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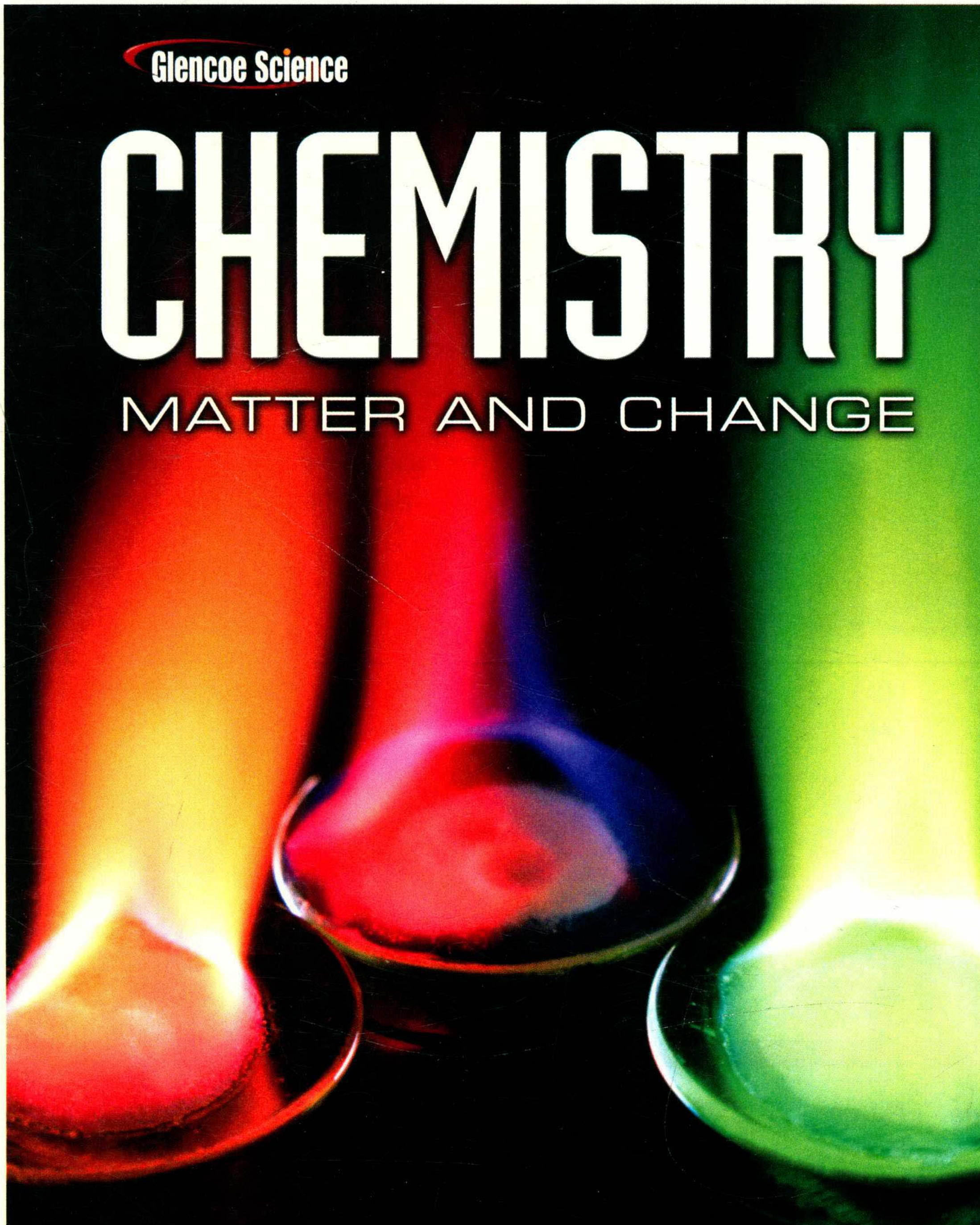
CHEMISTRY

MATTER AND CHANGE



Thandi Bu lo • Nicholas Hainen
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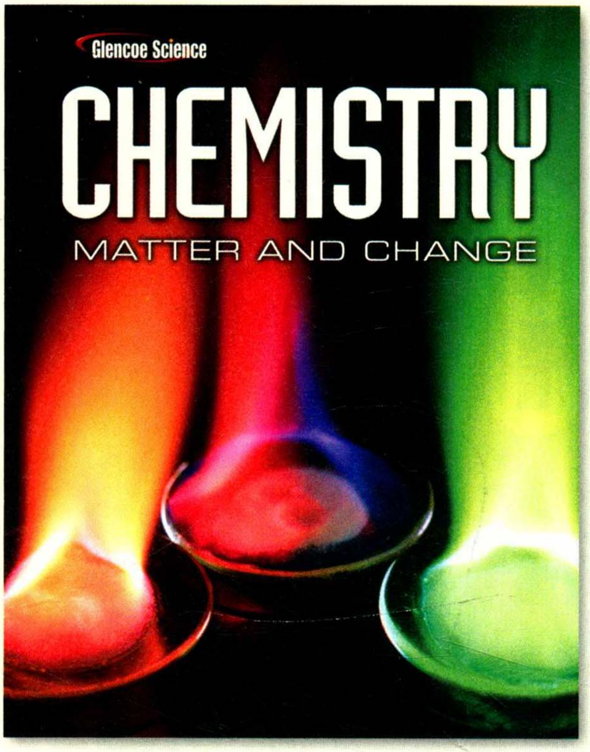

About the Photo:

Some chemicals produce flames of distinctive colors when burned. Sodium produces an orange flame, strontium produces a red flame, and boron produces a bright green flame. To view a video demo of a flame test, visit glencoe.com.

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Safety Symbols

These safety symbols are used in laboratory and investigations in this book to indicate possible hazards. Learn the meaning of each symbol and refer to this page often. *Remember to wash your hands thoroughly after completing lab procedures.*

SAFETY SYMBOLS	HAZARD	EXAMPLES	PRECAUTION	REMEDY
DISPOSAL	Special disposal procedures need to be followed.	certain chemicals, living organisms	Do not dispose of these materials in the sink or trash can.	Dispose of wastes as directed by your teacher.
BIOLOGICAL	Organisms or other biological materials that might be harmful to humans	bacteria, fungi, blood, unpreserved tissues, plant materials	Avoid skin contact with these materials. Wear mask or gloves.	Notify your teacher if you suspect contact with material. Wash hands thoroughly.
EXTREME TEMPERATURE	Objects that can burn skin by being too cold or too hot	boiling liquids, hot plates, dry ice, liquid nitrogen	Use proper protection when handling.	Go to your teacher for first aid.
SHARP OBJECT	Use of tools or glassware that can easily puncture or slice skin	razor blades, pins, scalpels, pointed tools, dissecting probes, broken glass	Practice common-sense behavior and follow guidelines for use of the tool.	Go to your teacher for first aid.
FUME	Possible danger to respiratory tract from fumes	ammonia, acetone, nail polish remover, heated sulfur, moth balls	Make sure there is good ventilation. Never smell fumes directly. Wear a mask.	Leave foul area and notify your teacher immediately.
ELECTRICAL	Possible danger from electrical shock or burn	improper grounding, liquid spills, short circuits, exposed wires	Double-check setup with teacher. Check condition of wires and apparatus.	Do not attempt to fix electrical problems. Notify your teacher immediately.
IRRITANT	Substances that can irritate the skin or mucous membranes of the respiratory tract	pollen, moth balls, steel wool, fiberglass, potassium permanganate	Wear dust mask and gloves. Practice extra care when handling these materials.	Go to your teacher for first aid.
CHEMICAL	Chemicals that can react with and destroy tissue and other materials	bleaches such as hydrogen peroxide; acids such as sulfuric acid, hydrochloric acid; bases such as ammonia, sodium hydroxide	Wear goggles, gloves, and an apron.	Immediately flush the affected area with water and notify your teacher.
TOXIC	Substance may be poisonous if touched, inhaled, or swallowed.	mercury, many metal compounds, iodine, poinsettia plant parts	Follow your teacher's instructions.	Always wash hands thoroughly after use. Go to your teacher for first aid.
FLAMMABLE	Open flame may ignite flammable chemicals, loose clothing, or hair.	alcohol, kerosene, potassium permanganate, hair, clothing	Avoid open flames and heat when using flammable chemicals.	Notify your teacher immediately. Use fire safety equipment if applicable.
OPEN FLAME	Open flame in use, may cause fire.	hair, clothing, paper, synthetic materials	Tie back hair and loose clothing. Follow teacher's instructions on lighting and extinguishing flames.	Always wash hands thoroughly after use. Go to your teacher for first aid.

Eye Safety
Proper eye protection should be worn at all times by anyone performing or observing science activities.

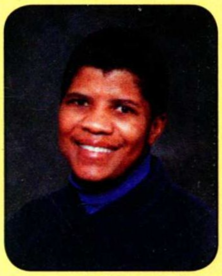
Clothing Protection
This symbol appears when substances could stain or burn clothing.

Animal Safety
This symbol appears when safety of animals and students must be ensured.

Radioactivity
This symbol appears when radioactive materials are used.

Handwashing
After the lab, wash hands with soap and water before removing goggles

About the Authors



Thandi Buthelezi is Associate Professor of Chemistry at Western Kentucky University, Bowling Green, KY. She earned her BA in Chemistry from Williams College, Williamstown, MA, and PhD in Experimental Physical Chemistry from the University of Florida, Gainesville, FL. Dr. Buthelezi has taught Chemistry at the undergraduate and graduate (master's) level for seven years. She is the co-founder and co-director of the Girls in Science Outreach Program at WKU. She is a member of the American Chemical Society, the American Association for the Advancement of Science, and Sigma Xi. She has co-authored over two dozen research papers published in peer-reviewed journals.

Laurel Dingrando is currently serving as the Secondary Science Coordinator for the Garland Independent School District. Mrs. Dingrando has a BS in Microbiology with a minor in Chemistry from Texas Tech University and an MAT in Science from University of Texas at Dallas. She taught Chemistry for 25 years in the Garland Independent School District. She is a member of the American Chemical Society, National Science Teachers Association, Science Teachers Association of Texas, Texas Science Educators Leadership Association, and T3 (Teachers Teaching with Technology).

Nicholas Hainen taught chemistry, AP chemistry, and physics in the Worthington City Schools, Worthington, Ohio, for 31 years. Mr. Hainen holds BS and MA degrees in Science Education from The Ohio State University, majoring in chemistry and physics. His honors and awards include: American Chemical Society Outstanding Educator in Chemical Sciences; The Ohio State University Honor Roll of Outstanding High School Teachers; Ashland Oil Company Golden Apple Award; and Who's Who Among America's Teachers. Mr. Hainen is a member of the American Chemical Society and the ACS Division of Chemical Education.

Cheryl Wistrom is an associate professor of chemistry at Saint Joseph's College in Rensselaer, Indiana where she has been honored with both the Science Division and college faculty teaching awards. She has taught chemistry, biology, and science education courses at the college level since 1990 and is also a licensed pharmacist. She earned her BS degree in biochemistry at Northern Michigan University, a BS in pharmacy at Purdue University, and her MS and PhD in biological chemistry at the University of Michigan. Dr. Wistrom is a member of the Indiana Academy of Science, the National Science Teachers Association, and the American Society of Health-System Pharmacists.

Dinah Zike is an international curriculum consultant and inventor who has developed educational products and three-dimensional, interactive graphic organizers for over 30 years. As president and founder of Dinah-Might Adventures, L.P., Dinah is the author of over 100 award-winning educational publications, including The Big Book of Science. Ms. Zike has a BS and an MS in educational curriculum and instruction from Texas A & M University. Dinah Zike's Foldables are an exclusive feature of McGraw-Hill textbooks.

Teacher Advisory Board and Reviewers

Teacher Advisory Board

The Teacher Advisory Board gave the authors, editorial staff, and design team feedback on the content and design in the Student Edition. We thank these teachers for their hard work and creative suggestions.

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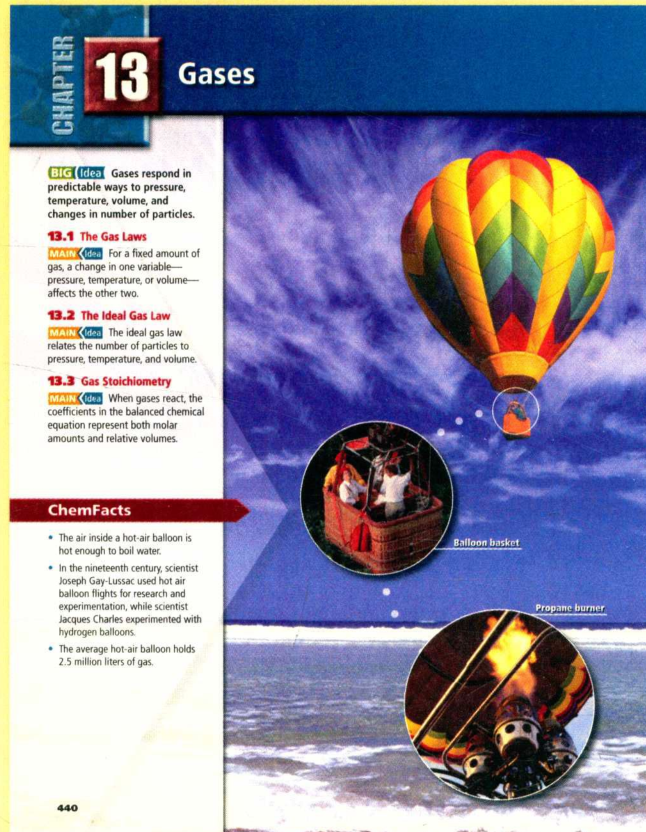
Reading for Information

When you read *Chemistry: Matter and Change*, you need to read for information. Science is nonfiction writing; it describes real-life events, people, ideas, and technology. Here are some tools that *Chemistry: Matter and Change* has to help you read.

Before You Read

By reading the BIG Idea, MAIN Idea, and Launch Lab prior to reading the chapter or section, you will get a preview of the coming material.

The BIG Idea describes what you will learn in the chapter. The MAIN Ideas within a chapter support the Big Idea of the chapter. Each section of the chapter has a Main Idea that describes the focus of the section.



CHAPTER 13 Gases

BIG Idea Gases respond in predictable ways to pressure, temperature, volume, and changes in number of particles.

13.1 The Gas Laws
MAIN Idea For a fixed amount of gas, a change in one variable—pressure, temperature, or volume—affects the other two.

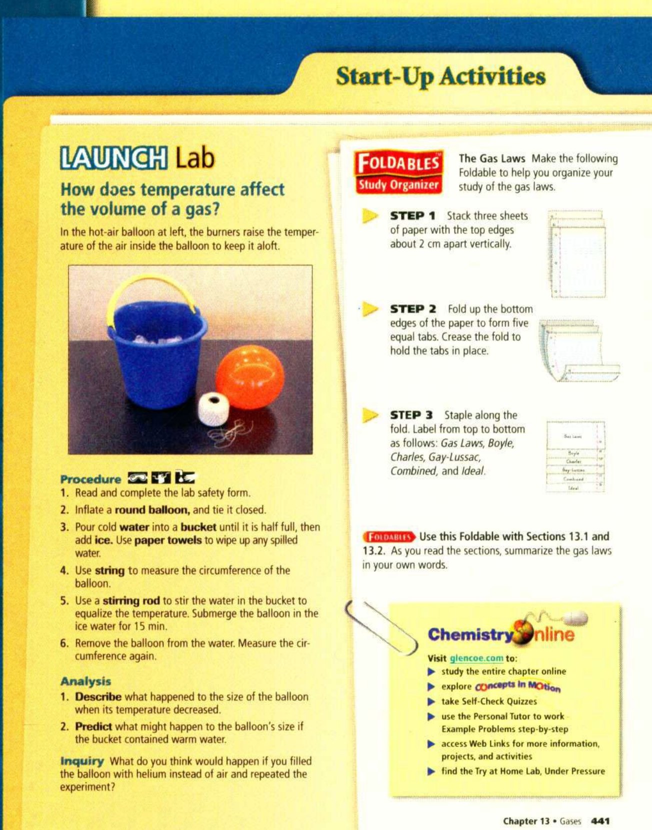
13.2 The Ideal Gas Law
MAIN Idea The ideal gas law relates the number of particles to pressure, temperature, and volume.

13.3 Gas Stoichiometry
MAIN Idea When gases react, the coefficients in the balanced chemical equation represent both molar amounts and relative volumes.

ChemFacts
- The air inside a hot-air balloon is hot enough to boil water.
- In the nineteenth century, scientist Joseph Gay-Lussac used hot air balloon flights for research and experimentation, while scientist Jacques Charles experimented with hydrogen balloons.
- The average hot-air balloon holds 2.5 million liters of gas.

440

Source: Chapter 13, p. 440



Start-Up Activities

LAUNCH Lab
How does temperature affect the volume of a gas?
In the hot-air balloon at left, the burners raise the temperature of the air inside the balloon to keep it aloft.

Procedure
1. Read and complete the lab safety form.
2. Inflate a **round balloon,** and tie it closed.
3. Pour cold **water** into a **bucket** until it is half full, then add **ice.** Use **paper towels** to wipe up any spilled water.
4. Use **string** to measure the circumference of the balloon.
5. Use a **stirring rod** to stir the water in the bucket to equalize the temperature. Submerge the balloon in the ice water for 15 min.
6. Remove the balloon from the water. Measure the circumference again.

Analysis
1. **Describe** what happened to the size of the balloon when its temperature decreased.
2. **Predict** what might happen to the balloon's size if the bucket contained warm water.

Inquiry What do you think would happen if you filled the balloon with helium instead of air and repeated the experiment?

FOLDABLES Study Organizer The Gas Laws Make the following Foldable to help you organize your study of the gas laws.

STEP 1 Stack three sheets of paper with the top edges about 2 cm apart vertically.

STEP 2 Fold up the bottom edges of the paper to form five equal tabs. Crease the fold to hold the tabs in place.

STEP 3 Staple along the fold. Label from top to bottom as follows: *Gas Laws, Boyle, Charles, Gay-Lussac, Combined,* and *Ideal.*

FOLDABLES Use this Foldable with Sections 13.1 and 13.2. As you read the sections, summarize the gas laws in your own words.

Chemistry Online
Visit glencoe.com to:
- study the entire chapter online
- explore Concepts in Motion
- take Self-Check Quizzes
- use the Personal Tutor to work Example Problems step-by-step
- access Web Links for more information, projects, and activities
- find the Try at Home Lab, Under Pressure

Chapter 13 • Gases 441

Source: Chapter 13, p. 441

Each chapter starts with a hands-on introduction to the material being covered. Read and perform the **Launch Lab** to discover concepts covered in the chapter.

OTHER WAYS TO PREVIEW

- Read the chapter title to find out what the topic will be.
- Skim the photos, illustrations, captions, graphs, and tables.
- Look for key terms that are boldfaced and highlighted.
- Create an outline using section titles and heads.

As You Read

Within each section you will find a tool to deepen your understanding and tools to check your understanding.

Section 13.2

Objectives

- **Relate** number of particles and volume using Avogadro's principle.
- **Relate** the amount of gas present to its pressure, temperature, and volume using the ideal gas law.
- **Compare** the properties of real and ideal gases.

Review Vocabulary

mole: an SI base unit used to measure the amount of a substance; the amount of a pure substance that contains 6.02×10^{23} representative particles

New Vocabulary

Avogadro's principle
molar volume
ideal gas constant (R)
ideal gas law

The Ideal Gas Law

MAIN Idea The ideal gas law relates the number of particles to pressure, temperature, and volume.

Real-World Reading Link You know that adding air to a tire causes the pressure in the tire to increase. But did you know that the recommended pressure for car tires is specified for cold tires? As tires roll over the road, friction causes their temperatures to increase. This also causes the pressure to increase.

Avogadro's Principle

The particles that make up different gases can vary greatly in size. However, kinetic-molecular theory assumes that the particles in a gas sample are far enough apart that size has very little influence on the volume occupied by a gas. For example, 1000 relatively large krypton gas particles occupy the same volume as 1000 smaller helium gas particles at the same temperature and pressure. It was Avogadro who first proposed this idea in 1811. **Avogadro's principle** states that equal volumes of gases at the same temperature and pressure contain equal numbers of particles. **Figure 13.5** shows equal volumes of carbon dioxide, helium, and oxygen.

Volume and moles Recall from Chapter 10 that 1 mol contains 6.02×10^{23} particles. The **molar volume** of a gas is the volume that 1 mol occupies at 0.00°C and 1.00 atm pressure. The conditions of 0.00°C and 1.00 atm are known as standard temperature and pressure (STP). Avogadro showed experimentally that 1 mol of any gas occupies a volume of 22.4 L at STP. Because the volume of 1 mol of a gas at STP is 22.4 L, you can use 22.4 L/mol as a conversion factor whenever a gas is at STP.

For example, suppose you want to find the number of moles in a sample of gas that has a volume of 3.72 L at STP. Use the molar volume to convert from volume to moles.

$$3.72 \text{ L} \times \frac{1 \text{ mol}}{22.4 \text{ L}} = 0.166 \text{ mol}$$

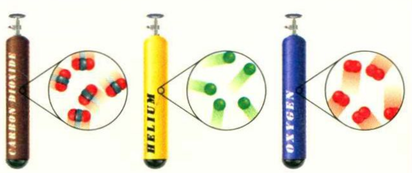


Figure 13.5 Gas tanks of equal volume that are at the same pressure and temperature contain equal numbers of gas particles, regardless of which gas they contain.
Infer *Why doesn't Avogadro's principle apply to liquids and solids?*

452 Chapter 13 • Gases

Source: Section 13.2, p. 452

The **Real-World Reading Link** describes how the section's content may relate to you.

Source: Section 13.2, p. 453

EXAMPLE Problem 13.5

Math Handbook
Unit Conversion
page 957

Molar Volume The main component of natural gas used for home heating and cooking is methane (CH_4). Calculate the volume that 2.00 kg of methane gas will occupy at STP.

1 Analyze the Problem

The number of moles can be calculated by dividing the mass of the sample, m, by its molar mass, M. The gas is at STP (0.00°C and 1.00 atm pressure), so you can use the molar volume to convert from the number of moles to the volume.

Known
$m = 2.00$ kg
$T = 0.00$°C
$P = 1.00$ atm

Unknown
$V = ?$ L

2 Solve for the Unknown

Determine the molar mass for methane.

$$\text{M} = 1 \text{ C atom}\left(\frac{12.01 \text{ amu}}{1 \text{ C atom}}\right) + 4 \text{ H atoms}\left(\frac{1.01 \text{ amu}}{1 \text{ H atom}}\right)$$

Determine the molecular mass.

$$= 12.01 \text{ amu} + 4.04 \text{ amu} = 16.05 \text{ amu}$$
$$= 16.05 \text{ g/mol}$$

Express the molecular mass as g/mol to arrive at the molar mass.

Determine the number of moles of methane.

$$2.00 \text{ kg}\left(\frac{1000 \text{ g}}{1 \text{ kg}}\right) = 2.00 \times 10^3 \text{ g}$$

Convert the mass from kg to g.

$$\frac{m}{\text{M}} = \frac{2.00 \times 10^3 \text{ g}}{16.05 \text{ g/mol}} = 125 \text{ mol}$$

Divide mass by molar mass to determine the number of moles.

Use the molar volume to determine the volume of methane at STP.

$$V = 125 \text{ mol} = \frac{22.4 \text{ L}}{1 \text{ mol}} = \mathbf{2.80 \times 10^3 \text{ L}}$$

Use the molar volume, 22.4 L/mol, to convert from moles to the volume.

3 Evaluate the Answer

The amount of methane present is much more than 1 mol, so you should expect a large volume, which is in agreement with the answer. The unit is liters, a volume unit, and there are three significant figures.

PRACTICE Problems

Extra Practice Page 984 and glencoe.com

20. What size container do you need to hold 0.0459 mol of N_2 gas at STP?
21. How much carbon dioxide gas, in grams, is in a 1.0-L balloon at STP?
22. What volume in milliliters will 0.00922 g of H_2 gas occupy at STP?
23. What volume will 0.416 g of krypton gas occupy at STP?
24. Calculate the volume that 4.5 kg of ethylene gas (C_2H_4) will occupy at STP.
25. **Challenge** A flexible plastic container contains 0.860 g of helium gas in a volume of 19.2 L. If 0.205 g of helium is removed at constant pressure and temperature, what will be the new volume?

Section 13.2 • The Ideal Gas Law 453

Example Problems take you step-by-step to solve problems in chemistry. Reinforce the skills you've learned by working through the **Practice Problems**.

OTHER READING SKILLS

- Ask yourself what is the BIG Idea?
  What is the MAIN Idea?
- Relate the information in *Chemistry: Matter and Change* to other areas you have studied.
- Predict events or outcomes by using clues and information that you already know.
- Change your predictions as you read and gather new information.

After You Read

Follow up your reading with a summary and assessment of the material to evaluate if you understood the text.

Each section concludes with an assessment. The assessment contains a summary and questions. The summary reviews the section's key concepts while the questions test your understanding.

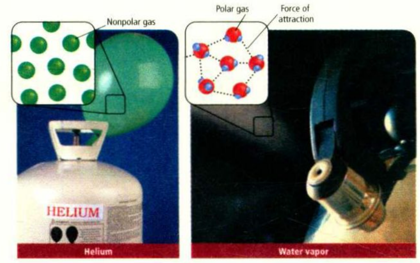


Figure 13.9 In a nonpolar gas, there is minimal attraction between particles. However, polar gases, such as water vapor, experience forces of attraction between particles.

Infer *Assuming the volume of the particles is negligible, how will the measured pressure for a sample of gas that experiences significant intermolecular attractive forces compare to the pressure predicted by the ideal gas law?*

Polarity and size of particles The nature of the particles making up a gas also affects how ideally the gas behaves. For example, polar gas molecules, such as water vapor, generally have larger attractive forces between their particles than nonpolar gases, such as helium. The oppositely charged ends of polar molecules are pulled together through electrostatic forces, as shown in **Figure 13.9.** Therefore, polar gases do not behave as ideal gases. Also, the particles of gases composed of larger nonpolar molecules, such as butane (C_4H_{10}), occupy more actual volume than an equal number of smaller gas particles in gases such as helium (He). Therefore, larger gas particles tend to exhibit a greater departure from ideal behavior than do smaller gas particles.

Section 13.2 Assessment

Section Summary

- Avogadro's principle states that equal volumes of gases at the same pressure and temperature contain equal numbers of particles.
- The ideal gas law relates the amount of a gas present to its pressure, temperature, and volume.
- The ideal gas law can be used to find molar mass if the mass of the gas is known, or the density of the gas if its molar mass is known.
- At very high pressures and very low temperatures, real gases behave differently than ideal gases.

31. MAIN Idea **Explain** why Avogadro's principle holds true for gases that have small particles and for gases that have large particles.
32. **State** the equation for the ideal gas law.
33. **Analyze** how the ideal gas law applies to real gases using the kinetic-molecular theory.
34. **Predict** the conditions under which a real gas might deviate from ideal behavior.
35. **List** common units for each variable in the ideal gas law.
36. **Calculate** A 2.00-L flask is filled with propane gas (C_3H_8) at a pressure of 1.00 atm and a temperature of −15.0°C. What is the mass of the propane in the flask?
37. **Make and Use Graphs** For every 6°C drop in temperature, the air pressure in a car's tires goes down by about 1 psi (14.7 psi = 1.00 atm). Make a graph illustrating the change in tire pressure from 20°C to −20°C (assume 30.0 psi at 20°C).

ChemistryOnline Self-Check Quiz glencoe.com

Section 13.2 • The Ideal Gas Law 459

Source: Chapter 13, p. 459

CHAPTER 13 Study Guide

STUDY TO GO Download quizzes, key terms, and flash cards from glencoe.com.

BIG Idea Gases respond in predictable ways to pressure, temperature, volume, and changes in number of particles.

Section 13.1 The Gas Laws

MAIN Idea For a fixed amount of gas, a change in one variable—pressure, temperature, or volume—affects the other two.

Vocabulary

- absolute zero (p. 445)
- Boyle's law (p. 442)
- Charles's law (p. 445)
- combined gas law (p. 449)
- Gay-Lussac's law (p. 447)

Key Concepts

- Boyle's law states that the volume of a fixed amount of gas is inversely proportional to its pressure at constant temperature.

$$P_1V_1 = P_2V_2$$

- Charles's law states that the volume of a fixed amount of gas is directly proportional to its kelvin temperature at constant pressure.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

- Gay-Lussac's law states that the pressure of a fixed amount of gas is directly proportional to its kelvin temperature at constant volume.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

- The combined gas law relates pressure, temperature, and volume in a single statement.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Section 13.2 The Ideal Gas Law

MAIN Idea The ideal gas law relates the number of particles to pressure, temperature, and volume.

Vocabulary

- Avogadro's principle (p. 452)
- ideal gas constant (p. 454)
- ideal gas law (R) (p. 454)
- molar volume (p. 452)

Key Concepts

- Avogadro's principle states that equal volumes of gases at the same pressure and temperature contain equal numbers of particles.
- The ideal gas law relates the amount of a gas present to its pressure, temperature, and volume.

$$PV = nRT$$

- The ideal gas law can be used to find molar mass if the mass of the gas is known, or the density of the gas if its molar mass is known.

$$M = \frac{mRT}{PV} \quad D = \frac{MP}{RT}$$

- At very high pressures and very low temperatures, real gases behave differently than ideal gases.

Section 13.3 Gas Stoichiometry

MAIN Idea When gases react, the coefficients in the balanced chemical equation represent both molar amounts and relative volumes.

Key Concepts

- The coefficients in a balanced chemical equation specify volume ratios for gaseous reactants and products.
- The gas laws can be used along with balanced chemical equations to calculate the amount of a gaseous reactant or product in a reaction.

ChemistryOnline Vocabulary PuzzleMaker glencoe.com

Chapter 13 • Study Guide 467

Source: Chapter 13, p. 467

At the end of each chapter you will find a Study Guide. The chapter's vocabulary terms as well as key concepts are listed here. Use this guide for review and to check your comprehension.

OTHER WAYS TO REVIEW

- State the BIG Idea.
- Relate the MAIN Idea to the BIG Idea.
- Use your own words to explain what you read.
- Apply this information in other school subjects or at home.
- Identify sources you could use to find out more information about this topic.

Scavenger Hunt

Chemistry: Matter and Change contains a wealth of information. Complete this fun activity so you will know where to look to learn as much as you can.

As you complete this scavenger hunt, either alone, with your teacher, or with others, you will quickly learn how *Chemistry: Matter and Change* is organized and how to get the most out of your reading and study time.

1. How many chapters are in this book?
2. On what page does the glossary begin? What glossary is online?
3. Where can you find a listing of Laboratory Safety Symbols?
4. If you want to find all the MiniLabs, Problem-Solving Labs, Data Analysis Labs, and ChemLabs, where in the front do you look?
5. How can you quickly find the pages that have information about an arson investigator?
6. What is the name of the table that summarizes the Key Concepts of a chapter?
7. Where can you find reference tables? What are the page numbers?
8. On what page can you find the BIG Idea for Chapter 1? On what pages can you find the MAIN Ideas for Chapter 2?
9. Where can you find information on hydrogen?
10. Name four activities that are found at Chemistry Online.
11. What study tool shown at the beginning of a chapter can you make from notebook paper?
12. Where do you go to view the Concepts In Motion?
13. How It Works and Everyday Chemistry are two types of chapter features. What are the other two types?

Contents in Brief

Student Guide

Chapters

Student Resources . . . 900

Contents

Your book is divided into chapters that are organized around Themes, Big Ideas, and Main Ideas of chemistry.

THEMES are overarching concepts used throughout the entire book that help you tie what you learn together. They help you see the connections among major ideas and concepts.

BIG Idea appears in each chapter and help you focus on topics within the themes. The Big Ideas are broken down even further into Main Ideas.

MAIN Idea draws you into more specific details about chemistry. All the Main Ideas of a chapter add up to the chapter's Big Idea.

THEMES

Matter
Physical and Chemical Changes
Bonding
Energy
Equilibrium

BIG Idea

One per chapter

MAIN Idea

One per section

Student Guide

Contents

Labs

LAUNCH Lab

Begin each chapter with a hands-on introduction to the subject matter.

PROBLEM-SOLVING LAB

Build your analytical skills using real-world applications of chemistry concepts.

DATA ANALYSIS LAB

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