioxide. It has a molecular weight of 28.975 with a density of 1.29 g/L at STPD.

Uses in Respiratory Care

Medical-grade air is most commonly blended with oxygen to provide a precise fractional inspired oxygen concentration (F_{IO_2}) or as a source gas to power small-volume nebulizers. Respiratory care equipment requiring a 50-psi gas source for operation, such as pneumatic percussors, may be more economically powered by compressed air. It can be supplied in several ways, including through piped systems, in high-pressure compressed gas cylinders, or from portable compressors. Respiratory care equipment, such as mechanical ventilators, may have a built-in compressor to provide a self-contained medical-grade air source for blended gas. Small, portable compressors are often used to power small-volume nebulizers for patients in their homes or in facilities (e.g., clinics and nursing homes) that do not have a piped-in air source.

Manufacturing

Air is a gas that is in abundant supply and available in several grades of purity. The grading system, developed by the Compressed Gas Association (CGA), ranges from A to N. Grade J is dry, free from oil and particulate, and considered medical grade.

Compressed medical air for high-pressure cylinders and/or bulk distribution through piping systems is manufactured in large quantities by the Claude or Linde process. Both methods compress and reexpand the air to cool it, which results in liquefaction. The Linde method requires much higher pressures (greater than 200 atmospheres [atm]) to produce liquefaction. The pressure needed to produce liquefaction with the Claude method is only 30 atm.

When air is produced through portable compressors, filters and Teflon piston rings are used to ensure it is free from oil and particulates.

Nitrogen

Nitrogen (N) is the most abundant gas, making up almost 78% of the Earth's atmosphere by volume. It is a colorless, odorless, and tasteless inert gas. It is nonflammable and will not support life nor combustion. It is less dense than air or oxygen, with a molecular weight of 28.01 and a density of 1.25 g/L (STPD).

Uses in Respiratory Care

Nitrogen is used medically to provide gas mixtures of inspired oxygen at concentrations less than ambient (i.e., <21%). The literature reports the use of subambient oxygen delivery to infants with unrepaired hypoplastic left heart syndrome (HLHS) or other single-ventricle lesions. The survival of these infants depends on success in maintaining patency of the ductus arteriosus, assuring adequate mixing of blood in the atria, and establishing and maintaining a balance between systemic and pulmonary blood flow at or near unity.[35] Oxygen concentrations less than 21% can be achieved by blending nitrogen with ambient concentrations of oxygen for infants requiring ventilator support;[36] for those not requiring ventilator assistance, devices such as a hood or high-flow nasal cannula can be used. Titrating the subambient gas concentration may be a tedious and time-consuming task, but it is essential for the respiratory therapist to take the time necessary to determine the precise F_{IO_2} necessary to alter the physiologic modifiers of pulmonary vascular resistance and maintain balanced circulation. Chatburn and colleagues have shown that the Mini-OX III and the Teledyne TED-190 provide accurate and reliable F_{IO_2} readings between 0 and 0.21 and are acceptable for delivering subambient oxygen concentrations.[37]

Nitrogen has also been used as a calibration gas for several types of gas analyzers. Typically, it is used to provide a zero reference point. It can generally be found in pulmonary function laboratories as a diagnostic gas.

Manufacturing

Nitrogen is produced during the liquefaction of atmospheric air. Large quantities of this gas are separated from impurities by fractionation.

Nitric Oxide

Nitric oxide (NO) is a colorless, nonflammable, and toxic gas at room temperature. It is present as a trace gas in air; however, additional nitric oxide is produced as a by-product of combustion and is thus considered an environmental pollutant. It is also a toxin produced by cigarette smoke. Nitric oxide is typically odorless but may carry a faint metallic smell. It is a very strong oxidizer and therefore supports combustion. Its molecular weight is 30.006, and, at STPD, it has a density of 1.245 g/L.[1] At high levels, it can contribute to the formation of methemoglobin and to tissue hypoxia. In the atmosphere, ozone readily changes nitric oxide to nitrogen dioxide (NO_2).

Uses in Respiratory Care

Nitric oxide is an important mediator of vasomotor control. Inhalation of nitric oxide at low doses (5–20 ppm) can be used to facilitate smooth-muscle relaxation and pulmonary vasculature dilation. As a result, oxygenation improves through better ventilation/perfusion matching. At higher doses (<80 ppm), it is a potent pulmonary vasodilator. Inhaled nitric oxide can effectively reduce pulmonary hypertension by lowering pulmonary artery resistance. Currently, there is only one Food and Drug Administration (FDA)–approved use for nitric oxide, the treatment of infants with hypoxic respiratory failure.[38] Term infants with persistent pulmonary hypertension, either as a primary cause or secondary to other disease processes, respond to inhaled nitric oxide with improvement in oxygenation indices and a decreased need for ECMO. In a study of 24 patients with congenital diaphragmatic hernia requiring surgical intervention and postoperative mechanical ventilatory support, inhaled nitric oxide contributed to a reduction of pulmonary hypertension, amelioration of respiratory symptoms, and recovery of pulmonary vascular function.[39]

The literature also reports positive patient outcomes with the use of nitric oxide with sickle cell disease,[40] for prevention of chronic lung disease in premature infants,[41] and for patients with acute respiratory distress syndrome (ARDS).[42,43]

Manufacturing

Nitric oxide is manufactured by the oxidation of ammonia at 932° F (500° C) in the presence of a platinum catalyst. It can also be produced when acid solutions of nitrates are reduced by metals.[1] Although rare and not a high yield for the amount of energy needed, at high temperatures (5792° F/3200° C), a direct combination of nitrogen and oxygen under energy-rich conditions can

obtain 5% volume of nitric oxide. Nitric oxide is stored in aluminum cylinders with a final gas purity of 99.0%. To enhance safety, the cylinders have CGA 626 valve outlets.

Nitrous Oxide

Nitrous oxide (N_2O) is a colorless, odorless, and tasteless nontoxic gas that cannot support life. It is nonflammable but will support combustion. There are several grades for this gas. Grade A is acceptable for medical use. It has a molecular weight of 44.0128 and, at STPD, a density of 1.947 kg/m^3.[2]

Uses in Respiratory Care

Nitrous oxide is a central nervous system (CNS) depressant. Typically, it is used for general anesthesia during surgical procedures. Its use without at least 20% oxygen may cause asphyxia and patient demise.

Manufacturing

Nitrous oxide is obtained by the thermal decomposition of ammonium nitrate. It can also be recovered as a by-product from the steam from adipic acid manufacturing.[1]

Medical Gas Distribution Systems

Medical gases are used in the care of patients with respiratory disorders along the continuum of care. Therefore, it is essential for respiratory therapists to understand how medical gases are distributed to patient care areas. A bulk gas delivery system is any type of equipment assembly and interconnecting piping that has the capacity to store more than 20,000 cubic feet of medical-grade gas for delivery to patient care areas.[2] Monitoring and alarm systems are built into the central supply and can take the form of (1) a high-pressure gas cylinder supply or (2) a bulk supply system. The central oxygen supply system should be designed with features allowing backup and/or redundancy in the event of system failure.

Typically, clinicians give little thought to this process. There is renewed interest if a problem with the piping or bulk storage system occurs or new construction is planned. Malfunction of the gas distribution system within a hospital can contribute to serious patient safety events. The consequences of an oxygen failure extend to all patient care areas, from intensive to general care. Immediate identification of the areas affected and evaluation of the extent of the problem can minimize adverse patient outcomes. Man-made or natural disasters place a strain on resources available in our current healthcare system. The ability to provide adequate oxygen therapy could be disrupted if a natural (e.g., tornado or hurricane) or man-made (e.g., explosion or construction accident) disaster affected the institution's bulk supply. The ability to provide medical gases would be further compromised if an interruption in the manufacturing or delivery process occurs because the consumption would outstrip the available supply. Delivering oxygen to patients requiring manual ventilation, oxygen therapy, or positive pressure ventilation during these scenarios would be very difficult.[44]

During new construction, attention should be focused beyond the nursing units. The need for piped medical gas extends to areas where special therapeutic and diagnostic procedures are performed. The need for a 50-psi gas source (for mechanical ventilators or high-flow oxygen delivery systems) should be anticipated. Respiratory therapists are instrumental in the planning phase and will have valuable input regarding the number and location of compressed gas outlets. Therapist involvement in the initial planning and testing phase of new construction projects can minimize construction delays and the additional expense of unexpected and unbudgeted renovations. Operationally, poor planning can contribute to delays in care or safety events. For example, if piped-in gas were not available in interventional radiology, additional resources and planning would be needed to safely transport a mechanically ventilated patient to and from the procedure and provide care during the procedure. If the amount of compressed gas needed for a patient was not properly calculated, a mechanical failure of the ventilator caused by an insufficient supply of source gas could cause the patient harm. Planning for and attending to patient needs may also require additional staff resources, all of which could have been avoided by adequate planning during the construction phase.

Usually, gases for bulk distribution to acute care institutions, such as hospitals or long-term acute care (LTAC) facilities, are stored in their liquid form in large reservoirs outside of the facility (**Figure 1-1**). High-pressure cylinders banked together with a manifold system are too expensive and cumbersome for large acute care organizations and are more commonly seen in the long-term care venue (**Figure 1-2**). However, the potential for mass-casualty and pandemic events sparked interest and increased the availability of systems used for bulk gas delivery.

In a survey of 35 hospitals in the greater Cleveland and Columbus, Ohio, metropolitan areas, Stoller and colleagues investigated the types of primary and reserve oxygen sources and the presence and configuration of a backup system. Bulk liquid oxygen systems (with primary and reserve liquid reservoirs) were predominantly used as a main central supply source, with some providing manifold cylinders as backup.[45] Mishaps regarding the main supply line from the bulk oxygen reservoir were reported by 16% (5/32) of responding institutions.[45] The authors also reported that main and reserve tanks were contiguous and fed through a single line to the hospital facility, suggesting ongoing risk for interruption of the oxygen supply. Regardless of the type of central supply system a healthcare organization has, it is essential to formulate a contingency plan to lessen the

FIGURE 1-1 Liquid oxygen vessel used for bulk storage for an acute care facility. This illustration shows the bulk oxygen vessel at a distance from the facility surrounded by a protective fence, lighting, and signage.
Courtesy of Captain-n00dle/Wikimedia Commons.

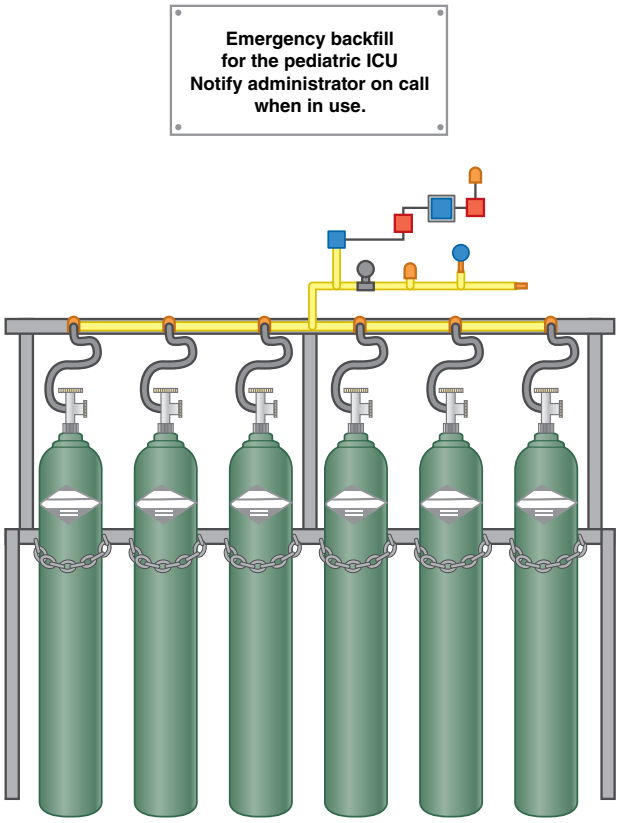


FIGURE 1-2 An illustration of a manifold system used to connect large high-pressure cylinders together to form a bulk gas system.

risk of an interrupted supply of medical gas owing to man-made or natural causes.

Bulk Gas Delivery Systems

Oxygen

The National Fire Protection Association (NFPA) defines a bulk oxygen system as one that has more than 20,000 cubic feet of oxygen stored at atmospheric temperature and pressure.[3] This also includes all unconnected reserves onsite. Most acute care institutions use bulk liquid systems to deliver oxygen to 50-psi outlets in patient care areas. Generally, these systems are affordable, take up less physical space within the institution, and are robust and very reliable. Liquid oxygen is less expensive when shipped in bulk and stored in large insulated, double-walled, stainless steel containers, outside of but near the healthcare facility (Figure 1-1). The construction of the containers is designed to keep the liquid oxygen in a liquid form. The storage container must maintain the contents at a temperature below −181.4° F (−118.6° C) to keep oxygen in a liquid state. Otherwise, a rise in temperature will cause oxygen to change from a liquid to a gaseous state. The bulk oxygen system takes up less physical space within the hospital or LTAC facility, when compared to systems that bank a series of large high-pressure tanks (Figure 1-2).

The contents of the medical gas within the storage containers are closely monitored by electronic systems. Monitoring is the responsibility of either the medical gas vendor or the hospital maintenance department. Occasionally, healthcare facilities have policies and procedures requiring that the vendor and the organization's maintenance department have joint monitoring responsibilities.

Large liquid gas transport trailers are used to refill the external containers. Refilling typically occurs during the late evening or at night to avoid congestion in the area surrounding the facility. The vendor delivery staff are trained and certified in the filling technique.

As the medical facility needs oxygen, the liquid oxygen passes through a vaporizer that also acts as a heat exchanger. The vaporizer absorbs the heat from the surrounding environment, raising its temperature to room temperature. This also raises the temperature of the gas and causes it to turn from a liquid to a gaseous state. As the oxygen turns from a liquid to a gas, the pressure increases within the container. Oxygen then passes through a reducing valve, which drops the pressure to a working pressure of approximately 50 psi.

Regulatory bodies govern the design and construction of bulk liquid oxygen systems. The NFPA regulates the location where the system can be in proximity to buildings and other surrounding structures (**Figure 1-3**). (The NFPA Recommendations and Regulations for Bulk Oxygen Systems can be found in **Appendix 1-B**.) The American Society of Mechanical Engineers (ASME) controls how the system is designed and the construction of the storage containers. Lastly, the Bureau of Explosives regulates the pressure-relief valves used within the system. The way a healthcare facility complies with the standards established by these regulatory bodies is also important. The Joint Commission requires hospitals to comply with these standards and assesses compliance during regularly scheduled credentialing visits.

FIGURE 1-3 The NFPA *Health Care Handbook* provides guidelines for minimum distances for locating structures around bulk oxygen supplies.
Courtesy of Bhakua/Flickr.

Air

Bulk delivery systems for air may also be part of a healthcare organization's gas distribution system. Two methods are commonly applied to this setting. As with oxygen, a large bank of high-pressure cylinders can be used to provide medical-grade air for bulk distribution. However, like systems used for oxygen, this method is costly, time consuming, and impractical for large organizations, such as hospitals. Therefore, most medical institutions will use industrial compressors to produce the air. Although high-pressure tanks contain air that is drier and cleaner, air produced by industrial compressors meets the standards for medical grade, and the system is much less expensive and cumbersome.

Medical industrial air compressors are also regulated by the NFPA. Typically, medical institutions are required to have at least two compressors onsite. These compressors are motor driven and run either in tandem or independently of each other. Regardless of how the compressors are set up, standards require that each compressor must be able to meet the complete needs of the institution during peak demand. The availability of redundancy (more than one compressor) with the capability of meeting peak institutional demand will minimize interruption of compressed air availability at the bedside in the event a compressor fails or requires service.

Each compressor must have its own pressure-relief valve, check valves between the two compressors, and header and isolation valves to prevent pressure from one compressor entering the other compressor. The compressors draw in air from the surrounding environment, filter and compress it, and reduce the working pressure to approximately 50 psi. The compressed air is then fed through an aftercooler and exposed to a sudden drop in temperature. As the air is cooled, any water vapor will rain out. This is an important process because ambient air contains moisture, and, as air is compressed and pressure increases, there is an increased risk of the air maintaining or holding onto that water vapor. Typically, as the air travels from the compressor through the piping system to the outlet at the bedside, the gas will cool. This will allow moisture to collect in the air piping, especially if the outlet has not been used. If the water vapor transferred through the piping reaches the compressed gas outlet, it can enter the respiratory care equipment and damage internal components.

FIGURE 1-4 A water trap with a drain and filter is often used in line with the high-pressure gas hose leading to moisture-sensitive equipment, such as mechanical ventilators and anesthesia machines.
Reproduced with permission from CareFusion.

Moisture collected as air is passed through the cooler and discarded. The dry air is stored in a reservoir tank until needed. This reservoir tank, also known as a receiver, must be equipped with a pressure gauge, relief valve, and automatic drain (for any condensate). A dryer is also located between the pressure regulator and receiver to further reduce moisture.

Although the systems in place remove most of the moisture and particulate matter, they are not entirely foolproof. Medical equipment requiring compressed air, such as ventilators, have filters to trap the particulate matter and prevent moisture from entering the device (**Figure 1-4**).

To prevent cross-contamination and the risk of a healthcare-acquired infection,[46] compressed medical air outlets should be used only for patient care equipment. The outlets should not be used to power engineering, maintenance, and other equipment that is nonmedical in nature.

Piping Distribution Systems

Bulk gases need to be distributed over zones that are located throughout the medical facility. The NFPA regulates the construction, installation, and testing of these systems. Gases are transported using seamless type K or L copper or brass pipes. These pipes are required to be labeled every 20 feet with the type of gas and direction of gas flow. A hospital may have bulk delivery systems for specialty gases, such as nitrous oxide, as well. Labeling allows for the gas within that piping to be easily identified and minimizes cross-connection within the facility's piping system. The diameter of piping used to deliver oxygen is 0.5-inch OD (outside diameter) and other gases are 0.375-inch OD.

The distribution of gases includes a series of pipe systems that include the pipes; pressure-relief valves; zone valves; alarms; and station outlets, or terminal units. Pipes are broken down into three categories and described as follows:

- *Main line:* Pipes that connect the operating supply to risers, branch lines, or both
- *Risers:* Pipes that are installed vertically that connect the main line with branch lines on each floor of the building
- *Branch (lateral) lines:* Pipes that travel from the risers to individual rooms or groups of rooms on the same floor of the building

Pressure-Relief Valves

Pressure-relief valves are a safety feature incorporated into the system. The valves allow for excess gas to vent from the system to prevent line damage should a buildup of pressure occur. These valves are usually set at a pressure that is 50% greater than the normal line pressure. Pressure-relief valves are located above each air compressor, downstream of the main-line pressure regulator, and upstream of any zone valve.

Zone Valves

Zone valves are also known as shutoff valves, isolation valves, or section valves. They are located in the branch and riser lines and allow for a room, section of rooms, or entire floor to be isolated. Typically, zone valves are located in easily accessible areas where healthcare practitioners can access them in the event of an emergency or when maintenance or repair of the central gas supply becomes necessary. Specifically, zone valves can be found near the operating gas supply, where the main line enters the building, at each riser supplied from the main line, adjacent to the riser connection, and in each branch line that serves non–life supporting patient rooms and outside each critical care area. If a zone valve is activated, the affected zone is isolated from the central gas supply source, allowing the remaining areas of the facility to be unaffected.

Respiratory care practitioners should know the location of the zone valves in their facility or at the very least in the unit in which the therapist is assigned. In many institutions, the respiratory therapist is responsible for activating a zone valve (shutting off the supply of gas to an area) in the event of an emergency, such as a fire. Typically, zone valves are located near a central workstation, such as a nursing station. These valves are labeled and installed in boxes with a removable window (**Figure 1-5**). Typically, only a quarter turn (from the 3 o'clock position to the 6 o'clock position) is necessary to activate a zone valve.

Pressure Gauges

Pressure gauges are an important feature of a gas distribution system because they allow healthcare workers and engineers to visualize the pressure of the gas in each line. Pressure gauges are installed in the main line adjacent to the actuating switch and in each area alarm panel. These gauges need to be labeled correctly, color coded, and readable from a standing position.

Alarms

All gas distribution systems require alarms to notify hospital personnel of a system malfunction. Alarms

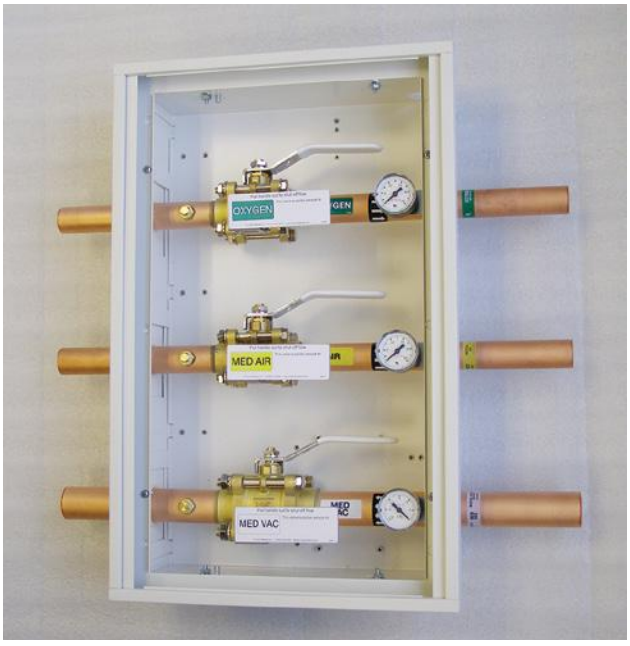


FIGURE 1-5 Oxygen, air, and vacuum zone valves.
Courtesy of Tri-Tech Medical Inc.

need to monitor the operating supply, reserve supply, and pressure in the main line and local supply lines. Typically, there is a master alarm system that consists of two panels. Each of these panels incorporates audible and visual alarms to signify system problems. The alarms also must be noncancelable if the operating pressure varies more than 20% from normal.[2] The alarms usually automatically reset after the issue has been resolved.

The following are system problems that will activate an alarm:

- Changing over from the primary to the secondary bank occurs as or just before the reserve supply goes into operation.
- Reserve supply is reduced to a one-day supply.
- Pressure in reserve supply is too low to allow proper function.
- Pressure in the main line drifts (increases or decreases) from normal operating pressures.
- Level of liquid in the bulk liquid oxygen supply reaches a predetermined minimum level.
- Dew point in the compressed air system exceeds a preset threshold.

There are also area alarm systems, which are common in critical care areas of the hospital, such as the emergency department, intensive care units (ICUs), operating rooms (ORs), and postanesthesia care units (PACUs). Area alarms must also have an audible and visual noncancelable alarm if the operating pressure fluctuates more than 20% of normal operating pressure. Usually, these alarms are installed downstream of the zone valve in the line specific to the unit they are servicing.

Hospital personnel responsible for alarm surveillance should be skilled in troubleshooting the bulk gas delivery system, piping zone valves, and station outlets. It is also essential to have response plans in place to ensure that any medical equipment in the affected area(s) continues to work properly. When alarms have been activated, appropriate personnel should be notified, usually engineering and respiratory care.

(A)

(B)

FIGURE 1-6 **A.** A typical quick-connect station. **B.** An oxygen flowmeter attached to a quick-connect station.
A. Courtesy of Tri-Tech Medical, Inc. **B.** © Jsnow my wolrd/Shutterstock.

Station Outlets

Once the gas has traveled to the bedside, it goes to a station outlet, or **terminal unit** (**Figure 1-6**). This is the point at which medical equipment (e.g., high-pressure lines from respiratory equipment, such as ventilators, air/oxygen blenders, and oxygen and air flowmeters) connects to and disconnects from the central gas supply system. The station outlets are made up of several components, specifically a base block, faceplate, primary and secondary valves, and connection point. The base block is the portion of the station outlet that connects to the piping system. Its function is similar to that of an electrical outlet at the end of an electrical wiring system. The faceplates cover the base block and are permanently labeled and color coded, based on the gas being supplied to that end. The primary and secondary valves are safety valves that open and allow gas to flow into the device when a male end of the respiratory care equipment is connected to the female end of the faceplate. The valves also automatically shut off the flow of gas when the male and female ends disconnect, which helps to minimize waste.

To prevent connection to the wrong gas source, each station outlet accepts only a gas-specific connector. Two types of systems are used, diameter index systems and quick-connect adapters.

Diameter Index Safety System

A **Diameter Index Safety System (DISS)** is a threaded connection specific to the gas that is needed. The DISS was developed by the CGA for medical gases at 200 psi or less. A DISS connection consists of a body, nipple, and nut assembly. The body contains two specifically sized shoulders. The small bore (BB) mates with the small shoulder (MM), and the large bore (CC) mates with the large shoulder (NN). Each gas (e.g., air, oxygen, and helium) has its own corresponding size, which makes it very difficult to accidently switch gas lines for a mechanical ventilator. One drawback is that these connections cannot be made quickly because they must be twisted on like a nut on a bolt. However, once seated, they have a low risk for leaks (**Figure 1-7**).

Quick-Connect Adapters

Quick-connect adapters allow the user to plug in and quickly access the gas source. There are two basic types, the National Compressed Gas (NCG) and the Ohio Diamond, or Ohio Quick, connecters. Both the NCG and Ohio Diamond connectors are nonthreaded and gas-specific male and female connections. They both work on the same principle; a plunger (female) is held by a spring, which prevents the gas from leaving the line. The probe (male) pushes the plunger back, which allows gas to flow out. When the probe comes out, the spring pushes the plunger back into place. The advantage of this system is that the quick connectors are easier to connect than DISS connectors (like a plug-and-play connector on a computer); however, they are more prone to leaks (**Figure 1-8**).

Testing and Verifying Medical Gas Distribution Systems

Once the gas pipes have been installed or serviced, testing must be conducted. It is important to verify that the system is free from leaks and no cross-connections have occurred. A visual inspection of the system is done to ensure the pipes are free from dirt, oil, grease, or other

FIGURE 1-7 Oxygen and air DISS connections to an oxygen flowmeter.
Courtesy of Owain.davies/Wikipedia.

(A)

(B)

FIGURE 1-8 Examples of quick-connect oxygen adapters. **A.** Ohio Diamond. **B.** Chemtron.
Courtesy of Allied Healthcare Products, Inc.

oxidized materials. It is also important to ensure the lines are not visibly damaged (e.g., dented, punctured, or bent) or cross-connected with another type of specialty gas (e.g., the oxygen line is cross-connected with a nitrous oxide line).

Pressure Testing

Gas pipelines need to meet specific parameters and be leak free. A leak in a gas line could pose a fire hazard. To ensure that the gas pipeline is leak free, the system is pressurized using either dry air or nitrogen up to 150 pounds per square inch, gauge (psig). Each joint and connection is tested with a leak-detection solution. Once a leak has been detected and fixed, the system must be tested again. When the system has been determined to be free from leaks and all alarm panels have been installed and are operational, the system is pressurized for 24 hours at 20% above normal operating pressure (typically, around 60 psi). If any further leaks are found during this process, the leaks are repaired, and the process is repeated until the system remains leak free for 24 hours.

To ensure that cross-connections do not occur, each station outlet is tested to ensure that the outlet is delivering the gas the label specifies. For example, to test an air outlet, connect an air flowmeter to the outlet station. Direct a flow of gas into a bag containing an oxygen analyzer. The analyzer should read 21%. If it reads less than 21%, a cross-connection with an oxygen line may have occurred, which needs to be corrected. Generally, each outlet station for each specialty gas is tested, one at a time. If all gas lines were tested at once, it would be difficult to know where the cross-connection occurred. Any suspicion of cross-connection should be explored and immediately corrected.

Component Testing

Testing should occur on all levels and include alarms and system function tests. The primary and secondary supply systems and the switch from primary to reserve supply need to be tested to ensure there is minimal interruption in gas flow should a malfunction occur or when a supply system needs to be shut off for maintenance. The alarms associated with each of these systems also need to be checked for proper function. Verify that pressure-relief valves vent off excess gas if the gas pressure rises above 50% of normal line pressure, and the alarms reset when the pressure drops back to normal levels. Also, test and confirm that the liquid oxygen low-level alarm is functioning. Test the compressed air system alarms and the function of the safety valve and automatic drain.

Each zone valve should be shut off and terminal units tested to ensure the zone valve controls the units for which it is designed. The valves should also be tested for tightness. This can be done by closing the zone valve and monitoring the downstream pressure for 30 minutes. If the pressure rises, then the valve is not shut or tight because gas is still flowing through and causing the pressure to rise.

Terminal units must also be tested for gas composition to confirm that all labeling is correct and no cross-connection has occurred. The station outlets also need to be checked annually for gas leakage, visual damage, and ease of insertion as well as locking and unlocking of the connector.

Periodic Testing

Testing of all components of the central bulk system should occur annually and the results of the testing process documented. This documentation should include details of any problems encountered during testing, corrective actions taken, and verification that the problems have been resolved. The compressed air system intakes should be inspected quarterly for contamination. The function of the automatic drain for the water from the receiver needs to be assessed daily.

Problems Associated with Medical Gas Distribution Systems

Although regulations and safeguards are built into bulk gas distribution systems, unexpected problems can still occur. Low or inadequate pressure can cause equipment to malfunction, especially when 50-psi working pressure is required (e.g., for ventilators, anesthesia machines, and air/oxygen blenders). Causes of low or inadequate pressure in the gas lines include the following:

- Inadvertent interruption of gas during construction
- Fire
- Motor vehicle accidents (usually involving the operating supply, causing a delay in the refill)
- Environmental forces (e.g., hurricane, tornado, or earthquake)
- Damage or depletion of the operating supply
- Human error (e.g., inadvertent closure of zone valve or improper adjustment of main-line regulator)
- Equipment failure (e.g., zone valve leaks, reserve supply failure, regulator malfunction, or failure of switchover systems)
- Obstruction of the pipeline (e.g., debris left behind during construction or installation)
- Quick-connect failure (e.g., improper fit, breakage, obstruction of the connector, or disconnection of the station outlet)

High pressures within the central gas system have the potential to cause serious safety events as well. However, if the pressure-relief valves are properly installed and functioning, then minimal harm to the equipment and/or the patient will result. Every system alarm, high

or low, must be investigated. An alarm may occur intermittently over a sustained period of time caused by miscalibration or malfunction. Lack of communication between maintenance and clinical departments, a lack of understanding by hospital personnel, and unfamiliarity with emergency measures contribute to delayed resolution of problems.

Gas Contamination

During construction and installation, it is not uncommon for particulate matter, such as oil, metal filings, solder flux, and other matter that contains hydrocarbons, to enter the system. Intrusions of such particulates can cause extreme damage to sensitive medical equipment and pose a serious hazard if they are inhaled by patients. As discussed earlier, it is necessary that proper care be taken when cleaning and purging pipe lines.

Oil used to lubricate and maintain the compressors can easily contaminate air lines. Contamination can also occur from improperly installed air intake filters and/or filters that were cleaned but not fully dried.[4]

Also, the moisture within the air system can support bacterial growth, which can be dispersed to patients.

Storage of Medical Gases

Cylinders Used for Gas Storage

Medical gases come in two forms, liquefied and nonliquefied. Liquefied gases come in specifically designed bulk and portable liquid storage units. Nonliquefied gases are stored in cylinders made of steel, aluminum, or chrome molybdenum. Cylinders must be able to hold in excess of 2000 psig of gas and be colored specifically for the type of gas they contain. Labels are affixed to the external surface, indicating the type of gas contained within the cylinder. There are a host of agencies that govern and regulate the manufacturing, storage, transportation, and use of medical gas cylinders. The NFPA and CGA Recommendations for Compressed Gas Cylinders can be found in **Appendix 1-A**.

Construction

Medical gas cylinders are usually constructed of seamless, high-quality steel, aluminum, or chrome molybdenum. Steel and chrome molybdenum are more durable than aluminum. Aluminum is lighter in weight and more often used in home care and for air or ground transport. Because aluminum cylinders are not affected by magnetic fields, they are also used in magnetic resonance imaging (MRI) suites.

The cylinders are formed by forcing a hardened steel press through a softer mass of cylinder material, called a billet, shaping it into a tubelike structure. Once the tube is formed, the bottom and top are heated, shaped, and closed. The top is threaded so that a valve stem can be fitted onto the tank. The stem valve is what allows the cylinder to be filled with gas and the gas to be released. The bottom is molded flat so the cylinders will stand up on their own.

Sizes

Medical gas cylinders come in various sizes, depending on their intended use. To identify their size and capacity, they are letter coded. The ML6 is the smallest, and the T is the largest (**Figure 1-9**). The most frequently used cylinders are the E and H sizes. E cylinders are commonly used for intrafacility transports or home care. They are often seen attached to crash carts or in carriers secured to wheelchairs or gurneys (**Figure 1-10**). Medical gas cylinders are designed to

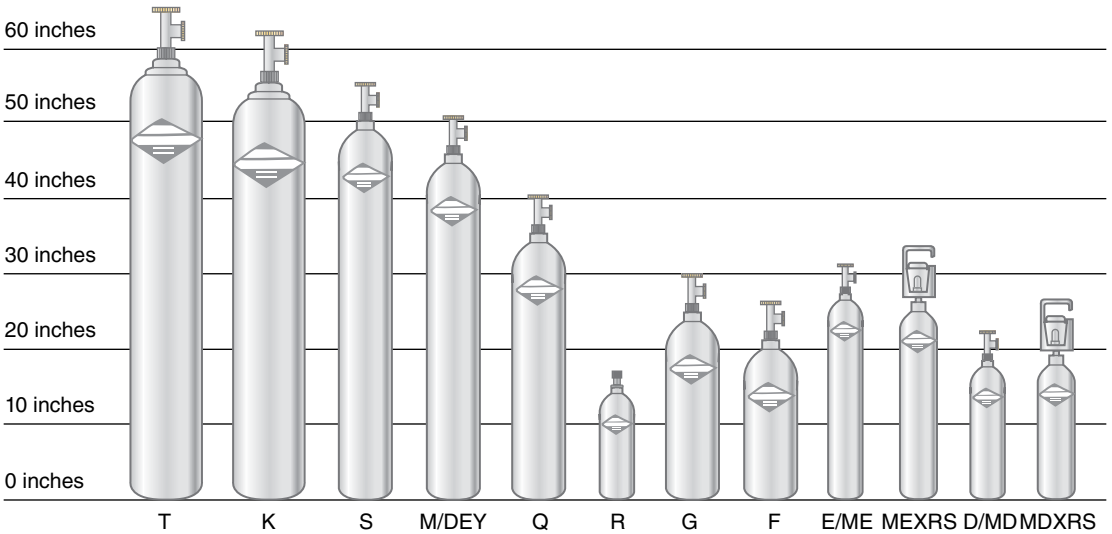


FIGURE 1-9 Sizes of high-pressure cylinders approved for medical gas therapy.

FIGURE 1-10 E cylinder with a built-in pressure gauge, flowmeter, and handle. This design facilitates handling of the cylinder and minimizes the manipulation the respiratory therapist needs to do (i.e., attaching the regulator and seal ring) to administer oxygen therapy.

hold 10% more than their actual filling capacity to allow room for the gas to safely expand with changes in ambient temperature.

Identification

Gas cylinders have several markings on them that healthcare providers should be familiar with. All tanks are color coded, based on the gas contents (**Table 1-1**). These color codes are designated by the U.S. National Formulary. If the cylinder contains a mixture of two or more gases, then the proportion of each gas is colored on the cylinder; for example, a tank containing a mixture of 80% helium and 20% oxygen would have 80% of the tank colored brown and 20% colored green. The color system is only a visual guide. It is important for healthcare providers to check the label affixed to the cylinder to verify contents.

Printed labels are required by the CGA and **American National Standards Institute (ANSI)** and include the name, gas/gas mixture, symbol, and volume of the cylinder in liters at a standard temperature (70° F/21.1° C). The label should also indicate any hazards of the gas (e.g., flammable or oxidizer) and a statement describing the dangers associated with exposure and how to avoid injury. The name and address of the manufacturer or distributor should also be included.

TABLE 1-1
Color Codes for Medical Gases

Gas	Chemical Symbol	Purity* (%)	Color Code
Air		99.0	Yellow or black and white‡
Carbon dioxide	CO_2	99.0	Gray
Carbon dioxide/oxygen	CO_2/O_2	99.0	Gray shoulder and green body†
Helium	He	99.0	Brown
Helium/oxygen	He/O_2	99.0	Brown shoulder and green body†
Nitric oxide	NO	99.0	Teal cylinder with silver or black shading
Nitrogen	N	99.0	Black
Nitrous oxide	N_2O	97.0	Light blue
Oxygen	O_2	99.0	Green or white‡

*National Formula Standards
†Always check labels to determine the percentage of each gas.
‡International Color Code

Gas cylinders are typically engraved with information specific to the manufacturing and latest testing of the cylinder, including the manufacturing point, material used in construction, service pressure of the cylinder, date of the original hydrostatic test, date the cylinder was reexamined and tested, manufacturer's name, owner's identification number, and size of the cylinder (**Figure 1-11**).

Compressed gas cylinders must undergo hydrostatic testing every 5 to 10 years. Hydrostatic testing is used to measure the thickness and durability of the tank. During testing, the cylinder is placed into a water container. Both the cylinder and container are filled with water, and the water level in the cylinder is recorded when atmospheric pressure is met. The water pressure in the cylinder is increased to 3000 psig while the water level in the container is measured and recorded. The volume of water displaced is equal to the expansion of the tank. A raised water level means that the wall thickness has been reduced either from damage or corrosion. If the tank fails this test, it can no longer be used.

Filling a gas cylinder can be a dangerous situation, and strict guidelines must be followed. These guidelines are set and controlled by the Department of Transportation (DOT), the FDA, and the U.S. Pharmacopeia/National Formulary (USP/NF). Companies that fill gas cylinders must register with the FDA and be inspected biannually. Only properly trained personnel should fill a gas cylinder. Cylinders must be clean and safe.

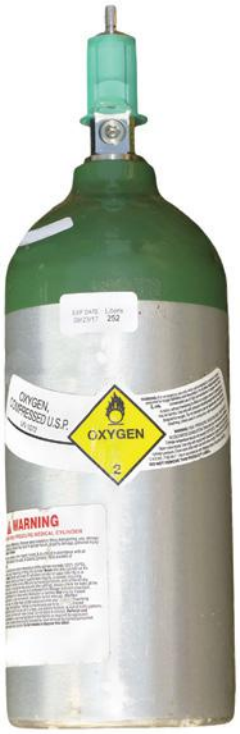


FIGURE 1-11 Example of compressed gas cylinder labeling. This photo denotes the typical markings on cylinders containing medical gases.

Gases must meet strict standards for purity according to the USP/NF. Each cylinder must have a current and readable label. All cylinders must meet FDA and DOT specifications.

Four steps need to be followed for a cylinder to be filled. The first step is the cylinder prefill inspection. During this inspection, all residual gas is removed, and a visual inspection is done to make sure there are no signs of damage, such as rust, dents, and corrosion, or damage to paint. The visual inspection also verifies that the last hydrostatic test date meets DOT criteria and the cylinder is properly labeled. A hammer, or "dead ring," test is performed at each refilling. To perform this test, a hammer is struck lightly on the side of the empty tank to listen for the tone it creates. If the cylinder is good, then the tone will be a clean ringing tone lasting approximately 3 seconds. If the tone is dull or flat or fades quickly, then the cylinder should be tested for damage.[2]

Step two is filling the cylinder with gas. Filling the cylinder must be done by a trained and certified person with certified equipment. The cylinder is attached to a manifold that is designed for filling; then, the tank is purged and filled with the appropriate gas from the supply source. There are special connections that are specific to the type of gas put in the tank, making it difficult to fill a tank containing helium and oxygen with carbon dioxide. Gas is introduced so that the filling rate is not greater than 200 psig/min. Once filled to STPD conditions, the valves are closed and the cylinders removed.

After removal, the valves are checked for leaks and that the contents meet the purity standards set by the USP/NF. Then, the tank, gas batch, and all the steps previously described must be carefully documented and recorded. The company must also have documentation on the daily gas calibration and that all connections and manifolds have been tested and inspected.

Cylinder Valves

To ensure that the gas does not accidentally leak or escape from the cylinder, valves are threaded onto the top portion of the tank during its construction. Turning the valve counterclockwise will allow gas to flow from the cylinder; turning the valve clockwise will prevent gas from escaping from the cylinder. The valves also can be opened to allow the cylinders to be refilled at the manufacturing plant. The valve for smaller cylinders (i.e., sizes A–E) is located on the top portion of the cylinder yoke. The yoke is the small rectangular stem that protrudes from the cylinder. A small hand wrench is needed to turn the valve, which opens and closes the flow of oxygen from the cylinder. The regulator is placed over and secured to the cylinder yoke. It is important to note that a small plastic washer is needed to seal the connection to prevent gas leaks between the regulator and the cylinder yoke. For larger tanks (i.e., H cylinders), a permanent handwheel is used to control the valve, and the regulator is attached to the cylinder by a threaded connection. Identical to the small cylinders, a clockwise turn will close the valve, and a counterclockwise turn will open the valve. Cylinder valves are constructed of materials that resist the mechanical, chemical, and thermal effects of the gas(es) contained within the cylinder. Typically, they are made of brass and are chrome plated. There are two types of valves, direct acting and indirect acting (**Figure 1-12**).

Direct-Acting Valves

Direct-acting valves have two fiber washers and a Teflon packing. *Direct acting* refers to the action the stem has on the seat. As the stem turns, so does the seat. As the seat rises, gas can escape from the cylinder through the yoke. The valve must also be in the open position to allow the cylinder to be filled by the gas manufacturing plant. When the seat is lowered, the gas flow to the yoke is closed off. These valves are manufactured to withstand pressures in excess of 1500 psi.

Indirect-Acting Valves

Indirect-acting valves are also known as diaphragm valves. A diaphragm is positioned between the stem and the seat of this type of valve and is controlled by turning the stem. As the stem is turned, the diaphragm raises and lowers, which opens and closes the valve,

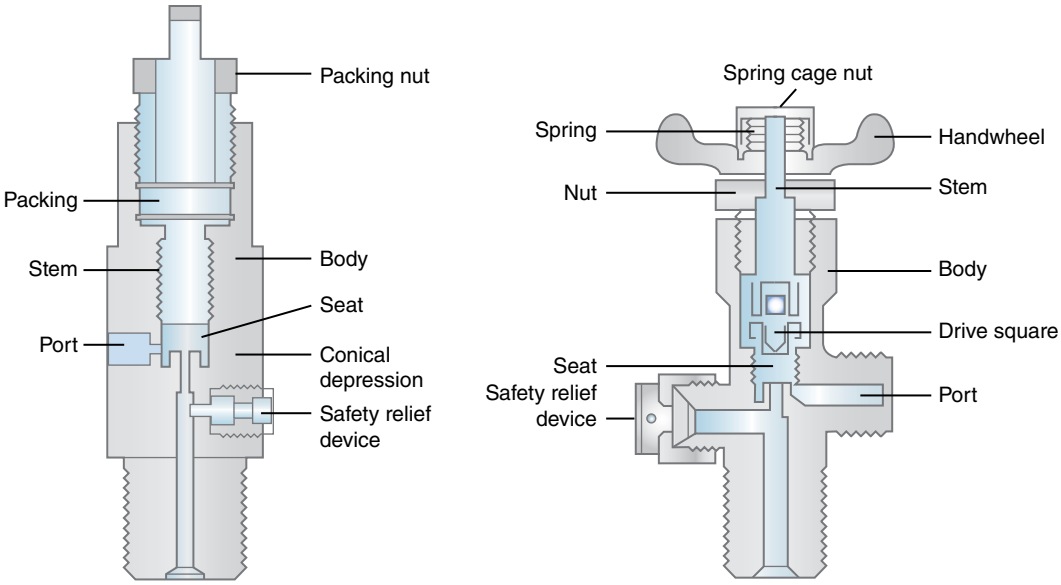


FIGURE 1-12 Schematic of cylinder valves.

respectively. A spring around the seat opposes the pressure applied to the diaphragm. This type of cylinder valve is more expensive to manufacture but is less prone to leaks and easier to open. Indirect-acting valves need only a half turn to open the flow of gas from the cylinder, compared to direct-acting valves, which need three-quarters of a turn. This type of valve is typically used in tanks where the pressure is less than 1500 psi. These valves are more commonly used for cylinders containing anesthetic gases, which are flammable and thus pose a high risk of fire if they leak.

Pressure-Relief Valves

A pressure-relief valve is a safety feature required on every gas cylinder. This safety feature is based on Gay-Lussac's law, which states that pressure in a closed container is directly proportional to the temperature of the gas. Pressure-relief valves are designed to vent gas and prevent the accumulation of excess pressure within the cylinder to reduce the risk of explosion when the cylinder is exposed to extreme or high temperatures. Excess pressure may also result from overfilling the cylinder.

There are three types of pressure-relief valves: **rupture disks**, **fusible plugs**, and **spring-loaded devices**. A rupture disk, also known as a frangible disk, is a thin metal disk with a specific pressure rating that will either break apart or buckle when the pressure increases beyond that rating, thus allowing gas to escape into the atmosphere. A fusible plug is made of a special metal alloy that will melt when the gas reaches temperatures between 208° F and 220° F (97.8° C and 104° C). As the plug melts, gas is permitted to escape. Typically, **Wood's metal**, a fusible alloy composed of bismuth, lead, cadmium, and tin, is used to construct a fusible plug valve. This alloy is also used to allow water to escape from automatic sprinklers. Spring-loaded devices are designed to maintain a certain pressure within the cylinder. As the pressure exceeds the predetermined level, the pressure pushes up on a spring, which causes a valve to be unseated, allowing the gas to escape. Once the pressure falls below the set pressure, the valve will reseat. This type of pressure-relief valve conserves the escaping gas, whereas rupture disks and fusible plugs release the cylinder's entire contents once the valve is broken. Unfortunately, spring-loaded pressure-relief valves are more susceptible to leaks and are affected by environmental changes. For example, should the cylinder be exposed to extreme cold, the spring-loaded pressure-relief valve may freeze and not function properly. This type of pressure-relief valve is more commonly found on larger cylinders. Rupture disks and fusible plugs are used more often with smaller cylinders (**Figure 1-13**).

Index Safety Connections

The outlets on high-pressure cylinders are manufactured to ensure the regulator or connector attached to the gas delivery system is the one appropriate for its use. For example, an oxygen regulator cannot attach to a cylinder containing a heliox mixture. There are three indexed safety systems specific for medical gases: **American Standard Safety System (ASSS)**, **Pin Index Safety System (PISS)**, and Diameter Index Safety System (DISS). The ASSS is used for large-capacity cylinders, above 200 psi, though typically this system is seen more often in the large cylinders, such as H and K sizes. This safety system sets the specifications for threaded high-pressure connections between compressed gas cylinders and their attachments, including the thread characteristics (i.e., right or left handed, number of

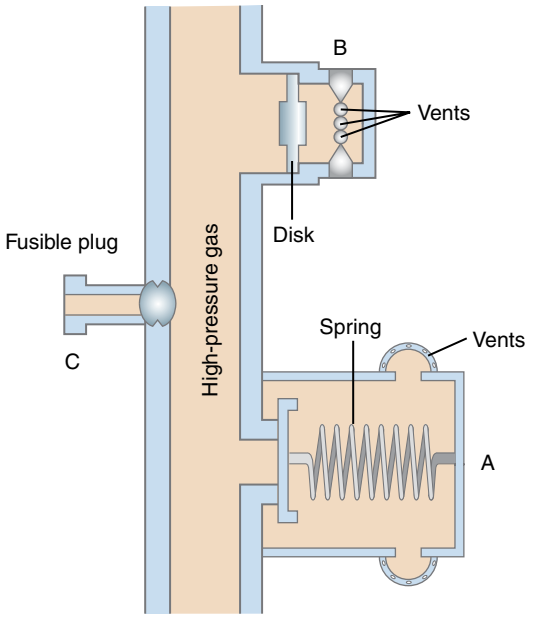


FIGURE 1-13 Pressure-relief valves. **A.** Spring-loaded device. When gas pressure exceeds the spring's tension, the spring is compressed to the top, allowing gas to escape through the vents. When gas pressure is reduced to normal, the relaxed spring tension reseats the valve. **B.** Rupture disk. When gas pressure exceeds safe limits, the disk ruptures, allowing the entire contents of the cylinder to escape into the atmosphere through the vents. **C.** Fusible plug. If the temperature inside or outside the cylinder exceeds safe limits, the plug melts, allowing the gas in the cylinder to safely escape.

Data from Branson RD, Hess DR, Chatburn RL. *Respiratory care equipment*, 2nd edition. Philadelphia, PA: Lippincott Williams & Wilkins; 1999.

threads per inch, and internal or external threads). The diameter of the outlet and the shape of the mating nipple on the corresponding regulator are unique to each type of specialty gas or gas mixture. The combination of the previously mentioned factors reduces error by making it very difficult for clinicians to place a regulator intended for one gas (e.g., air) on a cylinder containing a different type of gas or gas mixture (e.g., heliox) (**Figure 1-14**).

The numbers used in this system help with the identification process. A large cylinder containing oxygen will have a series of numbers to describe the characteristics of the threaded outlet, specifically 0.903-14-RH-Ext. The first number (0.903) describes the diameter of the cylinder's outlet in inches. The number of threads per inch on the connect is described by the next sequence. In the alphanumeric series above, the oxygen connection has 14 threads per square inch. The letters that immediately follow also refer to thread characteristics. In the example for oxygen, RH stands for right hand, the direction of the threads. The letters that follow (Ext or Int) refer to whether the threads are internal or external. In the previous example, oxygen has external threads, designated by the letters *Ext*.

FIGURE 1-14 **A.** Pin Index Safety System for small cylinders. **B.** American Standard Safety System for large cylinders.

Courtesy of Western Enterprises, a Scott Fetzer Company.

Small cylinders (i.e., sizes A–E) use the Pin Index Safety System. This system uses a specific combination of two holes on the post valve of the cylinder. Any device that connects to the yoke of the cylinder will have pins that correspond to the holes on the post valve. This system uses a series of pins in six locations. Each type of gas or gas mixture has a specific pin sequence (**Table 1-2**); for example, the pin sequence for oxygen is 2, 5. That means that only a regulator with pins in the 2 and 5 positions will sit correctly on an oxygen tank. The pin sequence for air is 1, 5. Therefore, it would be difficult to get a regulator or connector intended for an oxygen cylinder to fit onto a cylinder containing air (**Figure 1-15**).

TABLE 1-2
Pin Index Safety System Pin and Hole Positions for Medical Gases

Medical Gas	Index Pins
Oxygen	2, 5
He/O_2 (heliox): He ≤80%	2, 4
Air	1, 5
Ethylene	1, 3
Nitrous oxide	3, 5
Cyclopropane	3, 6
CO_2/O_2 (carbogen): CO_2 ≤7%	2, 6
CO_2/O_2 (carbogen): CO_2 >7%	1, 6

The DISS is designed by the CGA for low-pressure (less than 200-psi) connections and fittings. With this system a female nut and nipple mate with a specifically diameter-threaded male outlet. Gases (e.g., oxygen or nitrogen) and gas mixtures (e.g., HE/O_2 or CO_2/O_2) have connections that differ with respect to the diameter, pitch thread, and nipple configuration.

The DISS connection for the outlet of a flowmeter and the 50-psi working gas pressure connection have the same DISS-threaded connection. Respiratory therapists must use caution to avoid connecting low-flow devices, such as the humidifier for a nasal cannula, to the 50-psi working gas pressure connection. The excessive pressure delivered through this connection will cause the humidifier to rupture and delay delivery of medical gas to the patient. Equipment failure can also transpire because the high-pressure gas line (e.g., the high-pressure oxygen line for an air/oxygen blender) is attached to the threaded connection of

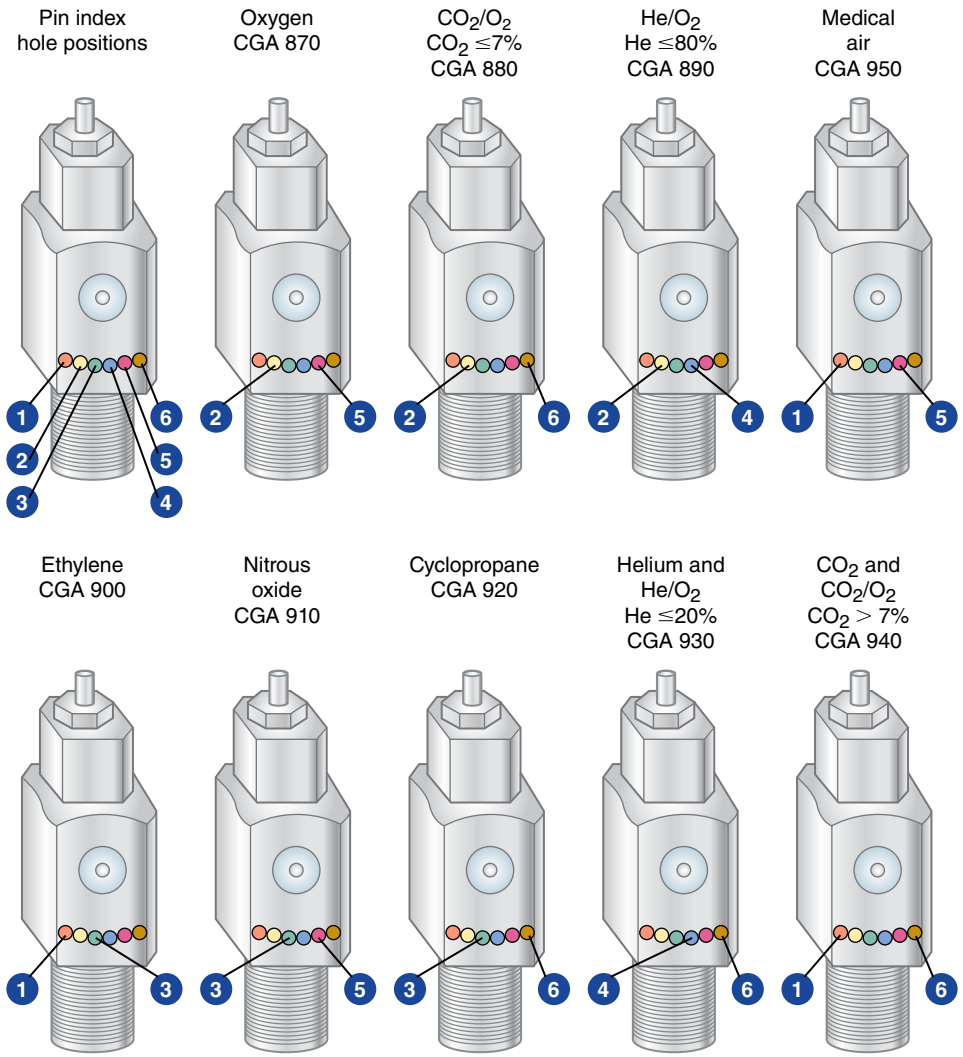


FIGURE 1-15 Pin Index Safety System.

a flowmeter. Equipment failure will result from the delivery of inadequate working pressure (15–20 psi with the flowmeter vs. 50 psi from the high-pressure connection).

Cylinder Duration

It is important to determine the volume of gas remaining in a cylinder and the duration of cylinder use. This skill is useful for intra- and interhospital transports and when educating patients and families on the use of their portable home oxygen equipment. Failure to calculate tank duration may cause equipment malfunction and compromise patient safety by inducing hypoxemia and/or hypoventilation. Calculating how much volume a cylinder may have is done by measuring either the weight of the cylinder, for gases stored partially in liquid form, or the pressure in the cylinder, for nonliquefied gases. For nonliquefied gases, it is important to know the conversion factor for the tank size. Each cylinder size has its specific conversion factor (**Table 1-3**).

The duration of flow for gas cylinders is calculated by dividing the product of the cylinder's pressure and the tank conversion factor by the set flow (L/min).

$$\text{Cylinder duration (minutes)} = \frac{\text{Cylinder pressure (psig)} \times \text{Conversion factor}}{\text{Flow (L / min)}}$$

For example, a patient who is ordered a nasal cannula at 4 L/min is transferred from the emergency department to the general care ward. An oxygen E cylinder is available for transport. The cylinder pressure is 1100 psig. To calculate the duration of oxygen flow:

1100 psig (cylinder pressure) × 0.28 L/psig

(conversion factor for an E cylinder) = 308 L

308 L ÷ 4 L/min (ordered flow of oxygen)

= 77 minutes

= 1 hour 17 minutes

TABLE 1-3
Volume–Pressure Conversion Factors

Cylinder Size	Conversion Factor
D	0.16
E	0.28
G	2.39
H or K	3.14

Common Problems and Troubleshooting

An easily followed list of rules and regulations can be found in the CGA's *Handbook of Compressed Gas*. The Joint Commission and state and local regulatory agencies may have additional regulations that respiratory care departments should comply with to keep errors from reaching the patient and causing harm.[47] Despite all the care given and precautions taken, there still may be isolated errors, most of which come from human error. Common problems respiratory therapists may encounter with gas cylinders and their potential solutions are provided in **Table 1-4**.

Cylinder Storage

Cylinders that are not in use must be securely stored in a specially designed metal rack (**Figure 1-16**) or in holders that are attached to the wall, secured by chains (**Figure 1-17**). Empty or nearly empty tanks must be segregated from full tanks. Each tank bank must be labeled with signs designating whether the tanks are full or empty.

When in use, cylinders must be placed in a cylinder holder. Portable wheeled holders or holders that can be

TABLE 1-4
Common Problems Encountered with High-Pressure Gas Cylinders

Problem	Actions Leading to Potential Solutions
Hissing noise and gas escaping at the yoke of the cylinder	1. For an E cylinder, assess the regulator to determine whether the plastic or Teflon washer is missing or damaged. a. Replace missing or damaged plastic or Teflon washer. b. Reseat the regulator. c. Release the flow of gas from the tank. 2. If the plastic or Teflon washer is present and intact on the regulator of an E cylinder or a larger cylinder (M or H) is in use: a. Reseat/reposition the regulator and tighten the connection with a wrench.
No gas flow from the flowmeter	1. Ensure the cylinder valve is turned fully to the on position. a. Cylinder valve may be damaged. Obtain another cylinder and appropriately label the cylinder for assessment by the gas supplier. 2. Assess the tank pressure to determine whether gas is present in the tank.

FIGURE 1-16 An example of a stationary cylinder rack.

FIGURE 1-17 Racks that are tethered to the wall are used to secure larger high-pressure cylinders (e.g., H cylinders). Chains are used to secure each cylinder within a holder.

(A)

(B)

FIGURE 1-18 **A.** A portable cylinder cart allows for the cylinder to be safely stored for use during patient transport or ambulation. **B.** Multi-cylinder portable holders require labeling to reduce the potential of selecting an empty cylinder for patient use.

secured on a patient's bed or cart allow the cylinder to be safely stored for use during intrafacility transport or ambulation (**Figure 1-18**).

Liquid Oxygen Systems

Bulk liquid oxygen systems were discussed earlier in this chapter. This type of system has very large reservoirs containing up to 10,000 gallons of liquid oxygen and are housed adjacent to the healthcare facility. Large-capacity liquid oxygen systems are expensive to maintain and are not practical for long-term facility or home use; however, liquid oxygen is available in

smaller vessels that can be stored within a long-term care facility or a patient's home. Portable liquid oxygen units can be transfilled from the larger base unit to allow residents of long-term care facilities or patients at home a viable means of oxygen delivery for ambulation. (The NFPA Recommendations and Regulations for Portable Liquid Oxygen Systems can be found in **Appendix 1-C**.) Liquid home units generally consist of two parts, a larger stationary reservoir unit and a smaller portable unit.

The stationary reservoir base is very similar in construction to large bulk oxygen systems used in hospitals. There is an insulated bottle that holds the liquid oxygen, a vaporizing coil to allow the liquefied gas to become nonliquefied, and a series of pressure-relief valves to deliver the gas at a working pressure of approximately 20 psig. Typically, liquid stationary units for use outside an acute care facility have a capacity of 12 to 60 liters of liquefied oxygen.

The systems operate when the flow control valve is open for gas flow to be delivered to the patient. A pressure gradient develops between the head pressure, or the gas-filled upper section of the container, and atmospheric pressure. Gas then flows through the economizer valve, then through warming coils, and then comes out the flow control valve to the patient. The warming coils help increase the temperature before it reaches the patient. As gas flow continues, the head pressure drops slowly until it falls below 0.5 psig. At that point, the economizer valve closes, and liquid oxygen is drawn up through the coils. The economizer valve ensures a constant flow of oxygen to the patient.

When the contents of the stationary unit are low, the system needs to be refilled properly. The manufacturer's specifications must be followed when transfilling stationary units. Transfilling must take place in a well-ventilated, non–patient care area. Each transfilling station should have its own pressure-relief valves and connectors from the manufacturer. Stationary units can also be equipped to fill smaller portable units, which allow the patients to be more mobile. These units are constructed as smaller versions of the stationary units and must be carried in an upright position. Generally, the portable units are equipped with a shoulder strap for ease of use.

When filling the smaller portable units from the stationary base, it is essential to follow the manufacturer's recommendations. Connections between the stationary unit and portable unit must be dry before seating the portable unit onto its stationary base. Moisture will cause the pressure valves to freeze in the open position and impair the filling process. The portable units must then remain out of service until the valve thaws and can close properly. Once the portable unit is filled, care should be taken not to touch the connections the unit was seated upon. Liquid oxygen is stored at very low temperatures, so touching the frosty connections with bare skin may result in frostbite and skin damage.

Liquid oxygen systems are a fire hazard if the connections or equipment becomes contaminated with a combustible material, such as oil or grease. Vaporization of spilled liquid oxygen can cause an oxygen-enriched environment and may increase the risk for fire. Failure to maintain the units in accordance with the manufacturer's recommendations increases the risk for improperly functioning pressure-relief valves. Should the pressure-relief valve fail, overpressure accidents may cause harm to patients or staff.

To determine the length of time a portable liquid system will last, the unit of measure of the liquid gas in the portable container must be converted from pounds to liters. There are two conversion factors that are essential to remember: (1) 1 liter of liquid oxygen weighs 2.5 pounds, or 1.1 kilograms, and (2) 1 liter of liquid oxygen produces 860 liters of gaseous oxygen. To calculate the duration of flow for liquid oxygen, the respiratory therapist must know the weight of the liquid vessel and the flow of gas the patient is receiving. The therapist must first calculate the amount of gas remaining in the liquid reservoir:

$$\text{Liquid weight (lb)} \times$$

$$\text{Gas volume that 1 L of liquid oxygen produces}$$

$$\text{Gas remaining} = \frac{\text{1 L of liquid oxygen produces (860 L)}}{\text{Weight of 1 L of liquid oxygen (2.5 lb)}}$$

The therapist then calculates the duration of the contents by dividing the gas remaining by the flow of oxygen the patient is receiving:

$$\text{Duration of contents (min)} = \frac{\text{Gas remaining (L)}}{\text{Flow (L / min)}}$$

For example, a portable liquid oxygen unit containing 3 pounds of liquid oxygen is used by a patient receiving oxygen by nasal cannula at 3 L/min. To calculate the amount of time the flow of gas from the liquid oxygen will last, use the following equation:

$$\text{Gas remaining} = \frac{3 \text{ lb} \times 860}{2.5 \text{ lb / L}}$$

$$\frac{2580 \text{ lb}}{2.5 \text{ lb / L}}$$

$$= 1032 \text{ L}$$

$$\text{Duration of contents} = \frac{1032 \text{ L}}{3 \text{ L / min}}$$

$$= 344 \text{ minutes, or 5 hours and 44 minutes}$$

Oxygen Concentrators

Oxygen concentrators entrain ambient air, separate oxygen from other gases through the use of special filters, and then store the oxygen for delivery to the patient. Oxygen concentrators are predominately used in non–acute care settings. This type of oxygen delivery system is commonly found in extended care facilities (nursing homes) or in the home. There are two types of oxygen concentrator designs: those using a molecular sieve and those using a semipermeable plastic membrane.

Molecular Sieve

This type of concentrator gained popularity because of its simplicity of operation. An air compressor within the unit draws in ambient air. As air enters the unit, it passes through a series of filters and a heat exchanger, where any moisture or heat is dissipated. It then passes through a solenoid valve, which directs it to pass through at least one molecular sieve bed, where the oxygen becomes concentrated. The sieve beds contain zeolite crystals, which separate gases according to their sizes and polarity. The zeolite traps nitrogen, water, and other gases but allows oxygen to pass through. These beds work well when they are pressurized.

The two sieve beds are alternately pressurized (to generate oxygen) and depressurized (to release nitrogen). As air is first pressurized in one sieve bed to help with the increase of nitrogen absorption, the oxygen it generates is diverted to a product tank where some of the oxygen is stored. The rest of the oxygen is used to purge the sieve of the nitrogen. This process is called pressure swing absorption. Pressure cycles occur every 10 to 30 seconds, a process that makes enough oxygen to fill the product tank and purge the beds of nitrogen.

The oxygen in the tank is typically less than 10 psig and is delivered to the patient after it has passed through a bacterial filter and then out the flowmeter. Oxygen delivery to the patient is inversely proportional to the flow. The lower the flow, the higher the concentration of oxygen. Gas flows of less than 6 L/min will generally deliver around 93% oxygen. It should be noted that the flowmeters on oxygen concentrators are not back pressure compensated.

Semipermeable Membranes

This type of oxygen concentrator passes air through a 1-micrometer-thick membrane, which separates the gases according to their diffusion rates. Gas diffusion depends on these factors: diffusion constant, solubility of the membrane, and pressure gradient across the membrane. The oxygen then passes through a condensing coil, where excess water vapor is removed. This type of concentrator can deliver approximately 40% oxygen at a flow of 1 to 10 L/min.

Stationary oxygen concentrators are good for use in homes or in long-term care facilities. Unlike cylinders or liquid oxygen units, concentrators do not need to be refilled, and only yearly maintenance service is needed. Some concentrators are equipped with alarms that signal a loss of power, high and low pressures, and low oxygen concentration. Many are nearly silent, which makes them ideal for home living because the noise will not interfere with the TV, radio, or sleeping. These units are electrically powered and can be plugged into an existing wall outlet.

Portable oxygen concentrators (POCs) are for home care patients; they give them the ability to travel and be more mobile in general. They can be battery powered or operated via an AC or DC power supply. Some have the option of an external battery for longer life. Many of the batteries will last up to 10 hours. Note, however, that there is a large variability in performance among POCs.[48]

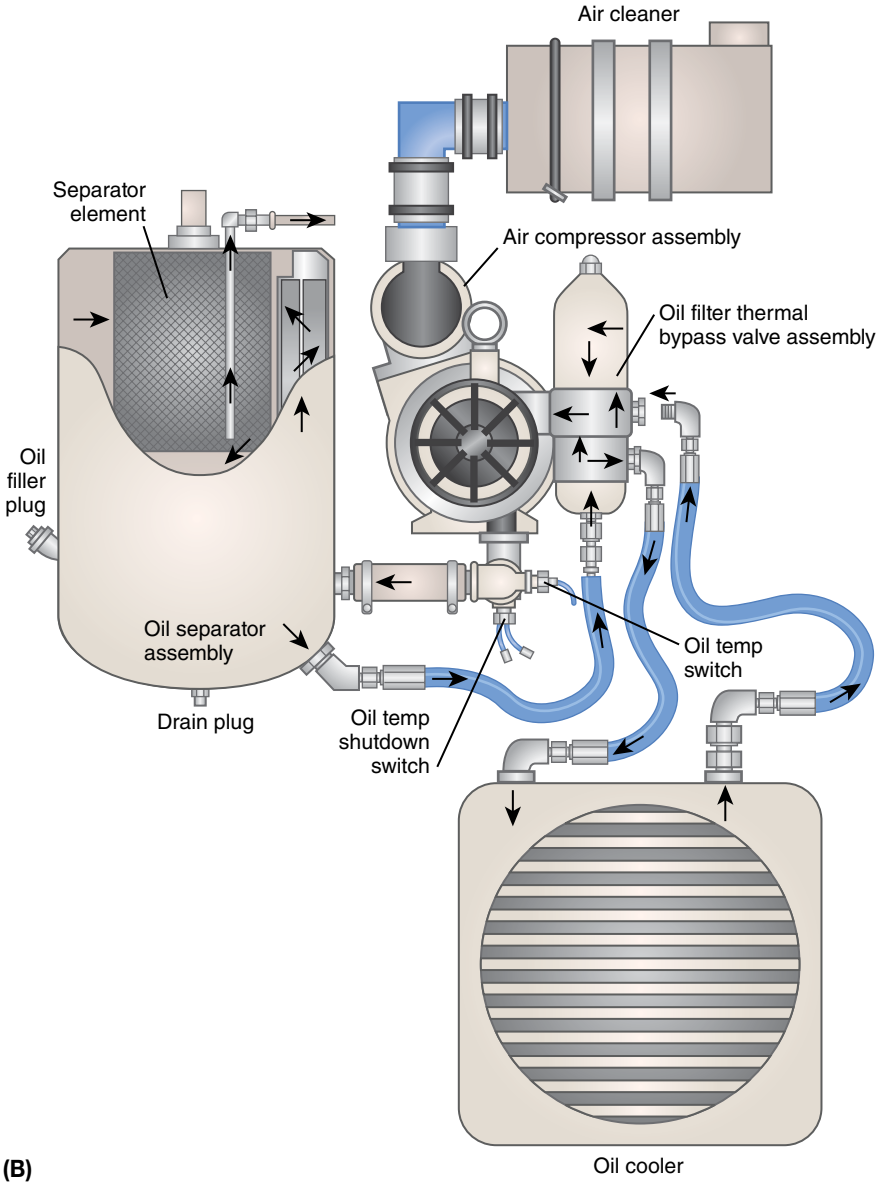
Portable Air Compressors

Air compressors are used to power many things in respiratory care, from delivery of 50 psi of air to a mechanical ventilator to running a small-volume nebulizer. Many institutions may have piped-in air from an onsite compressor. If a building does not have piped-in gases, portable compressors will come in handy. There are three types of portable air compressors: piston, diaphragm, and rotary (**Figure 1-19**).

A **piston compressor** uses a motor that drives the piston to compress the air. Air is pulled in through a one-way valve into a chamber as the piston moves down (downstroke). Once that chamber is filled or the piston is drawn back as far as it will go, the piston then starts to move up (upstroke). The one-way valve closes, and, as the air becomes pressurized, another one-way valve opens, allowing the pressurized gas to go through the valve. Because air cannot come in contact with contaminants, Teflon is used to seal the ring so that no air escapes. The air then goes through a coiled tube to allow the gas, which was heated, to cool to room temperature. This tube also removes moisture from the gas, which is then drained. Because this process does not completely remove all water from the compressed air, a filter/water trap is placed before the inlet of any device that has electronics. Some piston compressors can generate the high pressures and flows needed to run a mechanical ventilator.

Diaphragm compressors simply substitute a flexible diaphragm for the piston. As the diaphragm is pulled back, air enters the chamber through a one-way intake valve and then is compressed and pushed out a one-way outflow valve. Diaphragm compressors can generate only low pressures and moderate flows. They are typically used for running small-volume

(A)



(B)

FIGURE 1-19 **A.** Diaphragm compressor. **B.** Rotary compressor.

A. © Yanas/Shutterstock. **B.** Reproduced from the U.S. Army Technical Manual, TM 5-4310-354-14-HR, Compressor, Rotary; Air, Skid Mounted; Diesel Engine Driven, 125 CFM, 100 PSIG (Davey Model 6M125), Fig. 5-2.

nebulizers at home or in facilities where there is no piped-in gas.

A **rotary compressor** uses a vane that rotates at high speeds to entrain the air through a one-way valve. The air is compressed as the vane rotates and then is forced out a one-way outflow valve. Many companies use this type of compressor on their ventilators. Rotary compressors can generate pressures between 45 and 55 psi with flow rates of 60 to 80 L/min.

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APPENDIX

1-A

National Fire Protection Association (NFPA) and Compressed Gas Association (CGA) Recommendations for Compressed Gas Cylinders

Storage

1. Storage rooms must be dry, cool, and well ventilated. Cylinders should not be stored in an area where the temperature exceeds 125° F (51.7° C).
2. No flames should have the potential of coming in contact with the cylinders.
3. The storage facility should be fire resistant where practical.
4. Cylinders must not be stored near flammable or combustible substances.
5. Gases that support combustion must be stored in a separate location from those that are combustible.
6. The storage area must be permanently posted.
7. Cylinders must be grouped by content.
8. Full and empty cylinders must be segregated in the storage area.
9. Below-ground storage should be avoided.
10. Cylinders should never be stored in the operating room.
11. Large cylinders must be stored upright.
12. Cylinders must be protected from being cut or abraded.
13. Cylinders must be protected from extreme weather to prevent rusting, excessive temperatures, and accumulations of snow and ice.
14. Cylinders should not be exposed to continuous dampness or corrosive substances that could promote rusting of the cylinder and its valve.
15. Cylinders should be protected from tampering.
16. Valves on empty cylinders should be kept closed at all times.
17. Cylinders must be stored with protective caps in place.
18. Cylinders must not be stored in a confined space, such as a closet or the trunk of a car.

Transportation

1. If protective valve caps are supplied, they should be used whenever cylinders are in transport and until they are ready for use.
2. Cylinders must not be dropped, dragged, slid, or allowed to strike each other violently.
3. Cylinders must be transported on an appropriate cart secured by a chain or strap.

Use

1. Before connecting equipment to a cylinder, make sure that connections are free of foreign materials.
2. Turn the valve outlet away from personnel and crack the cylinder valve to remove any dust or debris from the outlet.
3. Cylinder valve outlet connections must be American Standard or CGA pin indexed; low-pressure connections must be CGA diameter indexed.
4. Cylinders must be secured at the administration site and not to any moveable objects or heat radiators.
5. Outlets and connections must be tightened only with appropriate wrenches and must never be forced.

6. Equipment designed to be used for one gas should not be used with another.
7. Never use medical cylinder gases when contamination by backflow of other gases may occur.
8. Regulators should be off when the cylinder is turned on, and the cylinder valve should be opened slowly.
9. Before equipment is disconnected from a cylinder, the cylinder valve should be closed and the pressure released from the device.
10. Cylinder valves should be closed at all times except when in use.
11. Do not transfill cylinders; this is hazardous.
12. Cylinders may be refilled only if permission is secured from the owner.
13. Cylinders must not be lifted by the cap.
14. Equipment connected to oxygen cylinders containing gaseous oxygen should be labeled OXYGEN—USE NO OIL.
15. Enclosures intended to contain patients must have the minimum text regarding No Smoking, and the labels must be located (1) in a position to be read by the patients and (2) on two or more opposing sides visible from the exterior. It should be noted that oxygen hoods fall under the classification of oxygen enclosure and require these labels as well. In addition, another label is required that instructs visitors to get approval from hospital personnel before placing toys in an oxygen enclosure.
16. High-pressure oxygen equipment must not be sterilized with flammable agents (e.g., alcohol and ethylene oxide), and the agents used must be oil free and nondamaging.
17. Polyethylene bags must not be used to wrap sterilized, high-pressure oxygen equipment because, when flexed, polyethylene releases pure hydrocarbons that are highly flammable.
18. Oxygen equipment exposed to pressure of less than 60 psi may be sterilized either with a nonflammable mixture of ethylene oxide and carbon dioxide or with fluorocarbons.
19. Cylinders must not be handled with oily or greasy hands, gloves, or clothing.
20. Never lubricate valve outlets or connecting equipment. (Oxygen and oil under pressure cause an explosive oxidation reaction.)
21. Do not flame test for leaks. (A soap solution is usually used.)
22. When a cylinder is in use, open the valve fully, and then turn it back a quarter to a half turn.
23. Replace the cap on an empty cylinder.
24. Position the cylinder so that the label is clearly visible. The label must not be defaced, altered, or removed.
25. Check the label before use; it should always match the color code.
26. No sources of open flames should be permitted in the area of administration. A No Smoking sign must be posted in the area of administration. It must be legible from a distance of 5 feet and displayed in a conspicuous location.
27. Inform all area occupants of the hazards of smoking and of the regulations.
28. Equipment designated for use with a specific gas must be clearly and permanently labeled accordingly. The name of the manufacturer should be clearly marked on the device. If calibration or accuracy depends on gas density, the device must be labeled with the proper supply pressure.
29. Cylinder carts must be of a self-supporting design with appropriate casters and wheels, and those intended for use in surgery where flammable anesthetics are used must be grounded.
30. Cold cylinders must be handled with care to avoid hand injury resulting from tissue freezing caused by rapid gas expansion.
31. Safety-relief mechanisms, uninterchangeable connections, and other safety features must not be removed or altered.
32. Control valves on equipment must be closed both before connection and when not in use.

Repair and Maintenance

1. Use only the service manuals, operator manuals, instructions, procedures, and repair parts that are provided or recommended by the manufacturer.
2. Allow only qualified personnel to maintain the equipment.
3. Designate and set aside an area that is clean and free from oil and grease for the maintenance of oxygen equipment. Do not use this area for the repair and maintenance of other types of equipment.
4. Follow a scheduled preventive maintenance program.

APPENDIX

1-B

National Fire Protection Association (NFPA) Recommendations and Regulations for Bulk Oxygen Systems

1. Containers that are permanently installed should be mounted on noncombustible supports and foundations.
2. Liquid oxygen containers should be constructed from materials that meet the impact test requirements of paragraph UG-48 of the ASME Boiler and Pressure Vessel Codes, Section VII, and must be in accordance with DOT specifications and regulations for 4L liquid oxygen containers. Containers operating above 15 psi must be designed and tested in accordance with the ASME Boiler and Pressure Vessel Code, Section VII, and the insulation of the liquid oxygen container must be of noncombustible material.
3. All high-pressure nongaseous oxygen containers must comply with the construction and test requirements of ASME Boiler and Pressure Vessel Code, Section VIII.
4. Bulk oxygen storage containers must be equipped with safety-release devices as required by ASME Code IV and the provisions of ASME-1.3 or DOT specifications for both container and safety releases.
5. Isolation castings on liquid oxygen containers shall be equipped with suitable safety-release devices. These devices must be designed or located so that moisture cannot either freeze the unit or interfere in any manner with its proper operation.
6. The vaporizing columns and connecting pipes shall be anchored or sufficiently flexible to provide for expansion and contraction as a result of temperature changes. The column must also have a safety-release device to properly protect it.
7. Any heat supplied to oxygen vaporizers must be done in an indirect fashion, such as with steam, air, water, or water solutions that do not react with oxygen. If liquid heaters are used to provide the primary source of heat, the vaporizers must be electrically grounded.
8. All equipment composing the bulk system must be cleaned to remove oxidizable material before the system is placed into service.
9. All joints and connections in the tubing should be made by welding or using flanged, threaded-slip, or compressed fittings, and any gaskets or thread seals must be of a suitable substance for oxygen service. Any valves, gauges, or regulators placed into the system must be designed for oxygen service. The piping must conform to ANSI B 31.3 piping that operates below −20° F (−28.0° C) and must be composed of materials meeting ASME Code, Section VIII.
10. Storage containers, piping valves, and regulating equipment must be protected from physical damage and tampering.
11. Any enclosure containing oxygen-control or -operating equipment must be adequately ventilated.
12. The location shall be permanently posted to indicate OXYGEN—NO SMOKING—NO OPEN FLAMES or an equivalent warning.
13. All bulk systems must be regularly inspected by a qualified representative of the oxygen supplier.
14. Weeds and tall grass must be kept to a minimum of 15 feet from any bulk oxygen container. The bulk oxygen system must be located so that its distance provides maximum safety for the other areas surrounding it. The maximum distances for location of

a bulk oxygen system near the following structures are as follows:

a. 25 feet from any combustible structure
b. 25 feet from any structure that consists of fire-resistant exterior walls or buildings of other construction that have sprinklers
c. 10 feet from any opening in the adjacent walls of fire-resistant structures
d. 25 feet from flammable liquid storage above ground that is less than 1000 gallons in capacity or 50 feet from these storage areas if the quantity is in excess of 1000 gallons.
e. 15 feet from an underground flammable liquid storage that is less than 1000 gallons or 30 feet from one in excess of 1000 gallons. The distance from the oxygen storage containers to connections used for filling and venting of flammable liquid must be at least 25 feet.
f. 25 feet from combustible gas storage above ground that is less than 1000 gallons capacity or 50 feet from the storage of over 1000 gallons capacity.
g. 15 feet from combustible liquid storage underground and 25 feet from the vent or filling connections
h. 50 feet from flammable gas storage less than 5000 cubic feet and 90 feet from flammable gas in excess of 5000 cubic feet, normal temperature and pressure (NTP)
i. 25 feet from solid materials that burn slowly (e.g., coal and heavy timber)
j. 75 feet away in one direction and 35 feet away at an approximately 90-degree angle from confining walls unless they are made from a fire-resistant material and are less than 20 feet high. (This is to provide adequate ventilation in the area in case venting occurs.)
k. 50 feet from places of public assembly
l. 50 feet from nonambulatory patients
m. 10 feet from public sidewalks
n. 5 feet from any adjoining property line
o. Must be accessible by a mobile transport unit that fills the supply system

15. The permanent installation of a liquid oxygen system must be supervised by personnel familiar with the proper installation and construction as outlined in NFPA 50.
16. The oxygen supply must have an inlet for the connection of a temporary supply in emergency and maintenance situations. The inlet must be physically protected to prevent tapering or unauthorized use and must be labeled EMERGENCY LOW-PRESSURE GASEOUS OXYGEN INLET. The inlet is to be installed downstream from the main supply line shutoff valve and must have the necessary valves to provide the emergency supply of oxygen as well as isolate the pipeline to the normal source of supply. There must be a check valve in the main line between the inlet connection and the main shutoff valve and another check valve between the inlet connection and the emergency supply shutoff valve. The inlet connection must have a pressure-relief valve of adequate size to protect the downstream piping from pressures in excess of 50% above normal pipeline operating pressure.
17. The bulk oxygen system must be mounted on noncombustible supports and foundations.
18. A surface of noncombustible material must extend at least 3 feet beyond the reach of liquid oxygen leaks during system operation or filling. Asphalt or bitumastic paving is prohibited. The slope of the area must be considered in sizing of the surface.
19. The same type of surface must extend at least the full width of the vehicle that fills the bulk unit and at least 8 feet in the transverse direction.
20. No part of the bulk system should be underneath electrical power lines or within reach of a downed power line.
21. No part of the system can be exposed to flammable gases or to piping containing any class of flammable or combustible liquids.
22. The system must be located so as to be readily accessible to mobile supply equipment at ground level as well as to authorized personnel.
23. Warning and alarm systems are required to monitor the operation and condition of the supply system. Alarms and gauges are to be located for the best possible surveillance, and each alarm and gauge must be appropriately labeled.
24. The master alarm system must monitor the source of supply, the reserve (if any), and the main-line pressure of the gas system. The power source for warning systems must meet the essentials of NFPA 76A.
25. All alarm conditions must be evaluated and necessary measures taken to establish or ensure the proper function of the supply system.
26. Two master alarm panels, with alarms that cannot be cancelled, are to be located in separate locations to ensure continuous observation. One signal must alert the user to a changeover from one operating supply to another, and an additional signal must provide notification that the reserve is supplying the system.
27. If check valves are not installed in the cylinder leads and headers, another alarm signal should be initiated when the reserve reaches a 1-day supply.
28. All piping systems must have both audible and visible signals that cannot be cancelled to indicate when the main-line pressure increases or decreases 20% from the normal supply pressure. A pressure gauge must be installed and appropriately labeled adjacent to the switch that generates the pressure alarm conditions.
29. All warning systems must be tested before being placed in service or being added to existing service. Periodic retesting and appropriate record keeping are required.

APPENDIX

1-C

National Fire Protection Association (NFPA) Recommendations and Regulations for Portable Liquid Oxygen Systems

1. Liquid oxygen units will vent gas when not in use, creating an oxygen-enriched environment. This can be particularly hazardous in the following situations:
   a. When the unit is stored in a closed space
   b. When the unit is tipped over
   c. When the oxygen is transferred to another container
2. Liquid oxygen units should not be located adjacent to heat sources, which can accelerate the venting of oxygen.
3. The unit surface should not be contaminated with oil or grease.
4. Verify the contents of liquid containers when setting up the equipment, changing the containers, or refilling the containers at home.
5. Connections for the containers are to be made with the manufacturer's operating instructions.
6. The patient and family must be familiar with the proper operation of the liquid devices along with all precautions, safeguards, and troubleshooting methods.
7. Transfill one unit for another in compliance with CGA pamphlet P-26, "Transfilling of Low Pressure Liquid Oxygen to Be Used for Respiration," and in accordance with the manufacturer's operating instructions.
8. All connections for filling must conform to CGA V-1, and the hose assembly must have a pressure release set no higher than the container's related pressure.
9. Liquid containers must have a pressure release to limit the container pressure to the rated level, and a device must be incorporated to limit the amount of oxygen introduced into a container to the manufacturer's specified capacity.
10. Delivery vehicles should be well vented to prevent the buildup of high oxygen levels, and transfilling should take place with the delivery vehicle doors wide open.
11. No Smoking signs must be posted, and there can be no sources of ignition within 5 feet.
12. The transfiller must affix the labels required by DOT and FDA regulations, and all records must be kept stating the content and purity. Instructions must be on the container, and the color coding and labeling must meet CGA and NFPA standards.
13. All devices used with liquid oxygen containers must be moisture free, and pressure releases must be positioned correctly to prevent freezing and the buildup of high pressures.
14. When liquid oxygen is spilled, both the liquid and gas that escape are very cold and will cause frostbite or eye injury. When filling liquid oxygen containers, wear safety goggles with side shields along with loose-fitting, properly insulated gloves. High-top boots with cuffless pants worn outside the boots are recommended.
15. Items exposed to liquid oxygen should not be touched because they can not only cause frostbite but also stick to the skin. Materials that are pliable at room temperature become brittle at the extreme temperatures of liquid oxygen.
16. If a liquid oxygen spill occurs, the cold liquid and resulting gas condense the moisture in the air, creating a fog. Normally, the fog will extend over an

area larger than the area of contact danger, except in extremely dry climates.

17. In the event of a spill, measures should be taken to prevent anyone from walking on the surface or wheeling equipment across the area for at least 15 minutes. All sources of ignition must be kept away from the area.
18. Liquid oxygen spilled onto asphalt or oil-soaked concrete constitutes an extreme hazard because an explosive reaction can occur.
19. If the liquid oxygen comes in contact with the skin, remove any clothing that may constrict blood flow to the frozen area. Warm the affected area with water at about body temperature until medical personnel arrive. Seek immediate medical attention for eye contact or blistering of the skin.
20. Immediately remove contaminated clothing and air it away from sources of ignition for at least 1 hour.

CHAPTER

2

Administering Medical Gases

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OBJECTIVES

1. Describe the basic operation of single-stage and multistage regulators.
2. Describe the basic operation of a Thorpe tube flowmeter.
3. Compare pressure-compensated devices to non–pressure-compensated devices.
4. Describe the basic operation of a Bourdon gauge.
5. Discuss the operation and uses of oxygen blenders.
6. List the indications for and hazards of oxygen therapy.
7. Define low-flow oxygen therapy, list the devices that provide low-flow therapy, and state the flow and F_{IO_2} specifications for these devices.
8. Discuss how the F_{IO_2} from a low-flow device is determined.
9. Describe the basic operation of oxygen-conserving devices.
10. Define high-flow oxygen therapy and list the specifications for each device.
11. Explain the operation and uses of reservoir delivery devices.
12. Describe the operation and uses of helium/oxygen therapy.
13. Describe the operation and uses of nitric oxide.
14. Describe the operation and uses of carbon dioxide/oxygen therapy.
15. Describe the basic function of an oxygen concentrator.

KEY TERMS

air-entrainment mask
air/oxygen blender
Bourdon gauge
carbogen
flowmeter
flow restrictor
heliox
high flow
high-flow nasal cannula (HFNC)
low flow
nasal cannula
nitric oxide
nonrebreathing mask
oxygen concentrator
oxygen-conserving device (OCD)
oxygen tent
reducing valve
reservoir cannula
simple mask
Thorpe tube
transtracheal oxygen catheter

Introduction

When Joseph Priestly discovered "dephlogisticated air" (later renamed oxygen) in 1774, he unknowingly introduced two problems into the practice of medicine. The first was when to use this purified air therapeutically, and the second was how to deliver it to the patient. Oxygen therapy has particular significance for the profession of respiratory care because the first respiratory care practitioners were typically hospital orderlies who specialized in the application of oxygen.[1] From those days in the 1940s, when oxygen technicians mostly set up oxygen tents and moved large gas cylinders, a profession began to form. Currently, although the general indications for oxygen therapy are well established, there is still ongoing debate as to the best methods for safely delivering medical gases.

This chapter is primarily concerned with the equipment necessary to provide precise doses of oxygen to patients. This equipment includes the devices (i.e., **flowmeters** and regulators) that allow precise flows from bulk oxygen sources (e.g., cylinders and wall outlets) and the specific interfaces that are attached to the patient (e.g., nasal cannulas and nonrebreathing masks). The chapter will also explore other therapeutic gases, such as helium/oxygen mixtures (heliox), nitric oxide, and carbon dioxide/oxygen mixtures (carbogen).

Pressure-Regulating Devices

Once the decision has been made to administer a prescribed amount of oxygen to a patient, the next logical step is to determine the best way to do it. Typically, the patient care setting will determine what oxygen source is available. Hospitals use large bulk liquid oxygen reservoirs and complex piping systems connected to outlets at the patient's bedside. Oxygen concentrators, portable liquid oxygen units, and high-pressure tanks are commonly used to provide oxygen to patients cared for at home or in long-term care facilities. Once the oxygen source has been identified, the clinician must determine whether there is a need to obtain equipment to regulate the flow from the oxygen source and then select the appropriate patient interface.

Reducing Valves/Regulators

When full, the typical high-pressure metal alloy cylinder stores its gas at a pressure of at least 2000 pounds per square inch (psi) or pounds per square inch gauge (psig). Because this pressure is so high, it must be reduced to a considerably lower pressure. Most oxygen delivery devices and flowmeters are designed to operate at a working pressure of 50 psig (the standard pressure in hospital medical gas delivery systems). Thus, for the cylinder to be clinically useful, it must have a valve that will lower and maintain the pressure at the necessary level. Essentially, *regulator* and *reducing valve* refer to the same type of device, with the principal difference being that a regulator combines a reducing valve with some type of flowmeter (usually, a Bourdon gauge; see later in this chapter).

A **reducing valve** can be either preset by the manufacturer (fixed) or adjustable. Fixed reducing valves are set to reduce the pressure to a single level (usually, 50 psig). On the other hand, an adjustable regulator can reduce the pressure to levels selected by the operator. Adjustable regulators are uncommon because the great majority of oxygen delivery devices and pneumatic-powered equipment is designed to operate at 50 psig.

Reducing valves can be either single stage or multistage. As the names suggest, a single-stage reducing valve drops the pressure to its working level in one stage, whereas a multistage reducing valve drops the pressure in two or more stages, with each stage connected in series. Multistage reducing valves are relatively uncommon in clinical practice because they are more expensive than single-stage valves and provide a level of precision that is generally unnecessary in typical clinical applications.

As can be seen in **Figure 2-1**, a single-stage reducing valve contains the following components: inlet port, pressure gauge, high-pressure chamber, pressure-relief valve, outlet port, flexible diaphragm, ambient pressure chamber, spring, and valve stem. Once the valve on the cylinder is opened, gas enters through the inlet port into the high-pressure chamber. The pressure exerted by the gas pushes against the flexible diaphragm, which would cause the valve stem to seal the valve inlet were it not for the pressure being countered by the tension of the spring. As long as the outlet is open, the

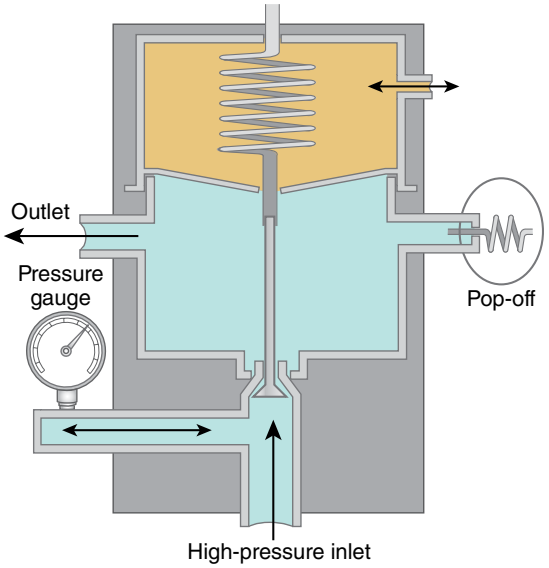

FIGURE 2-1 Single-stage regulator.

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