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UNIT 2

Forms of Matter: Gases

Chapter 4 *Exploring Gas Laws*

Answers to Questions for Comprehension, notes on Figures and Web Links appear throughout the chapter.

Teaching Unit 2: Forms of Matter: Gases

(16% of the course time; approximately 20 hours)

Student Textbook pages 90–157

General Outcomes

- explain molecular behaviour using models of the gaseous state of matter

Contents

Chapter 3: Properties of Gases

Chapter 4: Exploring Gas Laws

Content Summary

Gas behaviour and gas reactions are a part of everyday life. Gas-based technology has produced soft drinks, air bags, and combustion engines. Gases are used to preserve food, extract caffeine from coffee, and heat homes. In addition, compressed gases are an important part of many medical technologies and treatments. Students will be interested to learn that natural phenomena such as volcanoes and geysers also depend on gases under pressure.

Unit 2 introduces students to the properties of gases and to the gas laws, a series of relationships between the pressure, temperature, volume, and amount of an ideal gas (defined on student textbook page 100). Students will learn how the pressure and temperature of a gas can be measured, and how these properties are related to the volume of a fixed amount of an ideal gas. Students are led through a series of steps in which gas laws are combined to end at a universal law applicable in almost all situations.

In Chapter 3, students learn about the primary gas laws and the reasoning behind them. The properties of gases are understood in terms of the kinetic molecular theory, but the experiments that laid the basis for the theory began with understanding the limitation of water pumps used to keep mines dry. Measurements of gas pressure and volume on a fixed amount of gas are the basis of Boyle's law, the first gas law to which students are introduced. Next, Charles's law is discussed, relating the temperature and volume of a fixed amount of a gas. Charles's law leads naturally to the absolute temperature scale. Boyle's and Charles's laws are supported by hands-on student investigations, explanations using the kinetic molecular theory, and sample problems.

In Chapter 4, students see how Boyle's and Charles's laws lead to the combined gas law for a fixed amount of a gas. Experiments by Gay-Lussac on chemical reactions between gases lead to the law of combining volumes. Gay-Lussac's law and the atomic theory of John Dalton were used by Avogadro to propose a law that provides a link to the amount of gas present. Avogadro's law, which relates volume and amount of gas, is added to the combined gas law. This results in the ideal gas equation, which can be used to predict the behaviour of a gas in almost any situation. Students will use this equation to solve stoichiometric problems involving gases. The final gas law introduced is Dalton's law of partial pressures, which students will need in their calculations involving gases collected by the displacement of water. The deviation between ideal gases and real gas behaviour is discussed using the kinetic molecular theory. The chapter is supported with experiments and sample problems and culminates in asking students to design an activity to determine the value of the universal gas constant.

Curriculum Fit

Background: This unit builds on *Science 9*, Unit B: Matter and Chemical Change; and *Science 10*, Unit A: Energy and Matter in Chemical Change. This unit explores gases (matter with relatively weak intermolecular forces). Real gases deviate from ideal gas behaviour when the intermolecular forces between gas molecules are not negligible. This unit provides an introduction to *Chemistry 30*, Unit D: Equilibrium. Although generally applicable to other systems, the equilibrium law and Le Châtelier's principle will be developed for homogeneous gaseous mixtures.

Core Concepts

Concept	Outcome	Text Reference
Gases have characteristic physical properties. They are miscible, compressible fluids with relatively low density and viscosity. They expand to fill any container, and the volume of a gas increases as the temperature is increased, if the pressure remains constant.	20–B1.1k	Section 3.1, p. 99
A gas sample may be described in terms of four variables: volume, pressure, temperature, and amount.	20–B1.1k	Section 3.1, p. 99
The kinetic molecular theory of gases assumes molecules that are point masses, which interact through elastic collisions with no intermolecular attractions.	20–B1.1k	Section 3.1, p. 100; p. 111; p. 121
The volume of a fixed amount of gas at constant temperature is inversely proportional to the applied pressure on the gas. (Boyle's law)	20–B1.4k	Section 3.2, pp. 104-111
The volume of a fixed amount of gas at constant pressure is directly proportional to the absolute temperature of the gas. (Charles's law)	20–B1.4k	Section 3.3, pp. 113-120
An ideal gas has zero volume at zero on the absolute temperature scale (0 K).	20–B1.2k	Section 3.3, pp. 115-118
A change of one degree on the Kelvin scale is the same temperature change as one degree on the Celsius scale.	20–B1.2k	Section 3.3, pp. 115-118
When gases react, the volumes of the gaseous reactants and products, measured at the same conditions of temperature and pressure, are always in whole-number ratios. (Law of combining volumes)	20–B1.3k	Section 4.1, pp. 132-133
Equal volumes of all ideal gases at the same temperature and pressure contain the same number of molecules. (Avogadro's law)	20–B1.4k	Section 4.1, p.133
In a mixture of gases that do not react chemically, the total pressure is the sum of the partial pressures of each individual gas. (Dalton's law)	20–B1.4k	Section 4.2, pp.142-145
All real gases deviate from ideal behaviour at low temperature and high pressure.	20–B1.1k	Section 4.2, p.146

Beyond the Core Concepts

Concept	Outcome	Text Reference
The properties of gases are important in many areas, including industry, medicine, recreational activities, and processes in nature.	20–B1.2sts	Section 3.1, pp. 96; 98-99 Section 3.2, pp. 102-104; 108 Section 3.3, pp. 113-114; Section 4.1, pp. 126; 128; 131; 154-155
Progress in science depends on new ideas and on new evidence. The development of technologies capable of precise measurements of temperature and pressure led to a better understanding of gases and the formulation of the gas laws.	20–B1.1sts	Unit 2 Opener, p. 90 Section 3.2, pp. 102-103; 105; 108 Section 4.1, p. 131

Beyond the Core Concepts

Concept	Outcome	Text Reference
Students will perform calculations based on the equation $PV = \frac{mRT}{M}$		Section 4.2, p. 142

Related Skills

Skill	Outcome	Text Reference
Students must be able to describe procedures for safe handling and storage of gases used in the laboratory, with reference to WHMIS and consumer product labelling information.	20–B1.1s	Introductory Material, pp. xii-xv
Students will work as members of a team to investigate the properties of gases by stating hypotheses and designing and performing investigations.	20–B1.1s 20–B1.4s	Chapter 3, Launch Lab, p. 97 Section 3.2, pp. 106-107 Section 3.3, pp. 114-115 Chapter 4 Launch Lab, p. 127 Section 4.2, pp. 144-145; p. 148
Students will perform experiments, in which variables are identified and controlled, to illustrate the relationships that describe ideal gases.	20–B1.2s	Section 3.2, pp. 106-107 Section 3.3, pp. 114-115 Section 4.1, p. 137 Section 4.2, pp. 144-145; 148
Students will compare experimental results with the accepted value, calculate the percentage error, and suggest ways to improve methods of data collection.	20–B1.3s	Section 4.1, p. 137 Section 4.2, p. 148
Working in small groups, students will use mathematical and graphical techniques to analyze experimental data that relate pressure and temperature to gas volume.	20–B1.3s 20–B1.4s	Section 3.2, pp. 106-107 Section 3.3, pp. 114-115 Section 3.3, p. 117
Students will convert between the Celsius and Kelvin temperature scales.	20–B1.2k	Section 3.3, pp. 116; 117; 119-120; 122 Section 4.1, p. 130 Section 4.2, pp. 141; 142
Students will perform calculations based on the following relationships: • $P_1V_1 = P_2V_2$ (Boyle's law) • $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ (Charles's law) • $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ (Combined gas law) • $\frac{n_1}{V_1} = \frac{n_2}{V_2}$ (Avogadro's law) • $PV = nRT$ (Ideal gas law)	20–B1.4k 20–B1.4s	Section 3.1, p. 110 Section 3.2, p. 120 Section 4.1, p. 130 Section 4.2, p. 141

Activities and Target Skills

Activity	Target Skills
Chapter 3: Properties of Gases	
Launch Lab: Balloon in a Bottle, p. 97	■ Inferring properties of gases
Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas, pp. 106-107	■ Predicting the relationship between pressure and volume of a gas ■ Performing an experiment to illustrate Boyle's law ■ Drawing and interpreting graphs of experimental data that relate the pressure and the volume of a gas
Investigation 3.B: The Relationship between Temperature and Volume of a Gas, pp. 114-115	■ Predicting the relationship between the temperature and volume of gas ■ Performing an experiment to illustrate Charles's law ■ Drawing and interpreting graphs that relate temperature and the volume of a gas
Thought Lab 3.1: The Importance of the Kelvin Temperature Scale, p. 117	■ Drawing a graph to relate temperature to the volume of a gas ■ Determining absolute zero ■ Identifying the importance of an absolute temperature scale
Chapter 4: Exploring Gas Laws	
Launch Lab: Changing Gas Temperature, Pressure, and Volume at the Same Time, p. 127	■ Observing the effect of changing temperature and pressure on the volume of a gas
Thought Lab 4.1: Molar Volumes of Gases, p. 137	■ Solving problems involving molar volumes of gases ■ Comparing experimental values with theoretical values of molar volumes ■ Determining experimental error
Investigation 4.A: Finding the Molar Mass of a Gas, pp. 144-145	■ Performing an experiment to find the molar mass of a gas ■ Controlling variables in an experiment ■ Using thermometers, balances, and other devices to collect data on a gas
Investigation 4.B: Finding the Value of the Universal Gas Constant, *R*, p. 149	■ Communicating questions and ideas with others during group work to design an experiment on gases ■ Describing procedures for safe handling of laboratory equipment and chemicals ■ Designing an experiment to determine the universal gas constant

Conceptual Challenges

Section 3.1

- Students often use the terms *vapour* and *gas* interchangeably, but they are not the same and a careful distinction between these terms should be made throughout the teaching of this unit. A gas is a fluid that will fill the space of its container. A vapour is a substance in the gaseous state that is normally a liquid or solid at standard temperature and pressure.
- Many students do not understand that pressure is related to surface area. Give examples of items that illustrate this concept, such as snowshoes, skis, the large paws of some animals, bulldozer treads, nails, and cutting instruments.
- Many students think that the mass of a gas is negligible. The density of air is 1.20 kg/m^3, and it would be a useful exercise to ask students to estimate the mass of air present in their classroom. The mass of air inside a typical home refrigerator is typically greater than the mass of a dozen eggs.

Section 3.2

- Students often think that atmospheric pressure is negligible because they cannot feel it. They might argue that if there is a column of air pressing down upon us, why do we not feel its crushing effect? The air, of course, does not simply press downwards; air exerts a pressure in all directions. Inside our bodies there is air that similarly exerts a pressure in all directions. The Launch Lab on page 127 nicely illustrates what happens to a soft drink can when the pressure of air inside the can is reduced.

Section 3.3

- Emphasize at every opportunity that any problem solving involving temperature must be done in Kelvins. For example, a simple Charles's law problem where the temperature changes from 23 °C to 46 °C will not cause the volume to double.

- Even good mathematical problem solvers may have difficulty solving problems that involve ratios, especially those that include an inverse proportion. Teach students that numbers can be used to replace ratios, and they can solve a ratio problem as they would solve the same problem type if values were given. For example, if the pressure is doubled, $P_1 = 1$ and $P_2 = 2$ or if the temperature is halved (on the Kelvin scale!), then $T_1 = 1$ and $T_2 = 1/2$.
- Remind students that there are a number of commonly used units for gas pressure. Provided the gas pressure is expressed in common units in a problem, there is no reason to convert to another unit. Only when pressure units are mixed is it be necessary to convert one of the units to the other.
- Students have been taught that warm air rises and may wonder why the temperature at higher altitudes is colder. This is because the rising air expands due to lower air pressure, and this expansion of real gases absorbs thermal energy from the surroundings and, therefore, the air cools.

Using the Unit 2 Preparation Feature

The unit opener has been designed to establish a social, technical, and environmental context for the science in the unit. Use the unit opener to introduce the general unit topics within that context, and ask the Focussing Questions to guide students' thinking.

The Unit Preparation feature has been included in order to ensure that students are familiar with the science from previous courses that relates specifically to the material they are about to study. Encourage students to take the Unit Prequiz (found at **www.albertachemistry.ca**, Online Learning Centre, Student Edition) to gauge their recall, noting that if they are familiar with the background science, their experience with this unit will be much easier.

The Unit 2 Preparation feature covers four pages, and the topics reviewed include: density, pressure, viscosity, moles and mass, and solving equations (including a sample problem and six practice problems).

A number of assessment (AST) or reinforcement BLMs have been prepared for the Unit Preparation review. You will find them with the Chapter 3 BLMs on the CD-ROM that accompanies this Teacher's Resource or by going to **www.albertachemistry.ca**, Online Learning Centre, and logging on to the Instructor Edition.

Number (Type) Title
3.0.1 (AST) Density and Pressure Review Problems
3.0.1A (ANS) Density and Pressure Review Answer Key
3.0.2 (AST) Mass, Moles, and Molar Mass Problems
3.0.2A (ANS) Mass, Moles, and Molar Mass Answer Key
3.0.3 (AST) Solving Equations
3.0.3A (ANS) Solving Equations Answer Key

Answers to Practice Problems 1–6

Student Textbook page 95

For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

1. 2.55×10^3 g
2. 1.1 m^2
3. 1.7 kN
4. 1.42×10^7 cm^3
5. 380 g
6. 39.95 g/mol

UNIT 2: COURSE MATERIALS

Chapter, Section	Item Description	Suggested Quantity (assume 40 in class)	Text Activity
Chapters 3, 4	safety goggles	40 pairs	Chapter 4 Launch Lab; Investigations: 3.B, 4.A
Chapters 3, 4	nonlatex disposable gloves	40 pairs	Chapter 4 Launch Lab
Chapters 3, 4	aprons	40	Chapter 4 Launch Lab; Investigation 4.A
Chapter 3, Chapter Opener	balloons	1 per group	Launch Lab: Balloon in a Bottle, p. 97
	1 L or 2 L plastic bottles	1 per group	
	scissors (or sharp object)	1 per group	
Chapter 3, Section 3.2	60 mL syringe	1 per group	Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas, pp. 106–107
	square piece of plexiglass (about 15 to 20 cm on a side; a tray may be substituted)	1 per group	
	glue (strong)	1 bottle per group	
	retort stand	1 per group	
	clamps	3 per group	
	rubber stopper	1 per group	
	scale (with range up to 100 N)	1–3	
	weights (such as heavy books) totaling a mass of at least 6 kg	3-4 large books per group	
	barometer	1–3	
Chapter 3, Section 3.3	coloured water	1 mL per group	Investigation 3.B: The Relationship between Temperature and Volume of a Gas, pp. 114–115
	tap water	300 mL per group	
	ice cubes	4 per group	
	thin stem plastic pipette	1 per group	
	match or Bunsen burner	1 per group	
	scissors	1 per group	
	metric ruler (with mm calibrations)	1 per group	
	rubber bands	2 per group	
	400 mL beaker	1 per group	
	Celsius thermometer	1 per group	
	hot plate	1 per group	
	marker	1 per group	
Chapter 4, Chapter Opener	water	5 mL per group	Launch Lab: Changing Gas Temperature, Pressure, and Volume at the Same Time, p. 127
	large beaker of ice water	1 per group	
	empty, clean soft drink can	1 per group	
	hot plate	1 per group	
	beaker tongs	1 per group	
	10 mL graduated cylinder	1 per group	
Chapter 4, Section 4.2	tap water		Investigation 4.A: Finding the Molar Mass of a Gas, pp. 144–145
	4 L beaker or plastic pail (or sink)	1 per group	
	balance	3–4	
	disposable butane lighter	1 per group	
	200–500 mL graduated cylinder	1 per group	
	blow dryer	3–4	
	parafilm or plastic wrap	1 square per group	
	thermometer (alcohol or digital)	1 per group	
	barometer	1	
	small beaker	1 per group	
	masking tape	1 roll	
	paper towel	1 roll	

Chapter, Section	Item Description	Suggested Quantity (assume 40 in class)	Text Activity
Chapter 4, Section 4.2	variable from group to group but will include: mass balance thermometers pressure gauges or a barometer graduate cylinders various beakers balloons, ice, etc.		Investigation 4.B: Finding the Value of the Universal Gas Constant, *R*, p. 149

CHAPTER 3 PROPERTIES OF GASES

Curriculum Correlation

General Outcome 1: Students will explain molecular behaviour using models of the gaseous state of matter.

	Student Textbook	Assessment Options
Outcomes for Knowledge		
20–B1.1k describe and compare the behaviour of real and ideal gases in terms of kinetic molecular theory	Properties of Gases, Section 3.1, pp. 91, 99 Kinetic Molecular Theory, Section 3.1, p. 100 Gas Pressure and Volume, Section 3.2, p. 104 Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas, Section 3.2, p. 106 Connections: Technology and the Development of Barometers, Section 3.2, p. 108 Kinetic Molecular Theory and Boyle's Law, Section 3.2, p. 111 Kinetic Molecular Theory and Charles's Law, Section 3.3, p. 121 Connections: Chinook Winds and Gas Laws, Section 4.2, p. 146	ChemistryFile: FYI (sidebar), Section 3.2, p. 105 Section 3.1 Review: 4–9, p. 101 Connections: Technology and the Development of Barometers, 1, Section 3.2, p. 108 Section 3.3 Review: 1–3, p. 122 Chapter 3 Review: 1–7, p. 124 Chapter 3 Test BLM 3.0.5 What do you know about gases? BLM 3.1.2 Properties of Gases BLM 3.1.3 Modelling Gases in the Roller Rink BLM 3.2.4 Charles's Law and the Motion of Molecules Unit 2 Review: 1–3, pp. 156–157
20–B1.2k convert between the Celsius and Kelvin temperature scales	Interpreting the Volume versus Temperature Relationship, Section 3.3, pp. 115-117, 119-120, 122 Thought Lab 3.1: The Importance of the Kelvin Temperature Scale, Section 3.3, p. 117 Sample Problem: Using Charles's Law to Calculate Volume, Section 3.3, p. 119 Sample Problem: Using Charles's Law to Calculate Temperature, Section 3.3, p. 120 The Combined Gas Law, Section 4.1, p. 130 Ideal Gas Law, Section 4.2, pp. 141, 142	Practice Problems: 7, 8, Section 3.3, p. 119 Thought Lab 3.1: The Importance of the Kelvin Temperature Scale, Procedure 3, Section 3.3, p. 117 Questions for Comprehension: 8, 9, Section 3.3, p. 116 Chapter 3 Test BLM 3.3.2 The Celsius and Kelvin Scales Unit 2 Review: 1, 13, pp. 156–157

	Student Textbook	Assessment Options
20–B1.3k explain the law of combining gases	Combining Volumes of Gases, Section 4.1, p. 132 Combined Gas Law Calculations, Section 4.1, p. 129 Ideal Gas Law, Section 4.2, pp. 139-140 The Combined Gas Law, Section 4.1, p. 128 Connections: Technology and the Process of Discovery, Section 4.1, p. 131	BLM 3.3.5 Gas Pressure, Temperature and Volume Quiz Chapter 3 Test Practice Problems: 1-6, Section 4.1, p. 130 Practice Problems: 7-9, Section 4.1, p. 132 Questions for Comprehension: 1, 2, Section 4.1, p. 132 Questions for Comprehension: 3, 4, Section 4.1, pp. 135-136 Chapter 4 Review: 5, 26, 30, 33, p. 152 BLM 4.1.1 Combined Gas Law Problems (1) BLM 4.1.2 Combined Gas Law Problems (2) Unit 2 Review: 10, 19, 24, 29, pp. 156–157
20–B1.4k illustrate how Boyle's and Charles' laws, individually and combined, are related to the ideal gas law ($PV = nRT$) ■ express pressure using units of kilopascals, atmospheres and millimetres of mercury ■ perform calculations based on the gas laws under STP, SATP and other defined conditions.	Gases and Molecular Kinetic Theory, Section 3.1, p. 110 Gases and Pressure, Section 3.2, pp. 102–104 Boyle's Law, Section 3.2, p. 109 Using Boyle's Law to Calculate Volume, Section 3.2, p. 110 Charles's Law, Section 3.3, p. 117 The Combined Gas Law, Section 4.1, p. 133 Ideal Gas Law, Section 4.2, pp. 142-145	Section 3.2 Review: 1-3, p. 112 Questions for Comprehension: 3, Section 3.2, p. 104 Practice Problems: 14, Section 3.3, p. 120 Chapter 3 Test BLM 3.3.5 Gas Pressure, Temperature and Volume Quiz Unit 2 Review: 5–9, 11, 12, 14–26, pp. 156–157
Outcomes for Science, Technology and Society (Emphasis on the nature of science)		
20–B1.1sts explain that science provides a conceptual and theoretical basis for predicting, interpreting and explaining natural and technological phenomena by ■ *describing how the development of technologies capable of precise measurements of temperature and pressure led to a better understanding of gases and the formulation of the gas laws, e.g., thermocouples, thermistors, Bourdon gauges*	Using the Properties of Gases – Gas Technologies, Section 3.1, pp. 98-99 Atmospheric Pressure, Section 3.2, p. 102 Gases and Pressure, Gas Pressure and Volume, Gases and Temperature, Section 3.2, pp. 102–105 Discovery of Atmospheric Pressure, Section 3.2, pp. 102-103 Connections: Technology and the Development of Barometers, Section 3.2, p. 108 The Combined Gas Law, Section 4.1, p. 131	Questions for Comprehension: 2, Section 3.2, p. 104 Connections: Technology and the Development of Barometers: 1, 2, Section 3.2, p. 108 Chapter 3 Review: 1-7, 21-25, pp. 124-125 BLM 3.1.4 Research SCUBA

	Student Textbook	Assessment Options
20–B1.2sts explain that the goal of science is knowledge about the natural world by ■ *describing examples of natural phenomena and processes and products that illustrate the properties of gases, e.g., breathing, diffusion, weather, hot air balloons, scuba diving equipment, automobile air bags, gas turbines, internal combustion engines.*	Chapter 3 Launch Lab: Balloon in a Bottle, p. 97 Using the Properties of Gases – Gas Technologies, Section 3.1, pp. 98-99 Atmospheric Pressure, Section 3.2, p. 102 Gases and Pressure, Gas Pressure and Volume, Gases and Temperature, Section 3.2, pp. 102–105 Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas, Section 3.2, pp. 106–107 Investigation 3.B: The Relationship between Temperature and Volume of a Gas, Section 3.3, pp. 114–115 Discovery of Atmospheric Pressure, Section 3.2, pp. 102-103	Chapter 3 Launch Lab: Balloon in a Bottle, Analysis: 3, p. 97 Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas, Analysis: 1–5, Conclusion: 6, Section 3.2, pp. 106–107 Investigation 3.B: The Relationship between Temperature and Volume of a Gas, Conclusion: 7, Section 3.3, pp. 114–115 Questions for Comprehension: 2, Section 3.2, p. 104 Chapter 3 Review: 1-7, 21-25, pp. 124-125 BLM 3.1.4 Research SCUBA
Initiating and Planning		
20–B1.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by ■ stating hypotheses and making predictions based on information about the pressure, temperature and volume of a gas ■ describing procedures for safe handling, storage and disposal of materials used in the laboratory, with reference to WHMIS and consumer product labelling information ■ *designing an experiment to illustrate Boyle's and/or Charles's gas laws* ■ *designing an investigation to determine the universal gas constant* (R) *or absolute zero.*	Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas, Section 3.2, pp. 106–107 Investigation 3.B: The Relationship between Temperature and Volume of a Gas, Section 3.3, pp. 114–115 Chapter 4 Launch Lab, Changing Gas Temperature, Pressure, and Volume at the Same Time, p. 127 Safety in the Chemistry Laboratory, pp. xii-xv	Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas, Analysis: 1, 3-5, Section 3.2, pp. 106–107 Investigation 3.B: The Relationship between Temperature and Volume of a Gas, Analysis: 1, 4-7, Section 3.3, pp. 114–115
Performing and Recording		
20–B1.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by ■ performing an experiment, in which variables are identified and controlled, to illustrate the gas laws ■ *using thermometers, balances and other measuring devices effectively to collect data on gases* ■ *using library and electronic research tools to collect information on real and ideal gases and applications of gases, e.g., hot air and weather balloons* ■ *performing an investigation to determine molar mass from gaseous volume.*	Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas, Section 3.2, pp. 106–107 Investigation 3.B: The Relationship between Temperature and Volume of a Gas, Section 3.3, pp. 114–115 The Combined Gas Law, Section 4.1, p. 137 Ideal Gas Law, Section 4.2, pp. 144-145, 148	Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas, Analysis: 1, 3–5, Conclusion: 6, Section 3.2, pp. 106–107 Investigation 3.B: The Relationship between Temperature and Volume of a Gas, Analysis: 1, 2, 4, 5, Conclusion: 7, Section 3.3, pp. 114–115

	Student Textbook	Assessment Options
Analyzing and Interpreting		
20–B1.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by ■ drawing and interpreting graphs of experimental data that relate pressure and temperature to gas volume ■ *identifying the limitations of measurement* ■ *identifying a gas based on an analysis of experimental data*.	Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas, Section 3.2, pp. 106–107 Investigation 3.B: The Relationship between Temperature and Volume of a Gas, Section 3.3, pp. 114–115 Thought Lab 3.1: The Importance of the Kelvin Temperature Scale, Section 3.3, p. 117 Interpreting the Volume versus Temperature Relationship, Section 3.3, p. 115 The Combined Gas Law, Section 4.1, p. 137 Ideal Gas Law, Section 4.2, p. 148	Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas, Procedure 16, 17, Section 3.2, pp. 106–107 Investigation 3.B: The Relationship between Temperature and Volume of a Gas, Analysis: 2–5, Conclusion: 7, Section 3.3, pp. 114–115 Thought Lab 3.1: The Importance of the Kelvin Temperature Scale, Analysis: 1–6, Section 3.3, p. 117 Chapter 3 Review: 10, 21, pp. 124- 125 BLM 3.2.4 Interpreting Graphical Relationships Unit 2 Review: 12, 25, pp. 156–157
Communication and Teamwork		
20–B1.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by ■ communicating questions, ideas and intentions and receiving, interpreting, understanding, supporting and responding to the ideas of others during group work to collect data on gases ■ using appropriate International System of Units (SI) notation, fundamental and derived units and significant digits when performing calculations related to the gas laws ■ *preparing a group presentation, using multimedia, to illustrate how pressure, temperature, volume and amount of a gas determine* R, *the universal gas constant*.	Chapter 3 Launch Lab: Balloon in a Bottle, p. 97 Boyle's Law, Section 3.2, p. 109 Charles's Law, Section 3.3, p. 117 Sample Problem: Using Boyle's Law to Calculate Volume, Section 3.2, p. 110 Sample Problem: Using Charles's Law to Calculate Volume, Section 3.3, p. 119 Sample Problem: Using Charles's Law to Calculate Temperature, Section 3.3, p. 120 Chapter 4 Launch Lab: Changing Gas Temperature, Pressure and Volume at the Same Time, p. 127	BLM 4.2.4 Collecting a Gas in the Laboratory

Chapter 3

Properties of Gases

Student Textbook pages 96–125

Chapter Concepts

Section 3.1 Gases and Kinetic Molecular Theory

- The properties of gases are important for many common technologies.
- Gases have unique characteristics that distinguish them from liquids and solids.
- The kinetic molecular theory, based on the concept of an ideal gas, can explain the properties of gases.

Section 3.2 Gases and Pressure

- Atmospheric gases exert pressure on Earth's surface.
- The units for pressure reflect the historical development of knowledge about the gases.
- The pressure on a gas is inversely proportional to its volume as described by Boyle's law, as long as the temperature and amount of gas remain constant.

Section 3.3 Gases and Temperature

- As described by Charles's law, when the pressure and amount of gas remain constant the temperature of a gas is directly proportional to its volume.
- The concept of absolute zero determines an absolute temperature scale.

Common Misconceptions

- A few students may believe that when a gas expands, the gas molecules get larger. You can check for this misconception by asking students to draw a series of diagrams showing molecules representing a fixed amount of a gas inside containers with different volumes.
- In Section 3.1, students may have trouble accepting that atoms in a gas do not interact with one another except in elastic collisions. While intermolecular bonds in a gas become more important as the gas cools and nears its condensation point, an ideal gas is defined at nowhere near that temperature.
- Students may have many misconceptions about air pressure, possibly due to misunderstandings of prior demonstrations.
- In Section 3.2, in the discussion of Figure 3.6 (student textbook p. 103), the size of the container of mercury doesn't matter. This is a non-intuitive result, with which some students will argue. Suggest, however, that decreasing the diameter of the *tube* allows a finer temperature scale.
- Students often have an incorrect understanding of Charles's law. When a gas expands, its molecules must do work. This work results in a decrease in the kinetic energy of the gas molecules, and the temperature will drop. The drop in temperature predicted from Charles's law does not result from the breaking of intermolecular forces. Ideal gases (in which intermolecular forces are negligible) most definitely obey Charles's law. The additional drop in temperature when a real gas expands is the Joule-Thomson effect, but this extension should be avoided in a general class discussion.

Helpful Resources

Books and Journal Articles

- Erduran, Sibel, "Philosophy of Chemistry: An Emerging Field with Implications for Chemistry Education," *Science & Education,* 10, pp. 581–593. (Professor at King's College, University of London, includes an in-depth study of the uses and pitfalls of models)
- Gillespie, Ronald J., "Teaching Molecular Geometry with the VSEPR Model," *Journal of Chemistry Education,* 2004, Vol. 81, No. 3, p. 298.
- Harrison, Allan G. and Treagust, David F., "Learning About Atoms, Molecules, and Chemical Bonds: A Case Study of Multiple-model Use in Grade 11 Chemistry," *Science Education,* Vol. 84, Issue 3, pp. 352–381.
- Peterson, R.F., and Treagust, D., "Grade 12 Students' Misconceptions of Covalent Bonding and Structure," *Journal of Chemistry Education,* 1989, Vol. 66. No. 6, June 1989, p. 459.
- Pittman, Faith A., "Intermolecular Forces as a Key to Understanding the Environmental Fate of Organic Xenobiotics," *Journal of Chemistry Education,* 2005, Vol 82, No. 2, p. 260.

Web Sites

Web links related to chemical bonding, and structures and properties of substances, as well as other topics related to chemical reactions, can be found at **www.albertachemistry.ca**. Go to the Online Learning Centre and log on to the Instructor Edition. Choose Teacher Web Links.

List of BLMs

Blackline masters (BLMs) have been prepared to support the material in this chapter. The BLMs are either for assessment (AST); use as overheads (OH); use as handouts (HAND), in particular to support activities; or to supply answers (ANS) for assessment or handouts. The BLMs are in digital form, stored on the CD-ROM that accompanies this Teacher's Resource or on the web site at **www.albertachemistry.ca,** Online Learning Centre, Instructor Edition, BLMs. The BLMs can be modified to suit the needs of your students.

Number (Type) Title

3.0.1 (AST) Density and Pressure Problems
3.0.1A (ANS) Density and Pressure Problems Answer Key
3.0.2 (AST) Mass, Moles, and Molar Mass Problems
3.0.2A (ANS) Mass, Moles, and Molar Mass Problems Answer Key
3.0.3 (AST) Solving Equations
3.0.3A (ANS) Solving Equations Answer Key
3.0.4 (HAND) Launch Lab: Balloon in a Bottle

3.0.4A (ANS) Launch Lab: Balloon in a Bottle Answer Key
3.0.5 (AST) What Do You Know About Gases?
3.0.5A (ANS) What Do You Know About Gases? Answer Key

3.1.1 (OH) Movement of Gas Molecules
3.1.2 (AST) Properties of Gases
3.1.2A (ANS) Properties of Gases Answer Key
3.1.3 (AST) Modelling Gases in the Roller Rink
3.1.3A (ANS) Modelling Gases in the Roller Rink Answer Key
3.1.4 (HAND) Research SCUBA
3.1.4A (ANS) Research SCUBA Answer Key

3.2.1 (OH) Measuring Pressure
3.2.2 (OH) How a Water Pump Works
3.2.3 (HAND) Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas
3.2.3A (ANS) Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas Answer Key
3.2.4 (HAND) Interpreting Graphical Relationships
3.2.4A (ANS) Interpreting Graphical Relationships Answer Key
3.2.5 (OH) Boyle's Law
3.2.6 (OH) Boyle's Law and the Motion of Molecules
3.2.7 (AST) Atmosphere and Pressure
3.2.7A (ANS) Atmosphere and Pressure Answer Key

3.3.1 (HAND) Investigation 3.B: The Relationship between Temperature and Volume of a Gas
3.3.1A (ANS) Investigation 3.B: The Relationship between Temperature and Volume of a Gas Answer Key
3.3.2 (OH) The Celsius and Kelvin Scales
3.3.3 (HAND) Thought Lab 3.1: The Importance of the Kelvin Temperature Scale
3.3.3A (ANS) Thought Lab 3.1: The Importance of the Kelvin Temperature Scale Answer Key
3.3.4 (OH) Charles's Law and the Motion of Molecules
3.3.5 (AST) Gas Pressure, Temperature, and Volume Quiz
3.3.5A (ANS) Gas Pressure, Temperature, and Volume Answer Key

3.4.1 (AST) Chapter 3 Test
3.4.1A (ANS) Chapter 3 Test Answer Key

Using the Chapter 3 Opener

Student Textbook pages 96–97

Teaching Strategies

- Have students discuss different technologies that depend on the unique properties of gases, such as scuba tanks. Ask what happens if the pressure in a tank is too high.
- Use **BLM 3.0.5 (AST) What Do You Know About Gases?** to assess students' understanding of this topic. The answers can be found on **BLM 3.0.5A (ANS) What Do You Know About Gases? Answer Key.**
- Have students complete the Launch Lab. Have them write an explanation of their results, and ask them to describe any other air pressure demonstrations they may have seen in previous years.

Launch Lab — Balloon in a Bottle

Student Textbook page 97

Purpose

Students deduce some properties of gases by blowing up a balloon inside a bottle.

Outcomes

- 20–B1.4s
- CT–NS1

Advance Preparation

When to Begin	What to Do
2–3 days before	■ Gather materials (ask students to bring the bottles).
1 day before	■ Place materials where students can pick them up. ■ Photocopy **BLM 3.0.4 (HAND) Launch Lab: Balloon in a Bottle.**

Materials
■ balloons ■ plastic soft drink bottles ■ scissors

Time Required

30 minutes

Helpful Tips

- Remind students not to start blowing up the balloons before they have them down inside the soft drink bottles.
- If the bottoms of the soft drink bottles are made of thick plastic, have students make their hole anywhere near the bottom.
- Use **BLM 3.0.4 (HAND) Launch Lab: Balloon in a Bottle** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. Answers to the questions are on **BLM 3.0.4A (ANS) Launch Lab: Balloon in a Bottle Answer Key.**
- ***Expected Results:*** In the initial trial, the students will not be able to make the balloon fill the bottle because, although the air trapped in the bottle will compress, it will reach a point at which it will not compress any more and the balloon cannot become larger. When the students make a hole in the bottom of the bottle, air will be able to escape and the balloon would have the potential of filling the bottle completely.

Safety Precautions

Warn the students to not use so much force that the scissors slip on the plastic and cut them.

Answers to Analysis Questions

1. This depends on students' predictions. Many will predict that they can blow the balloon up completely when it is inside the bottle, whereas in fact they won't be able to inflate the balloon very much at all. The air inside the bottle will be compressed.
2. There is a huge difference. When there is a hole in the bottle, the balloon can be blown up so that it completely fills the inside of the bottle, because the balloon pushes the air out of the bottle as the balloon gets bigger. When there is not a hole in the bottle, the expanding balloon compresses the air inside the bottle until the pressure matches the maximum pressure that can be exerted by blowing.
3. The balloon cannot expand very far into the bottle because the space in the bottle is already taken up by air; gases occupy space.

Assessment Options

- Collect and assess answers to Analysis questions.

3.1 Gases and Kinetic Molecular Theory

Student Textbook pages 98–101

Section Outcomes

Students will:
- describe natural and technological examples that illustrate the properties of gases
- explain that science provides a conceptual and theoretical basis for explaining these events
- explain the behaviour of gases in terms of the kinetic molecular theory

Key Terms

viscosity
miscible
macroscopic
ideal gas
point mass
elastic collision

Chemistry Background

- The properties of matter come from attractive forces holding particles together against their natural inertial tendency to fly apart since they are in constant motion. In the case of gases, the inertial tendency is far greater than the attractive forces.
- If we assume that there are no attractive forces, then atoms or molecules of gases are free to fly in straight lines at a constant speed until they collide with other atoms or molecules or the walls of the container that they are in. Gravity does act on atoms but it can usually be ignored in the case of a gas in a closed container. Earth's gravity, however, prevents the atmosphere from escaping into space. (Gases such as hydrogen and helium, which have masses too small for them to be retained in Earth's atmosphere, are present in the atmospheres of massive gas giants such as Jupiter.)
- Under standard conditions, gas atoms or molecules have an average speed of approximately 500 m/s. These speeds are nowhere near Earth's escape velocity of 8 km/s, however, which is one of the reasons Earth still has an atmosphere.
- Sometimes gas atoms or molecules bombard larger particles within the gas, as with smoke in air. The smoke particles exhibit a random motion due to collisions with air molecules such as O_2 or N_2. This kind of motion is called Brownian motion.

Teaching Strategies

- There are many excellent applets to be found on the Internet that animate the kind of random motion the atoms of a gas follow. There is also a molecular motion apparatus (expensive) that sits on an overhead projector and jiggles metal and plastic spheres into this kind of motion. In both cases, it is important for students to observe the motion carefully.
- Have the students do research into "how things work," and make a schematic drawing of a technical device they have found that uses the properties of gases. At this point, the details need not be too specific.
- **BLM 3.1.4 (HAND) Research SCUBA,** can be used for the same purpose.
- When explaining the results of air pressure demonstrations, the key is usually in finding the difference between the air pressure on the inside and on the outside of the container. The apparatus for demonstrating Charles's law, for example, contains a trapped gas that is at one atmosphere of pressure. The pressure inside a Boyle's law apparatus, by contrast, can go higher or lower than the air pressure outside.
- Students will have some experience of pneumatic machinery from junior high. They should intuitively understand the way atoms behave in solids, liquids, and gases through their knowledge of particle theory. Have students demonstrate prior knowledge by drawing models of the particles in a solid, liquid, and a gas on the board. Discuss the models as a class.
- A variety of BLMs—overhead masters, handouts, and assessment tools—have been prepared to reinforce information in this section. You will find them with the Chapter 3 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

Number (Type) Title
3.1.1 (OH) Movement of Gas Molecules
3.1.2 (AST) Properties of Gases
3.1.2A (ANS) Properties of Gases Answer Key
3.1.3 (AST) Modelling Gases in the Roller Rink
3.1.3A (ANS) Modelling Gases in the Roller Rink Answer Key
3.1.4 (HAND) Research SCUBA
3.1.4A (ANS) Research SCUBA Answer Key

Figure 3.2

Student Textbook page 99
Gases can be compressed to extremely high pressures. Because the pressure in the jackhammer is so high, it exerts a tremendous force (remember that force equals pressure times area).

Chemistry File: Web Link

Student Textbook page 99
A regulator decreases the pressure of the air from the tank, through a series of valves, to a safe level before the air is inhaled.

Section 3.1 Review Answers

Student Textbook page 101

1. Gases expand when heated. This is important for ballooning because as the air inside the balloon expands, it reduces the density of air inside the balloon to less than the density of air outside the balloon and creates a net buoyant force on the balloon.
2. Gases are highly compressible. This is important for scuba divers because several hours' worth of air can be put into a scuba tank small enough for the diver to carry.
3. **(a)** Gases are compressible. Since gases are compressible, they cannot be sold by volume, but are instead sold by mass. Most tanks used on domestic barbeques will hold 9 kg of propane.
   (b) Gases expand as the temperature is increased if the pressure remains constant. When a can of hairspray is heated, the volume of the gas will be become too large to be contained by the can and the can will explode.
   (c) Gases have a very low resistance to flow and mix evenly and completely. Many toxic gases are also colourless and odorless, which makes them even more dangerous to transport.
   (d) Gases mix evenly and completely and have a low resistance to flow, which makes it much easier to move the hot gas through a building. Large buildings cannot be heated with forced air, however, because air's low specific heat capacity compared to water does not permit the storage of sufficient energy to heat a large area.
   (e) Gases have low viscosity. When a hole in a bicycle tire appears, it takes very little time for the air to squeeze out through the hole. (One way to measure viscosity is to see how quickly a fluid (i.e., a liquid or gas) can get through a small opening.)
4. The space between gas particles is huge compared to the size of the particles themselves. We can simplify the kinetic molecular theory by assuming that the particles have negligable size but do still have a mass.
5. No kinetic energy is lost by the particles in an elastic collision. In an inelastic collision, some or all of the kinetic energy is lost by the particles in the form of heat.
6. The definition of an ideal gas assumes that the total kinetic energy of a gas sample is conserved when the particles collide with one another and with the container. In other words, the collisions are elastic. Collisions in real gases are inelastic, therefore some kinetic energy is converted to thermal energy and may be transferred from the system to the surroundings.
7. Real gases behave differently from ideal gases when they get close to their condensation points. At these temperatures, the particles are close enough together and moving slowly enough that interactions between them cannot be ignored.
8. Figure (a), since it shows a random pattern to its motion, with straight lines of travel between collision with the container wall and other particles.
9. **(a)** The molecules of a second gas are able to fit into the spaces between the molecules of the first gas.
   (b) The molecules are in constant random motion, so if the container is expanded the molecules will travel further before contacting the walls of the container.
   (c) Because there are relatively large spaces between molecules in gases and no repulsive forces, the molecules in gases can be easily pushed closer together.

3.2 Gases and Pressure

Student Textbook pages 102–112

Section Outcomes

In this section, students will:

- perform investigations to determine the quantitative relationships between pressure and the volume of an ideal gas
- express atmospheric pressure using mmHg, atm, bar, and kPa
- use a broad range of tools and techniques to gather and record data

Key Terms

standard atmospheric pressure
Boyle's law

Chemistry Background

- Students may be familiar with kPa, possibly through study of the weather, but will likely not be familiar with any of the other pressure units. Moreover, their understanding of kPa is not likely to be mathematically rigorous.
- The SI unit of pressure, the pascal, is named after the French mathematician Blaise Pascal (1623–1662). One pascal is the pressure exerted by a 1 N force acting over a 1 m^2 surface, and one kilopascal is 1000 times as much pressure.
- A pressure scale with zero at atmospheric pressure is called gauge pressure. A pressure scale with zero at zero pressure, rather than atmospheric pressure, is called absolute pressure.
- If the pressures inside and outside an engine cylinder are equal, then the force exerted on top of the piston equals the force exerted below it and, since the forces are balanced, it shows no movement. If the pressure outside the cylinder is reduced, the pressure exerted on the bottom of the piston is greater than the pressure exerted on the top, and the piston will rise. See Figure 3.12 (student texbookt p. 111). This idea leads to Boyle's law.
- Robert Boyle (1627–1691) discovered that there is an inverse relationship between volume and pressure for gases.

Teaching Strategies

- Have students discuss the effects of pressure on their bodies. Our ears pop when the pressures inside and outside our eardrums are sufficiently different. The eardrum is built to be sensitive to air pressure differences since that's how sound waves manifest.
- There are many, many air-pressure demonstrations that can be done. One of the simplest and most effective is to fill a glass half full of water, place a piece of cardboard over top of it, and invert it. This old standby always gets a good response from classes. **BLM 3.2.1 (OH) Measuring Pressure** demonstrates what a column of air is. **BLM 3.2.7 (AST) Atmosphere and Pressure Problems** will give students practice with pressure units.
- Many students will have a tough time with the linearization process used in the Boyle's law experiment. **BLM 3.2.5 (OH) Boyle's Law** and **BLM 3.2.6 (OH) Boyle's Law and the Motion of Molecules** will help them with this difficult concept.
- Much of what students will do with Boyle's law is algebraic.
- The graphical analysis used to verify Boyle's law will seem difficult to most students. The concept of straightening a curve (linearization) is sophisticated. If you graph an inverse relationship, you see a hyperbolic graph curving down to the right. The idea here is that if you have an inverse relationship between y and x, you have a direct relationship between y and $\frac{1}{x}$.
- A number of overhead masters and quizzes have been prepared for this section. You will find them with the Chapter 3 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

Number (Type) Title
3.2.1 (OH) Measuring Pressure
3.2.2 (OH) How a Water Pump Works
3.2.4 (HAND) Interpreting Graphical Relationships
3.2.4A (ANS) Interpreting Graphical Relationships Answer Key
3.2.5 (OH) Boyle's Law
3.2.6 (OH) Boyle's Law and the Motion of Molecules
3.2.7 (AST) Atmosphere and Pressure
3.2.7A (ANS) Atmosphere and Pressure Answer Key

Answers to Questions for Comprehension

Student Textbook page 104

Q1. As the altitude increases there is less air on top of the air at that altitude. As a result the particles aren't forced as closely together thus lowering the density.

Q2. Depends on the type of barometer, but a mercury barometer works by allowing air pressure to hold up a column of mercury. As the air pressure rises, the air can support a higher column of mercury.

Q3. To convert pressure in mmHg to pressure in kPa, multiply
the pressure in mmHg by $\frac{101.325 \text{ kPa}}{760 \text{ mmHg}}$.

Q4. Standard atmospheric pressure is defined as the atmospheric pressure in dry air at 0 °C at sea level and is 101.235 kPa or 760 mmHg.

Chemistry File: Web Link

Student Textbook page 105

Weather balloons are filled with either hydrogen or helium. Twice a day, every day of the year, weather balloons are released simultaneously from almost 900 locations worldwide (the location in Alberta is at Stony Plain). The balloons stay aloft for around 2 h, can drift as far as 175 km, and rise up to over 30 000 m in the atmosphere.

An instrument called a radiosonde is attached to the balloon to measure pressure, temperature, and relative humidity. A transmitter on the radiosonde sends the data back to tracking equipment on the ground every 1–2 s. By tracking the position of the radiosonde, meteorologists can also calculate wind speed and wind direction. The radiosonde is powered by a small battery.

Chemistry File: Try This

Student Textbook page 105

The balloon is a certain size because the gas pressure inside is equal to the air pressure outside. If the outside air pressure suddenly increases, then the total force on the outside surface of the balloon will be more than the total force on the inside surface. The balloon will shrink, thus increasing the number of particle collisions on the inside surface until the pressures inside and outside are equalized.

Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas

Student Textbook page 106–107

Purpose

Students find a relationship between the pressure and volume of a gas.

Outcomes

- 20–B1.2s
- 20–B1.3s
- 20–B1.2sts
- PR–NS3
- PR–NS20
- AI–NS2
- ICT C6–4.2
- ICT F1–4.2
- ICT C6–4.3

Advance Preparation

When to Begin	What to Do
2–3 days before	■ Obtain clamps (try your physics lab or woodshop).
1 day before	■ Assemble materials. ■ Photocopy **BLM 3.2.3 (HAND) Investigation 3.A: The Relationship between the Pressure on and a The Volume of a Gas.**

Materials
■ 60 mL syringe ■ square piece of plexiglass (about 15 to 20 cm on a side). If plexiglass is not available, a tray may be substituted. ■ glue (strong) ■ retort stand ■ 3 clamps ■ rubber stopper ■ rubber stopper ■ scale (with range up to 100 N) ■ weights (such as heavy books) totaling a mass of at least 6 kg ■ barometer

Time Required

45–60 minutes to gather data

Helpful Tips

- The clamp must be below the plunger in order for the plunger to move.
- Do not tighten the middle clamp enough to distort the cross-section of the barrel of the syringe because the plunger of the syringe will not move smoothly.
- Insert the plunger into the top of the barrel of the syringe before attaching the stopper. The syringe-stopper connection must be airtight.
- Place water around the syringe/stopper connection to watch for any leaks (escaping air).
- The plunger tends to move quite slowly. Encourage students to be patient while waiting for the volume to stabilize.
- Have students repeat the investigation with a different initial volume.
- Use **BLM 3.2.3 (HAND) Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers to the questions are on **BLM 3.2.3A (ANS) Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas Answer Key.**
- Sample data is shown below:
  Table #1 – Sample Data for the Relationship between the Pressure and the Volume of a Gas

Number of Objects	Weight of added object (N)	Total Weight on Platform (N)	Total Pressure, kPa (atmospheric pressure plus pressure due to objects)	Inverse of Pressure (1/P) (1/kPa)	Volume (mL) Trial One	Volume (mL) Trial Two	Volume (mL) Trial Three
1 (plunger and platform)	0 kg=0.0 N	1.20 N	91	0.01099	50.0	49.5	50.0
2 (platform, 1kg mass)	1 kg= 9.81 N	11.01 N	100.81	0.00992	42.0	42.0	42.2
3 (platform, 2kg masses)	2 kg=19.62 N	20.82 N	110.62	0.00904	35.5	36.0	35.7
4 (platform, 3kg masses)	3 kg=29.43 N	30.63 N	120.43	0.0083	31.0	31.2	31.3
5 (platform, 4kg masses)	4 kg=39.24	40.44 N	130.24	0.00768	27.0	27.8	27.7
6 (platform, 5kg masses)	5 kg=49.05 N	50.25 N	140.05	0.00714	25.0	24.5	24.9
7 (platform, 6kg masses)	6 kg=58.86 N	60.06 N	149.86	0.00667	22.0	22.0	22.3
2.5 kg Unknown	2.5 kg=24.52 N	25.72 N	115.525	0.00866	33.5		
3.5 kg Unknown	3.5 kg=34.33 N	35.53 N	125.335	0.00798	29.0		

- ***Expected Results*** When students plot the pressure versus the volume of the air trapped inside the syringe, they will get an inverse relationship. The volume will decrease as the pressure on the gas increases. If the range of pressures is not great enough, the line might appear to be straight even though it is a curve. When they plot volume versus the inverse of the pressure, they should obtain a straight line.

Safety Precautions

- Ensure that the plexiglass is securely fastened to the plunger. If the plexiglass is not securely fastened, the books or other weights will likely tip over.

Answers to Analysis Questions

1. The manipulated variable is the pressure exerted on the gas. The responding variable is the volume of the gas.
2. P versus $\frac{1}{P}$ gives the straight line.
3. As the weight added increased, the measured volume would decrease to a greater extent.
4. A greater temperature will result in a greater volume.
5. They are controlled variables since they were unchanged during the experiment.

Answers to Conclusion Question

6. Pressure and volume are inversely related (inversely proportional) to each other.

Assessment Options

- Collect and assess answers to Analysis and Conclusion questions.
- Provide students with Assessment Checklist 3: Performance Task Self-Assessment and/or use Assessment Checklist 4: Performance Task Group Assessment (see Appendix A).

Connections (Nature of Science): Technology and the Development of Barometers

Student Textbook page 108

Teaching Strategies

- Use the pressure probe available for the TI-83 to measure local atmospheric pressure. Have students perform the calculation to adjust the pressure for local altitude and compare to the pressure reported by the local Environment Canada office. Discuss any differences.
- Have students design a simple barometer and use it to predict or validate weather changes over the course of the unit.

Connections Answers

1. If you live at 304 metres above sea level, you should add 38 millibars to your barometer reading to adjust it to sea level value.
2. Student answers will vary but will likely focus on satellites and on super computers that use mathematical modeling to predict the weather.

Math Tip

Student Textbook page 109

This quick refresher of equations representing straight lines will help students analyze temperature-volume graphs. For volume versus the Kelvin temperature scale, b = 0. The equation is y(temperature) = mx(volume). When temperature is 0 K, volume is 0 L.

Answers to Practice Problems 1–6

Student Textbook page 110

For full solutions, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

1. 24 L
2. 2.00 atm or 203 kPa
3. 2.25 L
4. 2.0 L
5. 1.03 bar
6. 0.97 atm

Chemistry File: Try This

Student Textbook page 111

Some students may have guardians, relatives or friends who work in these fields and can provide the students with information about working with compressed gases. Students could also ask about safety precautions and concerns. Encourage students to share their findings with the class.

Section 3.2 Review Answers

Student Textbook page 112

1. A mercury barometer (and all barometers) are based on the premise that the pressure that the atmosphere exerts on a dish of mercury will be equal to the height that the mercury is pushed up inside a sealed column overturned in the dish. The column is first filled with mercury completely and then turned over in a dish containing more mercury. A vacuum is created inside the column when the mercury flows out due to gravity. The more the mercury flows out (the shorter the column of mercury), the lower the atmospheric pressure pushing it back. Original water pumps functioned on this same principle. A pump created suction at the top of a column of water similar to the vacuum created in the mercury column. The atmospheric pressure pushing on the water coupled with the vacuum created by the pump caused water to rise in the column. Atmospheric pressure can push water up a column to a maximum height of approximately 10 m.
2. **(a)** $3.58\ \cancel{\text{bar}} \times \frac{101.325\ \text{kPa}}{1.01325\ \cancel{\text{bar}}} = 358\ \text{kPa}$

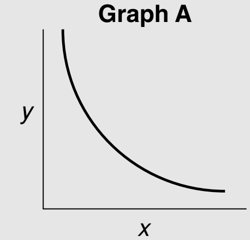
(b) $850\ \cancel{\text{mmHg}} \times \dfrac{101.325\ \text{kPa}}{760\ \cancel{\text{mmHg}}} = 113\ \text{kPa}$

(c) $1.75\ \cancel{\text{atm}} \times \dfrac{101.325\ \text{kPa}}{1\ \cancel{\text{atm}}} = 177\ \text{kPa}$

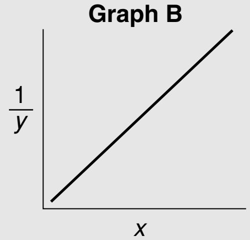
3. **(a)** 1.25 atm **(b)** 1.5 bar **(c)** 105 kPa **(d)** 1.25 atm

4. An inverse relationship is suspected when as one variable increases, the other decreases. The shape of an inverse relationship is a curve, as shown below in graph A. To test this hypothesis, a graph of x vs 1/y should be drawn. If, when drawn, a straight line is observed, then the variables are inversely proportional, as shown in graph B.

Graph A



Graph B



5. Since the pressure has tripled, the volume will drop to one third of its value, becoming 0.83 L.

6. From 10 mL to 5 mL, the volume is halved. This requires double the pressure. Going from 10 mL to 15 mL increases the volume by 1.5 times and requires that Raja lower the pressure to two-thirds of its old value. The first push created a bigger pressure difference.

7. $V = 5.0\ \text{L} \times \dfrac{95.8\ \cancel{\text{kPa}}}{20.6\ \cancel{\text{kPa}}} = 23\ \text{L}$

8. $3.35\ \cancel{\text{atm}} \times \dfrac{101.325\ \text{kPa}}{1\ \cancel{\text{atm}}} = 339.4\ \text{kPa}$

$V = 2.5\ \text{L} \times \dfrac{100\ \cancel{\text{kPa}}}{339.4\ \cancel{\text{kPa}}} = 0.737\ \text{L}$

9. Boyle's law states that as the volume of a fixed mass of gas decreases, the pressure increases proportionately. One application of Boyle's law is in the functioning of our respiratory system. When our diaphragm drops, it decreases the pressure inside our lungs, which causes an increase in volume, drawing air into our lungs.

10. $V = 10\ \text{L} \times \dfrac{1.75 \times 10^4\ \cancel{\text{kPa}}}{101.325\ \cancel{\text{kPa}}} = 1.73 \times 10^3\ \text{L}$

11. As the pressure around the gas sample drops, the gas will push outward and expand until the internal and external pressures are equal.

12. Sara should determine whether the atmospheric pressure has changed. The balloon could be smaller either because of an increase in atmospheric pressure, or because some of the gas has escaped from the balloon.

13. The student must assume the temperature is the same on both days, and that none of the oxygen gas has escaped.

$P = 102.1\ \text{kPa} \times \dfrac{27.3\ \cancel{\text{mL}}}{27.9\ \cancel{\text{mL}}} = 99.9\ \text{kPa}$

14. Water is not "drawn up" into a straw. Atmospheric pressure on the surface of the liquid pushes water up a straw in which a partial vacuum has been created. When the atmospheric pressure becomes higher, it takes a smaller partial vacuum to cause water to rise in the straw.

3.3 Gases and Temperature

Student Textbook pages 113–122

Section Outcomes

In this section, students will:

- perform an investigation to determine the effects of temperature changes on the volume of gases
- convert between Celsius and Kelvin temperature scales
- draw and interpret graphs of experimental data relating temperature to volume

Key Terms

absolute zero
Charles's Law

Chemistry Background

- Absolute degrees of temperature, or kelvins, named after the physicist William Thompson, Lord Kelvin (1824–1907), are measured from absolute zero. When the Centigrade (now Celsius) system was invented, scientists arbitrarily chose the freezing point of water at sea level and atmospheric pressure as their zero point.
- Jacques Charles (1746–1823) found that all gases expanded or contracted by $\frac{1}{273}$ of the volume at 0 °C for each Celsius degree change in temperature. The amount of gas and the pressure of the gas were held constant.
- Charles was better known in his lifetime for inventing (and flying in the maiden flight of) the hydrogen balloon. (The Montgolfier brothers' earlier flight had been in a hot air balloon.)
- Absolute zero was originally defined as the temperature at which molecular motion stops, but quantum physics has changed that definition to the temperature at which molecular motion reaches a minimum. Scientists today can cool substances to within a few billionths of a degree above absolute zero, or –273.15 °C. Such temperatures are measures in units called nanokelvins (1 nK = 10^{-9} K).
- One Celsius degree is equal in magnitude to one kelvin. Many formulas are much cleaner if you start counting degrees from absolute zero, which is why the Kelvin scale is used.

Teaching Strategies

- Have students discuss what their intuition says about the relationship between temperature and volume. They probably have a pretty good qualitative idea of what's going on.
- The idea that absolute zero is a true zero involves some sophisticated thinking. If students compare ratios of temperatures in Celsius degrees they will be quite different than the ratios of those same temperatures expressed in kelvins (degrees above absolute zero).
- Students should find the algebra of Charles's law relatively easy going, as long as they remember to convert to absolute degrees. Proportions only work if both variables compared begin with the real, or absolute, zero.
- When students interpret the data from the graph they produce in Investigation 3.B, they should have a fairly easy time interpreting the linear result. However, there are a few subtle points to be made. Students need to know that the pressure of the gas inside their pipettes is at 1 atm throughout this experiment. They also need to see that proportions don't work with 0 °C but do work with 0 K.
- The algebraic work should go a little more quickly after the Practice Problems in Section 3.2. Always stress that students must use absolute degrees in this work. .
- When discussing Figure 3.14 on page 116, tell students that when these types of plots are done with several *types* of gases, they still produce graphs with *x*-intercepts near absolute zero.
- Overhead masters have been prepared for this section. You will find them with the Chapter 3 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.
  Number (Type) Title
  3.3.2 (OH) The Celsius and Kelvin Scales
  3.3.4 (OH) Charles's Law and the Motion of Molecules
  3.3.5 (AST) Gas Pressure, Temperature and Volume Quiz
  3.3.5A (ANS) Gas Pressure, Temperature and Volume Answer Key

Investigation 3.B: The Relationship between Temperature and Volume of a Gas

Student Textbook pages 114–115

Purpose

Students find a relationship between the temperature of a gas and its volume, when held at constant pressure.

Outcomes

- 20–B1.2s
- 20–B1.3s
- 20–B1.2sts
- ICT F1–4.2
- AI–NS2
- ICT C6–4.3
- PR–NS20
- ICT C6–4.2
- PR–NS3

Advance Preparation

When to Begin	What to Do
1 day before	■ Collect the pipettes and other equipment. ■ Photocopy **BLM 3.3.1 (HAND) Investigation 3.B: The Relationship between Temperature and Volume of a Gas.**

Materials
■ scissors ■ rubber bands ■ ice ■ markers ■ coloured water ■ plastic pipettes ■ ruler ■ beakers ■ thermometers ■ hot plates

Time Required

45 – 60 minutes to gather data

Helpful Tips

- A good way to get the slug of water into the pipette and placed where you want it is to hold the pipette almost horizontally and bring the small end to the water tap. Briefly contacting the water will put a small slug into the pipette. With both ends open, tilting the pipette will allow the slug to move back and forth. Placing your thumb at the far end of the pipette will prevent the slug from moving any farther while you seal up the pipette.
- It may be easier to use a hot glue gun to seal up the end. Let the glue cool completely. The glue will easily stand the 60 °C temperature of the hot water.
- The students need the ice water. They want as big a temperature change as they can get in order to have the graph produce a value close to –273 °C for absolute zero. If you have a beaker of salt, ice, and water at a separate station, students can get a temperature as low as –15 °C too.
- Tell students to turn hotplates on at medium before starting Step 1 of the Procedure. Hotplates will then be ready for use when needed.
- When students draw the water into the pipette, there should be 30–40 mm of air below the coloured water plug to allow the students to collect sufficient data in the lab.
- Use a lit splint to heat the open end of the pipette. Use the pointed end of a scoopula on the open end of the pipette to press down firmly which will seal the pipette. The teacher should practice and demonstrate this technique before having students attempt to seal their pipettes.

- Students will find it easier to attach the pipette to the ruler or measuring card if the entire bulb is cut away from the pipette.
- A laminated (waterproof) card with line on it can be used for easier reading of the volume measurements.
- Tape may be more successful to attach the pipette to the ruler or card.
- Ensure that the bottom of coloured water plug is below water level in order to get accurate readings from temperature change.
- If readings appear off, have students check that pipette is still sealed.
- Students may find it easier to add another column to their table labelled "Actual Reading." Students may have difficulty reading data from volume measurement and then attempting to remember whether they have subtracted the 10 mm mark level. Alternatively, remind students to subtract from the 10 mm initial mark level.
- Use **BLM 3.3.1 (HAND) Investigation 3.B: The Relationship between Temperature and Volume of a Gas** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 3.3.1A (ANS) Investigation 3.B: The Relationship between Temperature and Volume of a Gas Answer Key.**
  Sample Data is shown below:
  Table #1 – Data on the Effect of Temperature on the Volume of a Gas

	Temperature (°C)	Actual reading (mm)	V (mm X A)
Initial Reading	21	41	31
After 5 min in Ice water	8	39.5	29.5
	20	40.8	30.8
	30	42.1	32.1
	40	44	34
	50	47	37
	60	52	42

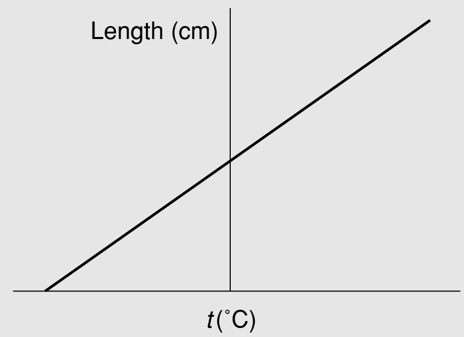
- ***Expected Results*** When students plot the volume versus the temperature of the air in the tube, they will obtain a straight line. The line should extrapolate to (roughly) –273 °C on the x or temperature axis. This temperature is, of course, absolute zero.

Safety Precautions

Be careful not to burn yourself or light the plastic on fire when sealing up the end of the pipette.

Answers to Analysis Questions

1. The manipulated variable is the temperature. The responding variable is the length of the column of gas below the water slug (proportional to volume). Two control variables would be the pressure and cross-sectional area inside the pipette.
2. Graphs should be approximately linear but with some scatter.



3. The *x*-intercepts will vary quite a bit. Ideally, the *x*-intercepts should be between –300 °C and –250 °C.
4. The data suggest two things. First, the relationship between temperature and volume is linear. Second, if the temperature scale starts with zero at the *x*-intercept, then the relationship is a direct one.
5. Students have not yet learned the concept of Absolute Zero, but may infer that, due to kinetic molecular theory, that there would be a temperature at which the molecules of gas no longer collide with the container and therefore exert no volume.
6. The data may be used to complete Thought Lab 3.1: The Importance of the Kelvin Temperature Scale on page 117 of the student textbook.

Answer to Conclusion Question

7. The volume of gas varies directly with the absolute temperature of the gas. Some students will say, for example, "If you double the absolute temperature, you double the volume." This is not as complete but has the essence of the idea.

Assessment Options

- Collect and assess answers to Analysis and Conclusion questions
- Use Assessment Checklist 2: Laboratory Report or Checklist 3: Performance Task Self-Assessment.

Answers to Questions for Comprehension

Student Textbook page 116

Q5. The Kelvin scale is based on two things: Firstly it starts from absolute zero and secondly, it uses degrees the same size as Celsius degrees.

Q6. A volume of zero is impossible if atoms take up any space (they do). Atoms of an ideal gas have zero volume.

Q7. Absolute zero is a theoretical value determined by extrapolating a volume versus temperature graph.

Q8. 310 K

Q9. –196 °C

Thought Lab 3.1: The Importance of the Kelvin Temperature Scale

Student Textbook page 117

Purpose

Students see for themselves the importance of beginning temperature scales at absolute zero.

Outcomes

- 30–B1.3s
- AI–NS2
- ICT C6–4.3

Advance Preparation

Students need to have completed Investigation 3.B.

Time Required

20–30 minutes

Helpful Tips

- Make sure students have their calculators with them.
- Use **BLM 3.3.3 (HAND) Thought Lab 3.1: The Importance of the Kelvin Temperature Scale** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers to the questions are on **3.3.3A (ANS) Thought Lab 3.1: The Importance of the Kelvin Temperature Scale Answer Key.**

Answers to Analysis Questions

1. These ratios will show a gradual change over time.
2. These ratios should remain relatively constant throughout.
3. A linear relationship is direct if it has a zero *x*-intercept. A direct relationship always has the same constant of proportionality between the variables compared.
4. The *x*-intercept should be fairly close to what we know absolute zero to be.
5. Starting at absolute zero is what turns this linear relationship into a direct one.
6. The volume of a gas varies directly with its temperature, as long as the temperature is measured in absolute degrees.

Assessment Options

- Collect and assess answers to Analysis and Conclusion questions.

Chemistry File: Try This

Student Textbook page 117

When the flask is placed in the hot water bath, the air is heated, leading to an increase in pressure. For best results, place the egg on the Erlenmeyer just after the flask has been heated. Some of the air will escape from around the egg due to this increase in pressure. When the flask and the air inside are cooled, the pressure will decrease due to the drop in temperature. The outside pressure (atmospheric pressure) will be higher than the inside pressure, forcing the egg into the flask.

Answers to Questions for Comprehension

Student Textbook page 118

Q10. $V = mt + b_n$

$V - b_n = mt$

$t = \dfrac{V - b_n}{m}$

Q11. Charles's Law, $V_1/T_1 = V_2/T_2$ is based on the relationship between volume and temperature where the graph passes through the origin. If the temperature is measured using the Celsius temperature scale, the value for the y-intercept, which will change with changing pressure, must be included in the calculations.

Answers to Practice Problems 7–10

Student Textbook page 119

For full solutions, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

7. (a) 300.4 K
(b) 311.0 K
(c) 395.6 K
(d) 248 K
(e) 233 K

8. (a) 100.0 °C
(b) 2 °C
(c) –100 °C
(d) –249.6 °C
(e) 600 °C

9. 0.29 L or 2.9×10^2 mL or

10. No, 3.2 L

Answers to Practice Problems 11–14

Student Textbook page 120

11. 308 K

12. Kelvin temperature is 1.25 times room temperature.

13. 606 °C

14. –214 °C

Answers to Questions for Comprehension

Student Textbook page 121

Q12. A direct proportion exists between two variables if, when one variable increases, the other increases at the same rate. This relationship exists between the volume and temperature (in Kelvins) of a fixed mass of gas. If the Kelvin temperature of a gas is doubled, then the volume will also double (if pressure is constant). An inverse proportion exists between two variables if, when one variable increases, the other decreases at the same rate. This relationship exists between the pressure and volume of a fixed mass of gas. If the pressure of a gas is doubled, then the volume will halve (if temperature is constant).

Q13. Charles's Law is based on a direct proportion between volume and temperature. This relationship only exists with temperatures measured in Kelvins, so temperature must be measured in Kelvins. The reason this relationship exists is because at 0 Kelvins (absolute zero), the volume of any gas will also be zero. The Kelvin temperature scale is based on this fact, while the Celsius scale is based on water. If the Celsius scale is used, then there will be another term in the Charles's law calculations, making the math much more difficult.

Section 3.3 Review Answers

Student Textbook page 122

1. The balloon floats because helium is less dense than the air around it. Above the barbecue the hot air expands, becomes less dense than its surroundings, and rises. This carries enough thermal energy to the balloon that it expands the gas inside, causing the balloon to break.

2. The air inside the tire should be at a high enough pressure that the force inside the walls of the tire is high enough not only to keep the tire hard but to support a quarter of the car's weight. If tires are thumping, the inside pressure isn't high enough, so the tire needs more air.

3. The aerosol can is a closed container with a constant volume. When a gas at constant volume is heated its pressure rises. The danger here is that the pressure inside the can may increase to exert a force stronger than the strength of the can, causing it to explode.

4. The graph shows that the volume of a gas increases as its temperature increases. The *y*-intercept of the graph should be 92 mL. The *x*-intercept of the graph should be –273 °C, demonstrating that in theory, at absolute zero, the volume of an ideal gas is zero. For temperature in Celsius, the equation of this graph, determined by the relationship $y = mx + b$, is $y = 0.34x + 92$.

5. $V = 6.0\ \text{L} \times \dfrac{450\ \text{kPa}}{200\ \text{kPa}} = 14\ \text{L}$

6. $V = 3.9 \times 10^2\ \text{L}$

7. $V_1 = 2.0\ \text{kL}$

$V_2 = ?$

$T_1 = 6.00\ °\text{C} = 279.15\ \text{K}$

$T_2 = 25\ °\text{C} = 298\ \text{K}$

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

$$V_2 = \frac{V_1 T_2}{T_1} = \frac{(2.0\ \text{kL})(298\ \text{K})}{(279.15\ \text{K})} = 2.1\ \text{kL}$$

8. $V_1 = 2.5\ \text{L}$

$V_2 = 2.0\ \text{L}$

$T_1 = 24.2\ °\text{C} = 297.4\ \text{K}$

$T_2 = ?$

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

$$T_2 = \frac{V_2 T_1}{V_1} = \frac{(2.0\ \text{L})(297.4\ \text{K})}{(2.5\ \text{L})} = 237.9\ \text{K}$$

$T\ (\text{in } °\text{C}) = 237.9\ \text{K} - 273.15\ \text{K} = -35\ °\text{C}$

9. $T_1 = 25\ °\text{C} + 273.15 = 298\ \text{K}$; $T_2 = -20\ °\text{C} + 273.15 = 253\ \text{K}$

step 1: $V = 600\ \text{L} \times \dfrac{253\ \text{K}}{298\ \text{K}} = 509\ \text{L}$

step 2: $V = 509\ \text{L} \times \dfrac{P_1}{4P_1} = 1.3 \times 10^2\ \text{L}$

10. As the air inside the balloon heats up, either the pressure inside the balloon must increase, or the air must expand. The pressure inside the balloon remains constant to balance the atmospheric pressure on the outside, so the air must expand. The balloon envelope is fairly rigid when inflated, but the air can escape at the bottom of the balloon. This reduces the density of air inside the balloon making it more buoyant, so that it rises.

11. **(b)** is invalid as there is no direct or indirect relationship between the Celsius temperature and pressure. If, as in **(a)**, the Kelvin temperature of a gas is doubled and the volume is held constant, the pressure will double.

Chapter 3 Review Answers

Student Textbook pages 124–125

1. Boyle's law is illustrated by **(a)**.

2. Charles's law is illustrated by **(e)**.

3. Example b. can be explained by a combination of the two laws.

4. (a) The column of mercury would get gradually shorter as it moved up the mountain. The air pressure outside is getting lower, as the column moves from sea level to a mountain.

5. A straw will not work for drinking water if it is longer than 10.3 m, even when attached to a vacuum pump. In practice, for lengths far less than this, the sides would crush together instead of pulling water up any great distance.

6. Absolute zero is the temperature at which the volume of a gas becomes zero. This cannot really happen in practice but until the temperature gets near absolute zero it is a good approximation. It was originally thought that molecular motion would cease at absolute zero, but today absolute zero is defined as the temperature at which molecular motion is at a minimum.

7. The particles of a gas are much farther apart in the particles of a liquid or gas. Therefore there is less mass in a given volume and hence a lower density.

Answers to Applying Concepts Questions

8. (a) False: the freezing point of water is 0 °C.
   (b) Likely true, since 313 K = 40 °C.
   (c) False; for example, –40 °C is still 233 K.
   (d) False: 310 K = 37 °C, which is normal human body temperature.

9. See answers to question 8.

10. Graph B correctly represents the relationship between the pressure and volume of a fixed mass of gas. Volume is inversely proportional to pressure, so as pressure increases, volume decreases, as shown in graph B. Graph C is incorrect as it does not display an inverse proportion. Only when volume and 1/pressure are graphed should there be a straight line.

Answers to Problem Solving Questions

11. P = 101 kPa × 50 mL / 14 mL = 361 kPa
    = (3.6×10^2 kPa)

12. V = 27 L × 308 K / 293 K = 28.4 L = (28 L)

13. V = 89 kPa × 1.5 L / 101.3 kPa = 1.3 L

14. T = 295 K × 2.8 mL / 10 mL = 83 K

15. The pressure must be multiplied by 5 times to about 38 atm.

16. Let the gas in the tank expand to the pressure in the balloons:
    V = 15 000 kPa × 5 L / 115 kPa = 652 L
    Divide by the volume of one balloon to get:
    652 L / 2 L per balloon = 326 balloons (= 3.3×10^2 balloons)

17. P = 110 kPa × 19 L / 1.0 L = 2090 kPa = (2.1 MPa)

18. P = 1273 K × 5.00 atm / 295 K = 22 atm

19. P = 102.3 kPa / 101.3 kPa = 1.010 atm
    Height of Hg is 1.010 atm × 760 mmHg = 768 mmHg

20. When the volume of air on the right side of the tube is compressed to one third its volume, the mercury on the right will move down (and up the right side) 10 mm. This mercury must be replaced. To compress the volume of the air to one third its original volume, the pressure must be increased three fold. The atomsphere provided one atm of pressure so mercury must provide two more atmospheres of pressure or 2 × 760 mmHg. Therefore, 2 × 763 + 10 = 1530 mmHg.

Answers to Making Connections Questions

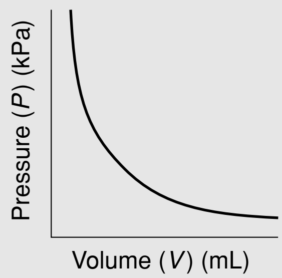
21. (a) As altitude increases, atmospheric pressure decreases. The temperature required to have the vapour pressure equal the atmospheric pressure is lower at higher altitudes as a result.
    (b) Using the data provided, the predicted boiling point would be 90.0 °C.

22. At the higher altitude, the atmospheric density is lower than at sea level. To carry enough oxygen from the lungs to body tissue, more red blood cells are necessary.

23. To efficiently transport gases, they are often transported under pressure. This allows for larger quantities of gas to be shipped, although they must then be shipped under higher pressures, which adds to the safety concerns. To address these safety concerns, a container must ensure that the gas remains contained and any leak would be quickly identified. Since gases expand when heated (which leads to an increase in pressure, which in turn would make a leak more likely and dangerous) containers should be insulated from the heat and made from materials that reflect heat well. The temperature of the gas inside the container should be carefully monitored and temperature should be controlled using refrigeration. Any leak would be identified by a decrease in pressure, so containers should be equipped with very sensitive pressure gauges that would measure any changes in pressure.

24. Experimental Design: Fill the syringe with 10.0 mL of air. Connect the syringe to the tubing and the pressure gauge. Record the initial volume of the air in the syringe (assume the volume of air included in the tubing is negligible). Record the pressure on the pressure gauge. Press on the

plunger of the syringe until the volume reads 8.0 mL. Record the pressure on the pressure gauge. Vary the volume of air in the syringe, recording both the volume of air and the corresponding pressure on the pressure gauge for values from 25.0 mL to 5.0 mL. The relationship obtained should be similar to the graph below:



25. Since the volume of air will vary with temperature, you could build a thermometer using a reservoir of air contained in an Erlenmeyer flask. Thread the glass tubing into a one-holed rubber stopper. Use a pipette bulb to draw up a small amount of coloured water into the glass tubing. Put your finger over the top of the tubing to ensure the water remains trapped. Seal an Erlenmeyer flask with the rubber stopper. The mass of air in the Erlenmeyer/glass tubing is now fixed. Calibrate your thermometer by heating the Erlenmeyer in a water bath and recording the level of the coloured water in the tubing at specific temperatures measured with a thermometer. Since the volume of a gas is not only affected by temperature but also by pressure, an open-ended thermometer such as this one will also be affected by variations in atmospheric pressure.

CHAPTER 4 EXPLORING GAS LAWS

Curriculum Correlation

General Outcome 1: Students will explain molecular behaviour using models of the gaseous state of matter.

	Student Textbook	Assessment Options
Outcomes for Knowledge		
20–B1.1k describe and compare the behaviour of real and ideal gases in terms of kinetic molecular theory	Investigation 4.A: Finding the Molar Mass of a Gas, Section 4.2, pp. 144–145	Investigation 4.A: Finding the Molar Mass of a Gas, Analysis: 3 Conclusion: 6, 7, Section 4.2, pp. 144–145 Chapter 4 Review: 6, 7, 10, p. 152 Chapter 4 Test Unit 2 Review: 1–3, pp. 156–157
20–B1.2k convert between the Celsius and Kelvin temperature scales	Thought Lab 3.1: The Importance of the Kelvin Temperature Scale, Section 3.3, p. 117 Sample Problem: Using Charles's Law to Calculate Volume, Section 3.3, p. 119 Sample Problem: Using Charles's Law to Calculate Temperature, Section 3.3, p. 120 Interpreting the Volume versus Temperature Relationship, Section 3.3, pp. 115-117	Thought Lab 3.1: The Importance of the Kelvin Temperature Scale, Section 3.3, p. 117 Practice Problems: 7, 8, Section 3.3, p. 119 Questions for Comprehension: 8, 9, Section 3.3, p. 116 Chapter 4 Test BLM 3.3.2 The Celsius and Kelvin Scales Unit 2 Review: 1, 13, pp. 156–157
20–B1.3k explain the law of combining gases	Combining Volumes of Gases, Section 4.1, p. 132 Combined Gas Law Calculations, Section 4.1, p. 129 Ideal Gas Law, Section 4.2, pp. 139-140 The Combined Gas Law, Section 4.1, p. 128 Connections: Technology and the Process of Discovery, Section 4.1, p. 131	Practice Problems: 1-6, Section 4.1, p. 130 Practice Problems: 7-9, Section 4.1, p. 132 Questions for Comprehension: 1, 2, Section 4.1, p. 132 Questions for Comprehension: 3, 4, Section 4.1, pp. 135-136 Chapter 4 Review: 5, 26, 30, 33, p. 152 Chapter 4 Test BLM 4.1.1 Combined Gas Law Problems (1) BLM 4.1.2 Combined Gas Law Problems (2) Unit 2 Review: 10, 19, 24, 29, pp. 156–157
20–B1.4k illustrate how Boyle's and Charles's laws, individually and combined, are related to the ideal gas law ($PV = nRT$) ■ express pressure using units of kilopascals, atmospheres and millimetres of mercury ■ perform calculations based on the gas laws under STP, SATP and other defined conditions.	The Combined Gas Law, Section 4.1, p. 128 Ideal Gas Law, Section 4.2, p. 139	Practice Problems: 10-16, Section 4.2, p. 141 Practice Problems: 17, Section 4.2, p. 142 Questions for Comprehension: 6, 7, Section 4.2, p. 141 Section 4.2 Review: 1, p. 150 Chapter 4 Review: 12, 16, 18-34, p. 152 Chapter 4 Test Unit 2 Review: 5–9, 11, 12, 14–26, pp. 156–157

	Student Textbook	Assessment Options
Outcomes for Science, Technology and Society (Emphasis on the nature of science)		
20–B1.1sts explain that science provides a conceptual and theoretical basis for predicting, interpreting and explaining natural and technological phenomena by ■ *describing how the development of technologies capable of precise measurements of temperature and pressure led to a better understanding of gases and the formulation of the gas laws, e.g., thermocouples, thermistors, Bourdon gauges*	Using the Properties of Gases – Gas Technologies, Section 3.1, pp. 98-99 Atmospheric Pressure, Section 3.2, p. 102 Gases and Pressure, Gas Pressure and Volume, Gases and Temperature, Section 3.2, pp. 102–105 Discovery of Atmospheric Pressure, Section 3.2, pp. 102-103	Connections: Technology and the Development of Barometers: 1, 2, Section 3.2, p. 108 Questions for Comprehension: 2, Section 3.2, p. 104 Chapter 3 Review: 1-7, 21-25, pp. 124-125 BLM 3.1.4 Research SCUBA Chapter 4 Review: 35-37, pp. 152-153
20–B1.2sts explain that the goal of science is knowledge about the natural world by ■ *describing examples of natural phenomena and processes and products that illustrate the properties of gases, e.g., breathing, diffusion, weather, hot air balloons, scuba diving equipment, automobile air bags, gas turbines, internal combustion engines.*	Chapter 3 Launch Lab: Balloon in a Bottle, p. 97 Using the Properties of Gases – Gas Technologies, Section 3.1, pp. 98-99 Atmospheric Pressure, Section 3.2, p. 102 Gases and Pressure, Gas Pressure and Volume, Gases and Temperature, Section 3.2, pp. 102–105 Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas, Section 3.2, pp. 106–107 Investigation 3.B: The Relationship between Temperature and Volume of a Gas, Section 3.3, pp. 114–115 Discovery of Atmospheric Pressure, Section 3.2, pp. 102-103	Chapter 3 Launch Lab: Balloon in a Bottle, Analysis: 3, p. 97 Investigation 3.A: The Relationship between the Pressure on and the Volume of a Gas, Analysis: 1–5, Conclusion: 6, Section 3.2, pp. 106–107 Investigation 3.B: The Relationship between Temperature and Volume of a Gas, Conclusion: 7, Section 3.3, pp. 114–115 Questions for Comprehension: 2, Section 3.2, p. 104 Chapter 3 Review: 1-7, 21-25, pp. 124-125 BLM 3.1.4 Research SCUBA Chapter 4 Review: 35-37, pp. 152-153
Initiating and Planning		
20–B1.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by ■ stating hypotheses and making predictions based on information about the pressure, temperature and volume of a gas ■ describing procedures for safe handling, storage and disposal of materials used in the laboratory, with reference to WHMIS and consumer product labelling information ■ *designing an experiment to illustrate Boyle's and/or Charles's gas laws* ■ *designing an investigation to determine the universal gas constant* (R) *or absolute zero.*	Chapter 4 Launch Lab: Changing Gas Temperature, Pressure, and Volume at the Same Time, p. 127	Chapter 4 Launch Lab: Changing Gas Temperature, Pressure, and Volume at the Same Time, Analysis: 1–3, p. 127

	Student Textbook	Assessment Options
Performing and Recording		
20–B1.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by ■ performing an experiment, in which variables are identified and controlled, to illustrate the gas laws ■ *using thermometers, balances and other measuring devices effectively to collect data on gases* ■ *using library and electronic research tools to collect information on real and ideal gases and applications of gases, e.g., hot air and weather balloons* ■ *performing an investigation to determine molar mass from gaseous volume*.	Chapter 4 Launch Lab: Changing Gas Temperature, Pressure, and Volume at the Same Time, p. 127 Investigation 4.A: Finding the Molar Mass of a Gas, Section 4.2, pp. 144–145	Chapter 4 Launch Lab: Changing Gas Temperature, Pressure, and Volume at the Same Time, Analysis: 1–3, p. 127 Investigation 4.A: Finding the Molar Mass of a Gas, Analysis: 1–4, Conclusion: 5–7, Section 4.2, pp. 144–145
Analyzing and Interpreting		
20–B1.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by ■ drawing and interpreting graphs of experimental data that relate pressure and temperature to gas volume ■ *identifying the limitations of measurement* ■ *identifying a gas based on an analysis of experimental data*.	Thought Lab 4.1: Molar Volumes of Gases, p. 137	Thought Lab 4.1: Molar Volumes of Gases, Analysis: 1–4, p. 137 Chapter 4 Review: 34, p. 153 BLM 4.1.6 Molar Volumes and the Law of Combining Volumes Problems BLM 4.2.1 Ideal Gas Law Problems Unit 2 Review: 12, 25, pp. 156–157
Communication and Teamwork		
20–B1.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by ■ communicating questions, ideas and intentions and receiving, interpreting, understanding, supporting and responding to the ideas of others during group work to collect data on gases ■ using appropriate International System of Units (SI) notation, fundamental and derived units and significant digits when performing calculations related to the gas laws ■ *preparing a group presentation, using multimedia, to illustrate how pressure, temperature, volume and amount of a gas determine* R*, the universal gas constant.*	Thought Lab 4.1: Molar Volumes of Gases, p. 137 Investigation 4.A: Finding the Molar Mass of a Gas, Analysis: 3 Conclusion: 6, 7, Section 4.2, pp. 144–145	Thought Lab 4.1: Molar Volumes of Gases, Analysis: 1–4, p. 137 Investigation 4.A: Finding the Molar Mass of a Gas, Analysis: 3 Conclusion: 6, 7, Section 4.2, pp. 144–145 BLM 4.2.4 Collecting a Gas in the Laboratory

Chapter 4

Exploring Gas Laws

Student Textbook pages 126–153

Chapter Concepts

Section 4.1 The Combined Gas Law

- Gases can undergo changes in temperature, pressure, and volume simultaneously.
- The combined gas law summarizes a combination of temperature, pressure, and volume changes.
- The volumes of gaseous reactants and products in chemical reactions are in whole-number ratios.
- Equal volumes of gases at the same temperature and pressure contain equal number of molecules (or moles of molecules).
- Molar volume is the same for all gases under the same conditions.

Section 4.2 The Ideal Gas Law

- The ideal gas law includes Avogadro's law and the combined gas laws.
- The universal gas constant allows you to use the ideal gas law for any set of conditions.
- You can find the molar mass of a substance by applying the ideal gas law.
- Real gases approximate ideality at standard temperature and pressure.
- The behaviour of real gases diverges from ideality at high pressures and at low temperatures.

Common Misconceptions

- Students should do fairly well with this chapter. Their problems will not be misconceptions so much as difficulty grasping the concepts. This is especially true with Avogadro's law and with the idea of partial pressure. Students tend to want to memorize formulas, and from this viewpoint the values (and units) of Avogadro's number, 6.022×10^{23}, and the universal gas constant, $R = 8.314$ kPa • L/mol • K, are rather offputting. If, however, students are given the support and time necessary to grasp the basic concepts securely, the calculation process becomes much more straightforward because the formulas are then mostly common sense.
- There will likely be some confusion with units. Students need to know when specific units are needed (such as when using the universal gas constant) and when any appropriate unit will do.

Helpful Resources

Books and Journal Articles

- Hornbein, T.F., and Schoene, R.B. (2001). *High altitude: an exploration of human adaptation.* New York: Marcel Dekker.

Web Sites

Web resources related to the gas laws can be found at **www.albertachemistry.ca**. Go to the Online Learning Centre, and log on to the Instructor Edition. Choose Teacher Web Links.

List of BLMs

Blackline masters (BLMs) have been prepared to support the material in this chapter. The BLMs are either for assessment (AST); use as overheads (OH); use as handouts (HAND), in particular to support activities; or to supply answers (ANS) for assessment or handouts. The BLMs are in digital form, stored on the CD-ROM that accompanies this Teacher's Resource or on the web site at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs. They can be modified to suit the needs of your students.

Number (Type) Title

4.0.1 (HAND) Launch Lab: Changing Gas Temperature, Pressure, and Volume at the Same Time
4.0.1A (ANS) Launch Lab: Changing Gas Temperature, Pressure, and Volume at the Same Time Answer Key

4.1.1 (AST) Combined Gas Law Problems (1)
4.1.1A (ANS) Combined Gas Law (1) Answer Key
4.1.2 (AST) Combined Gas Law Problems (2)
4.1.2A (ANS) Combined Gas Law (2) Answer Key
4.1.3 (OH) Avogadro's Law, Volume Ratios and Balance Coefficients
4.1.4 (OH) Avogadro's Law
4.1.5 (OH) Standard Conditions of Temperature and Pressure
4.1.6 (AST) Molar Volumes and the Law of Combining Volumes Problems
4.1.6A (ANS) Molar Volumes and the Law of Combining Volumes Answer Key
4.1.7 (HAND) Thought Lab 4.1: Molar Volumes of Gases
4.1.7A (ANS) Thought Lab 4.1: Molar Volumes of Gases Answer Key

4.2.1 (AST) Ideal Gas Law Problems
4.2.1A (ANS) Ideal Gas Law Answer Key
4.2.2 (AST) Ideal Gas Law and Gas Density Problems
4.2.2A (ANS) Ideal Gas Law and Gas Density Answer Key
4.2.3 (OH) Dalton's Law of Partial Pressures
4.2.4 (OH) Collecting a Gas in the Laboratory
4.2.5 (OH) Partial Pressure of Water Vapour
4.2.6 (AST) Dalton's Law of Partial Pressures Problems
4.2.6A (ANS) Dalton's Law of Partial Pressures Answer Key
4.2.7 (HAND) Investigation 4.A: Finding the Molar Mass of a Gas

4.2.7A (ANS) Investigation 4.A: Finding the Molar Mass of a Gas Answer Key
4.2.8 (OH) High Pressure Effects on the Behaviour of Gases
4.2.9 (HAND) Investigation 4.B: Finding the Value of the Universal Gas Constant, *R*
4.2.9A (ANS) Investigation 4.B: Finding the Value of the Universal Gas Constant, *R* Answer Key
4.3.1 (AST) Chapter 4 Test
4.3.1A (ANS) Chapter 4 Test Answer Key

Using the Chapter 4 Opener

Student Textbook pages 126–127

Teaching Strategies

- Have students discuss why they do not feel the tremendous pressure that the atmosphere is exerting on them. Remind them that it is when there is a difference in pressure inside and outside a container that we notice the effects of pressure.
- Have students think about designing a submarine and a space capsule. How would the engineers have to design for pressure differences in these vehicles?
- Ask students to brainstorm how a suction cup works.

Launch Lab — Changing Gas Temperature, Pressure, and Volume at the Same Time

Student Textbook page 127

Purpose

Students observe the effects of sudden change of temperature and pressure on a gas.

Outcomes

- 20–B1.1s
- 20–B1.2s

Advance Preparation

When to Begin	What to Do
1 week before	■ Ask students to bring empty soft drink cans to class.
1 day before	■ Organize the equipment in the lab. ■ Prepare or obtain ice. ■ Photocopy **BLM 4.0.1 (HAND) Launch Lab: Changing Gas Temperature, Pressure, and Volume at the Same Time.**

Materials
■ beaker ■ tongs ■ hot plates ■ soft drink cans ■ ice ■ 10 mL graduated cylinder

Time Required

30 minutes

Helpful Tips

- This is an absolutely fantastic activity. If at all possible, let the students perform the lab in groups.
- The colder the water, the more easily the cans will crush down when placed in it.
- The easiest way to do this activity is to have the students perform the experiment in a chemistry laboratory. In a laboratory, each group of students can then use the sinks rather than any containers of ice water that you would have to provide them with. The sinks do not need to be deep and need only a handful of ice cubes each.
- Tell the students to wait until they are sure that they see steam coming from the can before they transfer the can to the water. Once they see the steam, they should make the transfer quickly, as time is of the essence.
- Use **BLM 4.0.1 (HAND) Launch Lab: Changing Gas Temperature, Pressure, and Volume at the Same Time** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. Answers are on **BLM 4.0.1A (ANS) Launch Lab: Changing Gas Temperature, Pressure, and Volume at the Same Time Answer Key.**
- ***Expected Results:*** As the water in the can boils and vapourized, it will expel the air out of the can. When the can is inverted and the top is inserted into the cold water, the water vapour inside the can will condense and create a partial vacuum. No air will be able to enter the can since the hole is under water. The atmospheric pressure will cause the can to collapse.

Safety Precautions

The biggest danger is boiling water. Grasp the can firmly with the tongs before making the transfer, or handle the cans with ceramic gloves.

Answers to Analysis Questions

1. The water molecules moved faster and faster as the water was heated. At 100 °C they moved into the space above the liquid water as the water boiled.
2. The steam displaced all the air that was in the can.
3. When the can was transferred to the cold water, very little, if any air, was able to enter the can. When the can

went into the water, the water sealed the can, preventing any air from entering, and condensed the steam. The can was left with a near vacuum inside. Air pressure exerts a force equal to the weight of 1 kg on every square centimetre of outside surface of the can—a force that easily crushes the can.

Assessment options

- Collect and assess answers to Analysis questions.

4.1 The Combined Gas Law

Student Textbook pages 128–138

Section Outcomes

Students will:
- solve problems using the combined gas law
- use appropriate SI notation, fundamental and derived units, and significant digits when performing gas law calculations
- predict volumes of gaseous reactants and products in chemical reactions
- calculate the molar volume of gases at STP and SATP

Key Terms

law of combining volumes
Avogadro's law
molar volume
standard temperature and pressure (STP)
standard ambient temperature and pressure (SATP)

Chemistry Background

- The method of combining the relationships in Boyle's law, Charles's law, and Gay-Lussac's law into one combined gas law is standard mathematics. In fact, it takes only one more step from there to the ideal gas law itself. Once you have the ideal gas law in front of you, it is easy to see that all the other gas laws are just special cases within it.
- Bourdon pressure gauges are great things to have around. They are very accurate and can measure pressures at temperatures where simpler equipment is incapable of doing so.
- Thermistors are made of a metal that changes resistance with temperature so that an electric current sent through one can be converted easily to a temperature. They can be made to be extremely small and light, and are used to measure temperatures in difficult places, such as high above Earth in the instrument package of a weather balloon. (Hygristors work in much the same way, except the metal changes resistance with humidity. Weather balloons carry hygristors for relative humidity measurements.)
- Thermocouples work using the Seebeck effect, where two different metals within the thermocouple are joined at two points and produce a voltage between them, the proportion of which depends upon the temperature of the junctions. Thermocouples can also be found in applications like oven thermometers. General-purpose thermocouples with a temperature range of –200 °C to 1200 °C can be built into probes such as the temperature sensor in your oven.
- The discovery that gases combine in simple volumetric ratios when they are formed was a surprise to the scientists who discovered it. Today, it is not seen as a big surprise at all. The ratios of the volumes are the same as the molar ratios in the chemical reaction that produces the gases. The thing we know that the scientists who discovered the phenomenon did not know is Avogadro's law: equal volumes of any gas at the same temperature and pressure have the same number of particles.
- Amadeo Avogadro proposed the idea of a constant number of particles in any given mole, Avogadro's number, in 1811. It was 50 years before anyone could calculate what this number actually is. A German chemist, J. Loschmidt, used the mathematics that James Clerk Maxwell and Ludwig Boltzman had devised, in conjunction with the Kinetic molecular theory, and calculated the first approximation of Avogadro's number. Jean Baptiste Perrin did work on Brownian motion in 1909 that led to another, more accurate measurement of this number.

Teaching Strategies

- **BLM 4.1.1(AST) Combined Gas Law Problems (1)** is a worksheet on the combined gas law. Many students will need to do more problems than those in the text.
- This is a good time to have the students do some work with ratios and proportions. The concept that gases A and B react to form gas C with whole-number volume ratios $x:y:z$ can be extended to any volume of one of the gases, as long as the ratios are kept constant.
- This might be a good time to ask students if they have any ideas about why these ratios work this way. From their modern perspective this may be an easier concept than instructors tend to think.
- Use the pictures in the text and any other visuals you may have to help present this concept. Note that the details of the gas particles are insignificant as long as the particles are far apart, as they are in an ideal gas.
- Have the students write a paragraph explaining how Avogadro's law explains the law of combining volumes.
- Do a few practice problems on the board and have the students do a few problems together before working on a problem set on their own.
- **BLM 4.1.2 (AST) Combined Gas Law Problems (2)** provides more practice working with the law of combining volumes.
- A number of overhead masters and quizzes have been prepared for this section. You will find them with the Chapter 4 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

Number (Type) Title
4.1.1 (AST) Combined Gas Law Problems (1)
4.1.1A (ANS) Combined Gas Law (1) Answer Key
4.1.2 (AST) Combined Gas Law Problems (2)
4.1.2A (ANS) Combined Gas Law (2) Answer Key
4.1.3 (OH) Avogadro's Law, Volume Ratios and Balance Coefficients
4.1.4 (OH) Avogadro's Law
4.1.5 (OH) Standard Conditions of Temperature and Pressure
4.1.6 (AST) Molar Volumes and the Law of Combining Volumes Problems
4.1.6A (ANS) Molar Volumes and the Law of Combining Volumes Answer Key

Answers to Practice Problems 1–6

Student Textbook page 130

For full solutions, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

1. 586 mL
2. 92 mL
3. 14 mL
4. 1.2 atm
5. 84 °C
6. 56.9 °C

Connections (Nature of Science): Technology and the Process of Discovery

Student Textbook page 131

Teaching Strategies

- The *Concise Dictionary of Scientific Biography* (Charles Scribner's Sons, 2nd edition, 2000; for J. Loschmidt, Jean Baptiste Perrin, and Albert Einstein) and the entry on Avogadro's constant in the *McGraw-Hill Concise Encyclopedia of Science and Technology* (McGraw-Hill Professional, 5th edition, 2004) are excellent sources for information on Avogadro's number.

Connections Answers

1. A good place to start is a web site on how things work. Web links to resources related to thermistors and other relevant topics can be found at **www.albertachemistry.ca**, Online Learning Centre, Student Edition Students will be surprised at the number of familiar things that use thermistors. A search on thermocouples will produce similar results.
2. The best modern values for what we now call Avogadro's number or (Avogadro's constant) are the result of x-ray diffraction measurement of lattice distances in metals and salts. The value accepted today is $6.022\ 141\ 99 \times 10^{23}$.
3. When students respond to a question like this, let them set their creative sides loose and encourage their ideas, even the "way out" ones. Have them write how the information gathered with the new instrument will give them the insight they need for the phenomenon they are investigating.

Answers to Practice Problems 7–9

Student Textbook page 133

For full solutions, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Editions, Full Solutions

7. 250 mL
8. 5.0 mL
9. 700 mL

Answers to Questions for Comprehension

Student Textbook page 133

Q1. The combined gas law combines Boyle's law and Charles's law.

Q2. The law of combining volumes applies to chemical reactions involving gases.

Chemistry File: Try This

Student Textbook page 133

These calculations are based on whole-number masses for the atoms involved.

- 88.9 g of oxygen, 11.1 g of hydrogen in 100 g of water
- $\frac{88.9}{11.1} = 8.00$ times as much oxygen
- 94.1 g of oxygen, 5.88 g of hydrogen in 100 g of hydrogen peroxide
- $\frac{94.1}{5.88} = 16.0$ times as much oxygen
- The ratio of oxygen to hydrogen in water is double that of the ratio in hydrogen peroxide. They are both small whole-number ratios, however.

Answers to Questions for Comprehension

Student Textbook page 135–136

Q3. Avogadro's law states that equal volumes of all ideal gases at the same temperature and pressure contain the same number of molecules. That does not mean that they have the same mass. Scientists had to separate the concepts of ratios of volumes and ratios of mass. They are not directly related, only related through molar mass.

Q4. According to Avogadro's law, equal volumes of gases as the same temperature and pressure will contain the same number of molecules. Therefore, the volume of nitrogen at that temperature and pressure will also be 29 L.

Q5. Since gas volumes are affected by temperature and pressure, it allows scientists to communicate information about gas volumes at these convenient temperatures.

Thought Lab 4.1: Molar Volumes of Gases

Student Textbook page 137

Purpose

Students practise finding the molar volumes of gases.

Outcomes

- 20–B1.3s
- 20–B1.4s

Advance Preparation

None

Time Required

20 – 30 minutes

Helpful Tips

- The lab should go fairly smoothly for students as long as they have seen enough example problems first.
- Use **BLM 4.1.7 (HAND) Thought Lab 4.1: Molar Volumes of Gases** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. Answers are on **BLM 4.1.7A (ANS) Thought Lab 4.1: Molar Volumes of Gases Answer Key.**

Answers to Procedure Questions

Three Gases at 296 K and 98.7 kPa

Gas	Carbon dioxide	Oxygen	Methane
Volume of gas (*V*)	150 mL	150 mL	150 mL
Mass of empty syringe	25.08 g	25.08 g	25.08 g
Mass of gas + syringe	25.34 g	25.27 g	25.18 g
Mass of gas (*m*)	0.26 g	0.19 g	0.10 g
Molar mass of the gas (*M*)	44.01 g/mol	32.00 g/mol	16.05 g/mol
Number of moles of gas ($n = \frac{m}{M}$)	0.005 91 mol	0.005 94 mol	0.006 23 mol
Calculations for STP			
Volume of gas at STP (273.15 K and 101.325 kPa)	135 mL	135 mL	135 mL
Molar Volume at STP $= \frac{V}{n}$	22.8 L/mol	22.7 L/mol	21.6 L/mol
Calculations for SATP			
Volume of gas at SATP (298.15 K and 100 kPa)	149 mL	149 mL	149 mL
Molar Volume at SATP $= \frac{V}{n}$	25.3 L/mol	25.1 L/mol	23.9 L/mol

Answers to Analysis Questions

1. The three molar volumes are almost equal to one another.
2. CO_2, 2%; O_2, 1%; CH_4, 4%
3. The three molar volumes are almost equal to one another.
4. CO_2, 2%; O_2, 1%; CH_4, 4%

Assessment Options

- Collect and assess answers to Analysis questions.

Section 4.1 Review Answers

Student Textbook page 138

1. As the gas is heated, it expands and some of the gas particles leave the container.
2. She probably heated the can too long. The water boiled away, so the can was full of air when she transferred it to the cold water. A vacuum does not form, and the can does not crush. (It would, however, compress somewhat as the air in the can cools.)
3. Hydrogen : chlorine : hydrogen chloride = 1 : 1 : 2. This comes from the balanced chemical reaction.
4. 6.98 g / 70.90 g/mol = 0.0984 mol

   22.4 L/mol x 0.0984 mol = 2.21 L
5. The ratio of hydrogen gas water vapour is 1 to 1. You make 2.3 L of water vapour.
6. $P = 60\text{ mL} \times 100\text{ kPa} \times 328.15\text{ K} /(120\text{ mL} \times 298.15\text{ K}) = 55\text{ kPa}$
7. This describes SATP so the answer should be 24.8 L/mol. Calculations with the data give:

   $V = 2.27\text{ L} \times 101.325\text{ kPa} \times 298.15\text{ K} /(100\text{ kPa} \times 273.15\text{ K}) = 2.51\text{ L}$

   The amount of gas is 6.98 g / 35.45 g/mol = 0.197 mol

   Molar volume is 2.51 L / 0.197 mol = 25.5 L/mol
8. $T = 110\text{ kPa} \times 24\text{ mL} \times 273\text{ K} / (101.3\text{ kPa} \times 48\text{ mL}) = 1.5 \times 10^2\text{ K} (-1.3 \times 10^2\text{ °C})$
9. $V = 100.8\text{ kPa} \times 4.2\text{ L} \times 248\text{ K} / (271\text{ K} \times 103\text{ kPa}) = 3.8\text{ L}$
10. If you are looking for the relationship between molar volume and pressure then you have to control the temperature. The manipulated variable is the pressure and the responding variable is the molar volume. Conversely, if you are looking for the relationship between molar

volume and temperature, then control the pressure. The manipulated variable is the temperature and the responding variable is the molar volume. This is a good exercise for a spreadsheet solution. Reading across the rows works for the pressure-molar volume relationship. Reading down the columns works for the temperature-molar volume ratio. Charting these numbers as a bar chart or line graph would work just fine. If the students had coloured diagrams similar to Figures 4.2, 4.3, and 4.4, that would give them what they need to do the presentation.

11. As a balloon rises in the atmosphere, it will be subjected to a decrease in pressure (atmospheric) and a decrease in temperature. The decreased pressure will lead to an increase in the balloon's volume since pressure and volume are inversely proportional. The decrease in temperature will lead to a decrease in volume since volume and temperature are directly proportional. Whether the balloon expands (and perhaps eventually pops) or gets smaller will depend on whether the pressure decreases at a greater or lesser rate than the Kelvin temperature decreases. If the temperature decreases at a faster rate, then the balloon will shrink in size; if the pressure decreases at a faster rate, then the balloon's volume will increase. In reality, balloons will increase in size and eventually pop. Weather and other instrument carrying balloons are designed to release some of the trapped gases when the difference in pressure becomes too great instead of popping violently.

4.2 Ideal Gas Law

Student Textbook pages 139–150

Section Outcomes

In this section, students will:

- explain Boyle's law, Charles's law, and combined gas laws and their relationship to the ideal gas law
- solve problems based on the ideal gas law
- determine molar mass from gaseous volume
- describe and compare the behaviour of ideal gases and real gases
- design an investigation to determine the universal gas constant, *R*

Key Terms

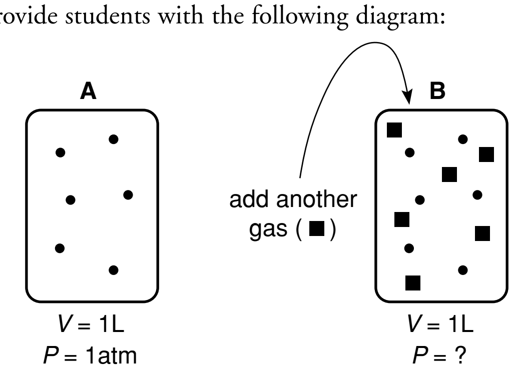
ideal gas law
partial pressure
Dalton's law of partial pressures

Chemistry Background

- It is worth noting that the product of a kilopascal and a litre is equal to a joule! (Measuring pressure in pascals and volume in cubic metres works just as well.) The universal gas constant, *R*, is 8.314 J/mol • K, and equals the energy that one mole of any gas has for each degree of temperature above absolute zero.
- Because gases are totally miscible with one another, adding them together makes the pressure of the mixture equal to the sum of the pressures of the individual gases. This idea of partial pressures has all kinds of applications. In the early days of space travel, U.S. astronauts operated in a pure oxygen environment that was at one-third atmospheric pressure. This made the partial pressure of oxygen for the astronauts close enough to what they were used to on Earth that they could breathe pure oxygen.
- When gases are collected by downward displacement of water, some of the water evaporates into the space with the gas. This vapour pressure of water has its own partial pressure, which adds to the total pressure of the gas above the water and needs to be accounted for in experimental work. This point is made clear in the two investigations.

Teaching Strategies

- Show students the derivation of the ideal gas law. Work through several examples with the students before having them work on a set of practice problems. **BLM 4.2.1 (AST) Ideal Gas Law Problems** has a set of practice problems.
- Partial pressure is a tricky concept. It seems simple but may be seen by many students as a confusing complication. It's a good idea to rely on diagrams to help get this concept across.
- Before students do the laboratory activities, show a demonstration of the downward displacement of water. Drop half an Alka-Seltzer® tablet into the water and place a graduated cylinder over the top of it. Show students how to guarantee that the pressure inside the cylinder is the same as the air pressure in the room.
- The ideal gas law puts everything together in one equation. The big difference in working with this formula, compared to all the other gas laws, is in the way units are handled. The other gas laws are proportions, so any unit of pressure, volume, or absolute temperature works as long as students are consistent on both sides of the equal sign. With the ideal gas law, pressure is measured in kilopascals, volume in litres, temperature in kelvins, and amount in moles. This makes the universal gas constant $R = 8.314$ kPa • L/mol • K.
- Provide students with the following diagram:



Refer to the diagram and ask students what will happen to the pressure inside the container if another gas is added. (There will be a greater chance for collision with the walls of the container and the pressure will increase. If the same number of particles is added, the pressure should double in B. The total pressure of a gaseous system is equal to the sums of the individual gas pressures that make up the system.)

- A number of overhead masters and quizzes have been prepared for this section. You will find them with the Chapter 4 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Editions, BLMs.
  Number (Type) Title
  4.2.1 (AST) Ideal Gas Law Problems
  4.2.1A (ANS) Ideal Gas Law Answer Key
  4.2.2 (AST) Ideal Gas Law and Gas Density Problems
  4.2.2A (ANS) Ideal Gas Law and Gas Density Answer Key
  4.2.3 (OH) Dalton's Law of Partial Pressures
  4.2.4 (OH) Collecting a Gas in the Laboratory
  4.2.5 (OH) Partial Pressure of Water Vapour
  4.2.6 (AST) Dalton's Law of Partial Pressures Problems
  4.2.6A (ANS) Dalton's Law of Partial Pressures Answer Key
  4.2.8 (OH) High Pressure Effects on the Behaviour of Gases

Answers to Practice Problems 10–16

Student Textbook page 141

For full solutions, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Editions, Full Solutions.

10. 118 kPa

11. 1.4×10^2 L

12. 1.01×10^{-3} mol

13. 2.8 L

14. 3.0×10^5 K

15. 166 °C

16. 38.0 g/mol

Answers to Questions for Comprehension

Student Textbook page 141

Q6. To solve for the universal gas constant, start with molar volume at STP.

$n = 1.00$ mol

$P = 101.325$ kPa

$T = 273.15$ K

$V = 22.4$ L

$R = ?$

$PV = nRT$

$$R = \frac{PV}{nT}$$

$$= \frac{(101.325 \text{ kPa})(22.4 \text{ L})}{(1.00 \text{ mol})(273.15 \text{ K})}$$

$$= 8.31 \frac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}$$

Q7. If you use 8.314 kPa•L/mol•K as the universal gas constant, then you must use matching units so they will cancel.

Answers to Practice Problems 17–19

Student Textbook page 142

For full solutions, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Editions, Full Solutions.

17. 1.78 g/L

18. 0.17 g/L

19. 97.6 kPa

Answers to Questions for Comprehension

Student Textbook page 144

Q8. If you ignore all other gases in the atmosphere, the partial pressure of oxygen is the difference between the total pressure (102 kPa) and the pressure of nitrogen gas (71 kPa) or 102 kPa – 71 kPa = 31 kPa. On a humid day, if the total pressure remained at 102 kPa, the partial pressures of nitrogen and oxygen gases would be lower because the total pressure would include the partial pressure exerted by water vapour.

Q9. Two factors that must be considered when collecting gas using water displacement are: the possibility that some of the gas will dissolve in the water and the possibility that the pressure of the gas collected is affected by the partial pressure of water vapour.

Q10. The pressure of the "dry" hydrogen is the total pressure of the gas collected minus the vapour pressure of water at that temperature.
P_{H_2} = 99.8 kPa – 2.33 kPa = 97.5 kPa.

Investigation 4.A: Finding the Molar Mass of a Gas

Student Textbook page 144–145

Purpose

Students use the ideal gas law to measure the molar volume of a gas.

Outcomes

- 20–B1.4k
- 20–B1.2s
- 20–B1.4s
- ICT F1–4.2
- PR–NS2
- ICT C6–4.1
- 20–B1.1s
- 20–B1.3s
- CT–NS2
- PR–NS3

- AI–NS6
- CT–NS1

Advance Preparation

When to Begin	What to Do
2–3 days before	■ Check the equipment, especially the lighters.

Materials
■ balance ■ graduated cylinder (500 mL) ■ pail (or sink) or 4 L beaker ■ barometer ■ thermometer ■ butane lighters ■ parafilm or plastic wrap ■ small beakers ■ masking tape ■ paper towel ■ blow dryer

Time Required

- 45–60 minutes on the first day
- 10 minutes on the next day

Helpful Tips

- Many barometers are calibrated to the atmospheric pressure at sea level, which makes them useful for determining whether high or low pressure systems are coming in. You do not want your barometer calibrated this way. Instead, it should be reading the atmospheric pressure at your school's altitude.
- Remind students to be extremely careful in adjusting their graduated cylinders so that the pressure is equal, both inside and out.
- The lighters must be dry.
- A new class will require a new set of lighters.
- Use **BLM 4.2.7 (HAND) Investigation 4.A: Finding the Molar Mass of a Gas** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. Answers are on **BLM 4.2.7A (ANS) Investigation 4.A: Finding the Molar Mass of a Gas Answer Key.**
- ***Expected Results:*** The students will probably find a value of roughly 0.8 to 0.9 g for the mass of their gas. Students should then start with the equation, $PV = nRT$ and substitute $\frac{m}{M}$ for n. They should then solve for M which will give them, $M = \frac{mRT}{PV}$. Their result should be close to 58 g/mol.

Safety Precautions

The gas in the lighters is flammable. Students should exercise care when using them.

Answers to Analysis Questions

1. This is a straightforward step. Each group will have slightly different numbers here.
2. Students will subtract the partial pressure of water from the pressure they measured inside their cylinder.
3. The ideal gas law will allow students to solve for the number of moles of gas they have. They will then know the mass and amount of the gas, which will allow them to calculate a molar mass.
4. Actual molar mass of butane is 58.14 g/mol.

Answers to Conclusion Questions

5. Percentage experimental error will be different for each group of students.
6. What students write here will depend on how large their percentage error is. Possible sources of error include:
   - An incorrect temperature caused by the temperature of the gas not being the same as the temperature of the water. (This is a small problem.)
   - An incorrect pressure caused by students not holding the cylinder at the right height in the water container. (This can be a big error if students are not careful.)
   - An incorrect volume caused by reading of a large cylinder. (This should be a small error.)
   - An incorrect pressure caused by a barometer that has been adjusted to sea level pressure. (Hopefully this will not be a problem at all.)
7. The experimental design here is pretty good. In order to get more accurate results, more sophisticated measuring tools would be needed. For example, a digital thermometer would give results within a tenth of a degree precision.

Assessment Options

- Collect and assess answers to Analysis and Conclusion questions.
- Use Assessment Checklist 2: Laboratory Report or Checklist 3: Performance Task Self-Assessement

Connections (Social and Environment Contexts): Chinook Winds and the Gas Laws

Student Textbook page 146

Teaching Strategies

- Ask students to share their experiences of Chinook winds.
- Have students ask their guardians or relatives if they have ever experienced a Chinook wind like that described in the student textbook.

Connections Answers

1. Several Chinook winds can occur in Southern Alberta every year. They can last less than an hour or for several days.
2. Some people can experience headaches, anxiety, and insomnia because of the sudden changes in weather caused by Chinook winds.
3. Chinook type winds can destroy vegetation, cause dust storms, and increase the risk of forest and grass fires.

Investigation 4.B: Finding the Value of the Universal Gas Constant, *R*

Student Textbook page 149

Purpose

Students design and carry out an experiment to find a value for the universal gas constant.

Outcomes

- 20–B1.1s
- 20–B1.4s
- IP–NS3
- ICT1–4.2
- IP–NS4
- 20–B1.2s
- IP–NS2
- PR–NS2
- ICT C6–4.2
- PR–NS3
- ICT F1–4.2

Advance Preparation

When to Begin	What to Do
3–4 days before	■ Present the problem to the students.
1–2 days before	■ Read the proposed designs and check the availability of the various equipment requested.
1 day before	■ Get equipment ready in the lab. ■ Photocopy **BLM 4.2.9 (HAND) Investigation 4.B: Finding the Value of the Universal Gas Constant, *R*.**

Materials
Variable from group to group but will include: ■ mass balance ■ thermometers ■ pressure gauges or a barometer ■ graduate cylinders ■ various beakers ■ balloons, ice, etc.

Time Required

- 30 minutes for designing the experiment
- 30 minutes to write the procedure
- 30–50 minutes to gather data

Helpful Tips

- The better your students understand precisely what they are trying to do, the more easily the experiment will proceed in the laboratory. Give students 30 minutes of class time to brainstorm for ideas once they have been given the problem. Discuss equipment, possible errors, dangerous situations, etc. Have them hand in their designs two periods before they actually do the investigation.
- This is not the easiest way to do a chemistry lab, but it is one of the best. Many students will come up with a procedure very similar to Investigation 4.A, and that is fine. A few students will come up with a creative way to find results; provided the procedure is not dangerous, encourage them in this direction.
- Use **BLM 4.2.9 (HAND) Investigation 4.B: Finding the Value of the Universal Gas Constant, *R*** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. Answers are on **BLM 4.2.9A (ANS) Investigation 4.B: Finding the Value of the Universal Gas Constant, *R* Answer Key.**

Safety Precautions

This will depend upon the students' designs. If they do not work with flammable gases, hot materials, or high pressures, there may be very few precautions that need to be taken.

Answers to Analysis Questions

1. The results will be quite different from each other, although there should be a cluster of results fairly close to the predicted value.
2. The percentage error is the absolute value of the difference between the students' result and the predicted result, divided by the predicted result and expressed as a percentage.
3. Possible ideas here could include: using different equipment, repeating measurements several times, taking more care with the measurements, and controlling for unforeseen influences.

Answers to Conclusions Questions

4. When evaluating an experiment, think about three things:
   – Was the idea a good one?
   – If the idea was good, were the steps chosen the best set of steps to get the measurements?
   – Did students have the skills needed to use the equipment chosen?

   The experimental designs should be good because you will have gone through them with the students before they did their experiments. The procedures often do have flaws. Perhaps the same measurements would have worked better if done in a different order. Maybe some steps were not needed. When students design their own experiments, they are unlikely to choose equipment that they do not understand, so they should have the skills needed.

5. This is a very hard question for students. Those students who can answer this are the ones who truly understand what they are doing. Some pitfalls include: If they have a small mass of gas, they need a scale with the precision to give them a few significant digits, even with this small mass. Thermometers read to the nearest degree and may not be well-calibrated. If they use a barometer, it has to measure the actual pressure in the room. Has the barometer been checked for correct calibration? Often students have good results but do not know it because they make mathematical mistakes. This is not technically an experimental error, but it is fairly common in a chemistry class.
6. The need for safety precautions would come from deciding to use dangerous gases, heating gases in closed containers, or the use of hot plates and hot water. Be sure the students have addressed safety concerns in their experiment.
7. Students are usually quite positive about this kind of lab. They appreciate the opportunity to create and carry out their own experiments.

Assessment Options

- Collect and assess answers to Analysis and Conclusion questions.
- Use Assessment Checklist 1: Designing an Experiment to assess students' designs.
- Use Assessment Checklist 2: Laboratory Report to assess students' write-ups.
- Provide students with Assessment Checklist 3: Performance Task Self-Assessment.
- Use Assessment Checklist 4: Performance Task Group Assessment to assess group behaviours.

Section 4.2 Review Answers

Student Textbook page 150

1. The ideal gas law uses moles of a gas not the mass of the gas. This makes the law work no matter how heavy a particle is.
2. One method would be to calculate the molar volume of a gas at particular conditions of temperature, pressure, and volume, and then to take a sample of a gas at those same conditions. Measure the temperature, pressure, and volume, and use the ideal gas law to calculate the number of moles. Measure the mass of the gas as a separate step. The molar mass is the mass divided by the amount of the gas.

   Another method is to produce a gas from a chemical reaction and use volume ratios to determine the amount of gas produced. Measure the mass of the gas, and again you have the numbers needed to find the molar mass of the gas.
3. No. Hydrogen sulfide, like all acid forming substances, is highly soluble in water. Only gases that do not dissolve in water can be collected with this method.
4. 22.4 L + 22.4 L + 33.6 L + 22.4 L = 100.8 L and for significant figures the answer is 1.0×10^2 L
5. Using the chart, the partial pressure of water at this temperature is 0.16 kPa. The pressure of the gas is therefore 100.2 kPa – 2.41 kPa = 97.8 kPa.
6. The diagrams suggest that there is lots of space between gas particles, even after adding the two gases together so the total pressure is the sum of the partial pressures.
7. $5.25 \times 10^{27} / 6.02 \times 10^{23} = 8721 \text{ mol} \times 24.8 \text{ L/mol} = 2.16 \times 10^5 \text{ L}$
8. Solving the ideal gas law for n gives n = 0.0135 mol. So M = 0.087 g / 0.0135 mol = 64 g/mol.
9. The volume inside the cylinder is too high. When collecting a gas using the downward displacement of water, you must equalize the internal and external pressure to obtain accurate results for the quantity of gas produced. The cylinder should be carefully lifted until the level of water outside the cylinder is equal to the water level inside the cylinder. When the water levels are equal, the pressure in the cylinder is the same as atmospheric pressure, which can be easily measured. Currently, the pressure inside the cylinder is higher than the atmospheric pressure outside the cylinder, and therefore the volume of gas will be less than it would be at atmospheric pressure (since pressure and volume are inversely proportional). When they calculate n, their value will be too low.
10. $V = \frac{nRT}{P} = \frac{(1.2)(8.314)(298.15)}{100} = 30 \text{ L}$

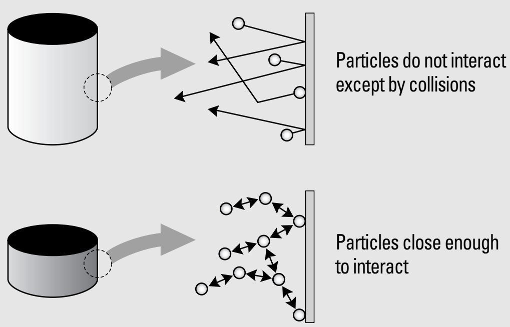
Chapter 4 Review Answers

Student Textbook pages 152–153

1. The combined gas law is more general, (less constrained). You do not need a constant pressure, as in Charles's law, or a constant temperature, as in Boyle's law.
2. In chemical reactions, volumes add in the same proportions as the mole ratios. This means that equal amounts (moles) of any gas occupy equal volumes.
3. Since equal amounts of any gas have the same volume, we expect the volume to be related to the amount of gas. The diagram shows the amount increasing and the volume responding accordingly.
4. Having the same molar volume means having the same number of particles in a given volume. Density is mass divided by volume and different densities result because different gas particles have different masses.

5. This assures that the mole ratios are accurate.
6. The kinetic molecular theory describes an ideal gas as one where the particles can be thought of as point masses, there are no chemical interactions between the particles, and there is lots of space between the particles.
7. Since the space between gases is so large in comparison to the size of the particles there is plenty of room for different types of particles. Each type of particle exerts an average force on the container in proportion to the number of particles there are.
8. Every gas has the same molar volume at a given set conditions. STP and SATP are special conditions.
9. **(a)** 8.314 kPa • L/mol • K × 1 atm/101.325 kPa = 0.08205 atm • L/mol • K

   (b) 8.314 kPa • L/mol • K × 760 mmHg/101.325 kPa = 62.4 mmHg • L/mol • K
10. The two things that cause a gas to behave differently than an ideal gas are high pressure and low temperature. High-pressure squeezes the particles together so that the space between the atoms is not large in comparison to the size the particles and particle interactions begin to matter. At low temperatures the particles slow down and come closer together, again, causing particle interactions to become important.
11.



The diagram shows the particles much closer together at high pressure than low pressure. The attractions between particles take something away from the pressure they might exert on the walls.

12. At high pressure the particles are close enough to attract one another, which reduces the force with which they hit the container's walls. As a result, the pressure is reduced. Calculations of *n* with the ideal gas law will be low as a result.
13. The volume is directly proportional to the temperature and inversely proportional to the pressure. The dropping temperature would tend to reduce the volume of the balloon, but the dropping pressure would tend to increase it. In absolute terms, the pressure changes are likely bigger than the temperature changes, so the balloon would probably increase in volume.

Answers to Applying Concepts Questions

14. When a liquid changes to gas, particles absorb enough energy to move away from the surface of the liquid and fly free. This does not change the temperature of the substance but in a closed container would drastically increase pressure because the volume has a tendency to increase dramatically. Adding heat can trigger a chemical reaction that creates gases. The heat produced by compressing the fuel is enough to ignite diesel fuel in a vehicle.
15. Avogadro's idea that equal volumes of gases contain the same number of particles explains why they combine in small (mole) ratios, which agrees with Dalton's ideas.
16. Assuming the containers are sealed:

    (a) The volumes of the two gases are equal.

    (b) The amounts of the two gases are equal.

    (c) The mass of the oxygen gas will be eight times the mass of the helium gas.

    (d) Assuming that the container has a constant volume and the amounts of each gas are still the same, the pressure of the oxygen gas would be less than the pressure of the helium gas, and since the temperature has decreased, the average kinetic energy of the oxygen particles is less than the average kinetic energy of the helium particles.
17. It means that the gas has no (or a very small amount) of water particles mixed in with it.

Answers to Problem Solving Questions

18. Use the combined gas law. $V_2 = P_1V_1T_2/P_2T_1$; V_2 = (1.33 atm × 101.325 kPa/atm × 532 mL × 273.15 K)/(101.325 kPa × (31.4 °C + 273.15) K = 635 mL
19. 21 mL
20. Use the combined gas law to find the total volume of the Helium. $V_2 = P_1V_1T_2/P_2T_1$; V_2 = (25 atm × 100 L × (25 °C + 273.15) K)/(1.05 atm × (20 °C + 273.15) K) = 2421.56 L. Now subtract the 100 L that are still in the cylinder. 2421.56 L – 100 L = 2321.56 L. Correct for significant figures. $V = 2.3 \times 10^3$ L.
21. Assuming an ideal gas (which may be a poor assumption here due to such a high pressure): Find the amount: *n* = 265 g / 32.00 g/mol = 8.28 mol
    Then T = 20 atm × 101.325 kPa/atm × 10 L / (8.314 kPa • L/mol • K × 8.28 mol) = 294 K
22. Assuming an ideal gas (which may be a poor assumption here due to such a high pressure):

    n = 200 bar × 100 kPa/bar × 5.4 L / (8.314 kPa • L/mol • K × 295.15 K) = 44.0 mol

    Then *m* = 44.0 mol × 32.00 g/mol = 1408 g = 1.4 kg

23. The volume of the cylinder is $3.14 \times (11.5\text{cm})^2 \times 140\text{ cm} = 58137\text{ cm}^3$

This is 58.1 L

$n = 108\text{ kPa} \times 58.1\text{ L} / (8.314 \times 294\text{K}) = 2.57\text{ mol} \times 44.02\text{ g/mol} = 113\text{ g}$

24. Find the amount: $n = 1.25\text{ g} / 4.00\text{ g/mol} = 0.3125\text{ mol}$

Then: $22.4\text{ L/mol} \times 0.3125\text{ mol} = 7.00\text{ L}$

And $D = 1.25\text{ g} / 7.00\text{ L} = 0.179\text{ g/L}$

25. Use one mole: $V = 1\text{ mol} \times 8.314 \times 362\text{ K} / 155\text{ kPa} = 19.4\text{ L}$

$m = 1\text{ mol} \times 70.90\text{ g/mol} = 70.90\text{ g}$ and $D = 70.90\text{ g} / 19.4\text{ L} = 3.6\text{ g/L}$

26. (a) $C_3H_{8(g)} + 5O_{2(g)} \rightarrow 3CO_{2(g)} + 4H_2O_{(g)}$

(b) Using Avogadro's law: 1 L of propane will produce 3 + 4 = 7 L of products.

27. $n = 103\text{ kPa} \times 0.800\text{ L} / (8.314 \times 351\text{ K}) = 0.0282\text{ mol}$

$M = 2.366\text{ g} / 0.0282\text{ mol} = 83.4\text{ g/mol}$. The gas is krypton.

28. $T = 206\text{ kPa} \times 4.00\text{ L} / (2.17\text{ mol} \times 8.314) = 45.7\text{ K} = -227\text{ °C}$

29. Use the combined gas law and solve for V_2/V_1.
$V_2/V_1 = (P_1T_2/P_2T_1) = (P_1 (75 + 273.15)\text{ K})/(2P_1 (25 + 273.15)\text{ K}) = 0.58$

30. 4.0% of 0.75 atm = 0.030 atm or 3.04 kPa

31. Vapour pressure is 2.81 kPa = 21.1 mm Hg.

Dry pressure is 750 mmHg – 21.1 mmHg = 729 mmHg

New volume is: $V = 729\text{ mmHg} \times 55\text{ mL} \times 313\text{ K} / (296\text{ K} \times 775\text{ mmHg}) = 54.7\text{ mL}$

32. Use the combined gas law to find the final pressure (partial pressure) for the individual gases and then add the partial pressures to obtain the total pressure.

$P_2 = P_1V_1T_2/V_2T_1$;

$P_{2(Ar)} = (1.2\text{ atm} \times 0.600\text{ L} (27 + 273.15)\text{ K})/(0.400\text{ L} (277 + 273.15)\text{ K}) = 0.9820\text{ atm}$

$P_{2(O_2)} = (502\text{ mmHg} (1\text{ atm}/760\text{ mmHg})\ 0.200\text{ L} (27 + 273.15)\text{ K})/(0.400\text{ L} (127 + 273.15)\text{ K}) = 0.2477\text{ atm}$

$P_2(\text{total}) = 0.9820\text{ atm} + 0.2477\text{ atm} = 1.2297\text{ atm}$

Corrected for significant figures: $P_{2(\text{total})} = 1.2\text{ atm}$ or $1.2 \times 10^2\text{ kPa}$

33. Vapour pressure is 2.81 kPa.

Dry pressure is $738\text{ mmHg} / 760\text{ mmHg} \times 101.3\text{ kPa/atm} = 98.37\text{ kPa} - 2.81\text{ kPa} = 95.56\text{ kPa}$

$n = 95.56\text{ kPa} \times 0.523\text{ L} / (8.314 \times 296\text{ K}) = 0.0203\text{ mol}$

$m = 0.0203\text{ mol} \times 26.04\text{ g/mol} = 0.53\text{ g}$

34. (a) Find the mass: 2.201 g – 2.150 g = 0.051 g

Find the amount: $n = 102\text{ kPa} \times 0.664\text{ L} / (8.314\text{ kPa} \bullet \text{L/mol} \bullet \text{K} \times 323.15\text{ K}) = 0.0252\text{ mol}$

The molar volume: = 0.664 L / 0.0252 mol = 26.3 L/mol

The molar mass: $M = 0.051\text{g} / 0.0252\text{ mol} = 2.02\text{ g/mol}$

(b) The gas is probably hydrogen ($H_{2(g)}$)

Answers to Making Connections Questions

35. The density of carbon dioxide is higher than the density of air. The lake was in a volcanic caldera, so the carbon dioxide that bubbled to the surface lay in the volcanic crater since carbon dioxide will sink to the bottom of a sample of air. This displaced the oxygen and asphyxiated the people and livestock.

36. Most of the gases used in a hospital are not toxic, however they must still be handled with caution as they will be stored under pressure. Gases will expand when heated, so canisters must be strong enough to withstand pressure changes that occur with changes in temperature and should be stored in areas where moderate temperatures will be maintained. Since oxygen is flammable, it must not be used around open flame.

37. A low pressure air mass will rise above a high pressure air mass because of the difference in pressure. As the low-pressure air mass rises, it will cool since temperatures are cooler at higher altitude. This will lead to the condensation of the air in the air mass which leads to precipitation.

Career Focus: Ask an Exercise Physiologist

Student Textbook pages 154–155

Teaching Strategies

- The 1968 Olympic Games were controversial because of the high altitude of host city Mexico City, which is 2300 m above sea level. Have students research the affects this altitude had on athletic performance in different Olympic events.
- Ask students to interview someone who works in one of the careers outlined on page 155 or in other careers that involve gases or respiration.

Go Further Answers

1. Vancouver is at sea level and Calgary is 1000 m above sea level. Airplanes are pressurized to about 2000 m, so the partial pressure of oxygen in the plane is about 80% of its value in Vancouver. The passengers' ears "pop" on takeoff and landing, and this is the mild symptom mentioned in the question. The difference in pressure between the two cities is negligible over the times involved in travelling.

2. Warm air can hold more moisture than cold air. The vapour pressure could be higher on warmer days, making partial pressure of oxygen lower. The percentage of oxygen does not change with temperature, so that will not change the partial pressure. Cold air contracts, so the change in temperature and volume will change the pressure, and therefore the partial pressure of oxygen, although that is a small effect.

3. The problems the divers experience result from the fact that nitrogen dissolves in blood at high pressure. As the diver descends and pressure increases, more nitrogen dissolves in his or her bloodstream. If the diver comes up too quickly, the nitrogen comes out of solution in tiny bubbles. If these bubbles reach the heart, the diver will feel pain and could even die. The solution is to come up slowly enough so the pressure drops slowly and the nitrogen comes out of solution slowly and bubbles cannot form. A hyperbaric chamber simulates this slow ascending of the diver by decreasing the pressure at a slow rate.

Another solution would be to fill the diver's tank with an oxygen-helium mixture. Helium does not dissolve in the bloodstream as well as nitrogen (one-fifth as well), and the problem is reduced.

Unit 2 Review Answers

Student Textbook pages 156–157

1. These are the same temperatures. The average kinetic energy is the same in both samples.

2. The pressure is caused by the sum total of all collisions of the particles of the gas and the walls of the container.

3. Increasing the temperature causes the particles to move faster and therefore hit the walls harder, thus raising the pressure.

4. This term describes the idea that the size of the particles is small compared to the spaces between them and explains why gases are so highly compressible.

5. The volume and the amount of gas must be controlled.

6. The balanced chemical reaction will tell you the ratios of the volumes of the gases involved.

7. The higher the temperature, the higher the vapour pressure. This means that there is more water vapour in a sample of gas at a higher temperature.

Answers to Applying Concepts Questions

8. The volume should drop to one-third of its original value.

9. Yes, as long as the temperatures are measured in absolute degrees. This is the statement of Charles's law.

10. $A(g) + 4B(g) \rightarrow 2C(g)$

11. Yes, if the gases are at STP. This follows from Avogadro's law.

12. The density goes up with an increase in pressure and down with an increase in temperature.

Answers to Solving Problems Questions

13. **(a)** 173 K **(b)** –273 °C **(c)** 516.7 K

14. **(a)** 2.50 bar **(b)** 374 kPa **(c)** 1.29 atm

15. 0.427 L

16. 115 kPa

17. 5 L

18. 6.20 L

19. 1.9 L

20. 3.3 L

21. 22.6 L/mol

22. 0.19 mol

23. 3.8 L

24. 54 kPa in both

25. **(a)** 20.0 g/mol

(b) polar molecule, acidic in water: hydrogen fluoride

(c) 0.809 g/L

26. 1.78 g/L

27. In order to determine the universal gas constant, the students must be able to collect data on volume, pressure, temperature, and the moles of the gas. Both methods would allow for the collection of all of this data; however, the procedure that would have to be followed in both cases would be significantly different. Given the laboratory equipment available in a high school laboratory, it would be significantly easier to collect gas in a plastic bag. Also, a plastic bag would be quite light initially, so the small change in mass would be measurable and a significant change. Collecting a gas under pressure could prove difficult in a high school laboratory and the container in which it would be collected may not change in mass significantly. Collecting gas in a plastic bag would be the method of choice in a high school laboratory.

Answers to Making Connections Questions

28. All three gases, helium, hydrogen, and hot air will cause a balloon to rise. Helium, hydrogen, and air, when heated, are less dense than regular air and will therefore rise. Currently, helium is used in "dirigibles," like the Goodyear Blimp, while hot air is used in most balloons in Alberta. Hydrogen gas is no longer commonly used in passenger ballooning as, although it is relatively inexpensive, it is very flammable. It is still used in weather balloons. Both helium and hot air are viable choices, with hot air being significantly less expensive and more readily available.

29. **(a)** $2C_8H_{18}(l) + 25O_2(g) \times 16CO_2(g) + 18H_2O(g) +$ energy

(b) The mixture is at a higher temperature when the piston is at the top at the end of the compression stroke.

(c) $N_2(g) + O_2(g) \rightarrow 2NO(g)$; the nitrogen is present in the air and reacts with the oxygen at the high temperatures inside the cylinder.

30. When an airbag deploys, a chemical reaction occurs that releases nitrogen gas. The ideal gas law, $PV = nRT$ is important in ensuring that enough, but not too much, gas is released into the bag for the volume of the bag and the temperature of the surroundings. If too much gas is released, the pressure inside the airbag may be too high, which could cause injury or perhaps the bag could explode. If not enough gas is released, then the bag may not provide enough cushioning for the crash. Since the conditions are not changing, the combined gas law is not applicable. Although airbags are designed to operate in wide-ranging temperature conditions, it is possible that extremely high or low temperatures may cause an airbag to inflate too much (high temperatures) or not enough (low temperatures), which may lead to unexpected injuries.