Lesson 3

The Behavior of Gases

Reading Guide

Key Concepts
ESSENTIAL QUESTIONS

- How does the kinetic molecular theory describe the behavior of a gas?
- How are temperature, pressure, and volume related in Boyle's law?
- How is Boyle's law different from Charles's law?

Vocabulary

kinetic molecular theory p. 292
pressure p. 293
Boyle's law p. 294
Charles's law p. 295

Multilingual eGlossary

What's Science Got to do With It?

Inquiry Survival Gear?

Why do some pilots wear oxygen masks? Planes fly at high altitudes where the atmosphere has a lower pressure and gas molecules are less concentrated. If the pressure is not adjusted inside the airplane, a pilot must wear an oxygen mask to inhale enough oxygen to keep the body functioning.

Launch Lab

15 minutes

Are volume and pressure of a gas related?

Pressure affects gases differently than it affects solids and liquids. How do pressure changes affect the volume of a gas?

1. Read and complete a lab safety form.
2. Stretch and blow up a **small balloon** several times.
3. Finally, blow up the balloon to a diameter of about 5 cm. Twist the neck, and stretch the mouth of the balloon over the opening of a **plastic bottle. Tape** the neck of the balloon to the bottle.
4. Squeeze and release the bottle several times while observing the balloon. Record your observations in your Science Journal.

Think About This

1. Why doesn't the balloon deflate when you attach it to the bottle?
2. What caused the balloon to inflate when you squeezed the bottle?
3. **Key Concept** Using this lab as a reference, do you think pressure and volume of a gas are related? Explain.

ACADEMIC VOCABULARY

theory
(noun) an explanation of things or events that is based on knowledge gained from many observations and investigations

Understanding Gas Behavior

Pilots do not worry as much about solids and liquids at high altitudes as they do gases. That is because gases behave differently than solids and liquids. Changes in temperature, pressure, and volume affect the behavior of gases more than they affect solids and liquids.

The explanation of particle behavior in solids, liquids, and gases is based on the kinetic molecular theory. The **kinetic molecular theory** *is an explanation of how particles in matter behave.* Some basic ideas in this theory are

- small particles make up all matter;
- these particles are in constant, random motion;
- the particles collide with other particles, other objects, and the walls of their container;
- when particles collide, no energy is lost.

You have read about most of these, but the last two statements are very important in explaining how gases behave.

Key Concept Check How does the kinetic molecular theory describe the behavior of a gas?

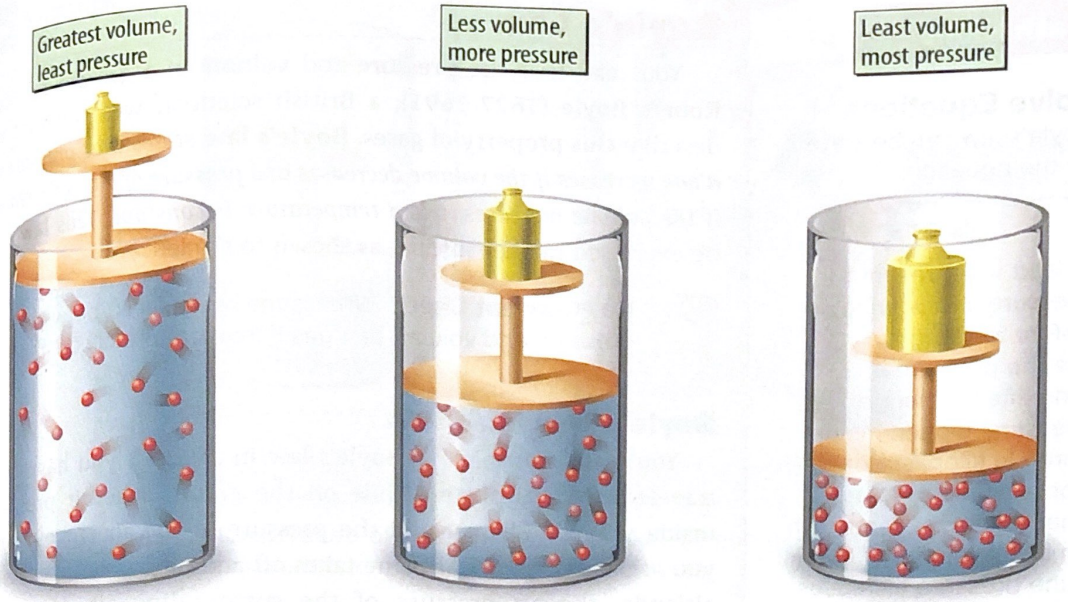


Figure 15 As pressure increases, the volume of the gas decreases.

What is pressure?

Particles in gases move constantly. As a result of this movement, gas particles constantly collide with other particles and their container. When particles collide with their container, pressure results. **Pressure** *is the amount of force applied per unit of area.* For example, gas in a cylinder, as shown in **Figure 15,** might contain trillions of gas particles. These particles exert forces on the cylinder each time they strike it. When a weight is added to the plunger, the plunger moves down, compressing the gas in the cylinder. With less space to move around, the particles that make up the gas collide with each other more frequently, causing an increase in pressure. The more the particles are compressed, the more often they collide, increasing the pressure.

WORD ORIGIN

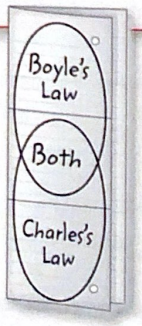
pressure
from Latin *pressura,* means "to press"

Pressure and Volume

Figure 15 also shows the relationship between pressure and volume of gas at a constant temperature. What happens to pressure if the volume of a container changes? Notice that when the volume is greater, the particles have more room to move. This additional space results in fewer collisions within the cylinder, and pressure is less. The gas particles in the middle cylinder have even less volume and more pressure. In the cylinder on the right, the pressure is greater because the volume is less. The particles collide with the container more frequently. Because of the greater number of collisions within the container, pressure is greater.

FOLDABLES

Fold a sheet of notebook paper to make a three-tab Foldable and label as shown. Use your Foldable to compare two important gas laws.



Math Skills

Solve Equations

Boyle's law can be stated by the equation

$$V_2 = \frac{P_1 V_1}{P_2}$$

P_1 and V_1 represent the pressure and volume before a change. P_2 and V_2 are the pressure and volume after a change. Pressure is often measured in kilopascals (kPa). For example, what is the final volume of a gas with an initial volume of **50.0 mL** if the pressure increases from **600.0 kPa** to **900.0 kPa**?

1. Replace the terms in the equation with the actual values.

$$V_2 = \frac{(600.0\ \text{kPa})(50.0\ \text{mL})}{(900.0\ \text{kPa})}$$

2. Cancel units, multiply, and then divide.

$$V_2 = \frac{(600.0\ \text{kPa})(50.0\ \text{mL})}{(900.0\ \text{kPa})}$$

$$V_2 = 33.3\ \text{mL}$$

Practice

What is the final volume of a gas with an initial volume of 100.0 mL if the pressure decreases from 500.0 kPa to 250.0 kPa?

Math Practice

Personal Tutor

Boyle's Law

You read that the pressure and volume of a gas are related. Robert Boyle (1627-1691), a British scientist, was the first to describe this property of gases. **Boyle's law** *states that pressure of a gas increases if the volume decreases and pressure of a gas decreases if the volume increases, when temperature is constant.* This law can be expressed mathematically as shown to the left.

Key Concept Check What is the relationship between pressure and volume of a gas if temperature is constant?

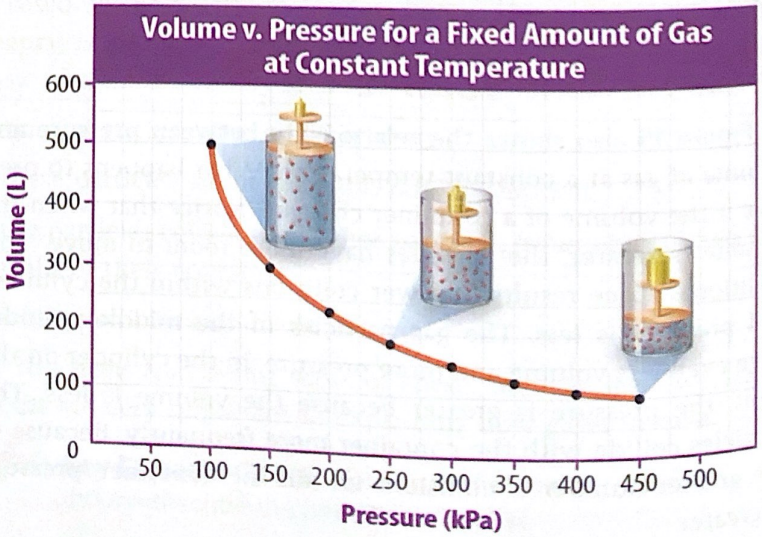
Boyle's Law in Action

You have probably felt Boyle's law in action if you have ever traveled in an airplane. While on the ground, the air pressure inside your middle ear and the pressure of the air surrounding you are equal. As the airplane takes off and begins to increase in altitude, the air pressure of the surrounding air decreases. However, the air pressure inside your middle ear does not decrease. The trapped air in your middle ear increases in volume, which can cause pain. These pressure changes also occur when the plane is landing. You can equalize this pressure difference by yawning or chewing gum.

Graphing Boyle's Law

This relationship is shown in the graph in **Figure 16.** Pressure is on the x-axis, and volume is on the y-axis. Notice that the line decreases in value from left to right. This shows that as the pressure of a gas increases, the volume of the gas decreases.

Figure 16 The graph shows that as pressure increases, volume decreases. This is true only if the temperature of the gas is constant.



Animation

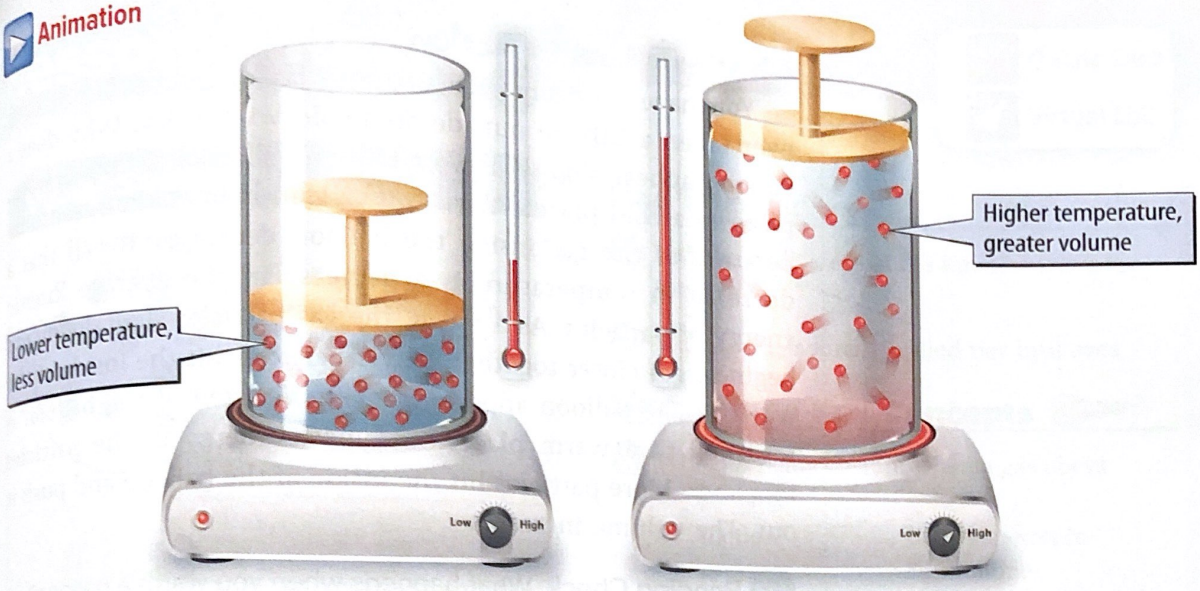


Figure 17 As the temperature of a gas increases, the kinetic energy of the particles increases. The particles move farther apart, and volume increases.

Temperature and Volume

Pressure and volume changes are not the only factors that affect gas behavior. Changing the temperature of a gas also affects its behavior, as shown in **Figure 17.** The gas in the cylinder on the left has a low temperature. The average kinetic energy of the particles is low, and they move closer together. The volume of the gas is less. When thermal energy is added to the cylinder, the gas particles move faster and spread farther apart. This increases the pressure from gas particles, which push up the plunger. This increases the volume of the container.

Charles's Law

Jacque Charles (1746–1823) was a French scientist who described the relationship between temperature and volume of a gas. **Charles's law** *states that the volume of a gas increases with increasing temperature, if the pressure is constant.* Charles's practical experience with gases was most likely the result of his interest in balloons. Charles and his colleague were the first to pilot and fly a hydrogen-filled balloon in 1783.

Key Concept Check How is Boyle's law different from Charles's law?

MiniLab 20 minutes

How does temperature affect the volume?

You can observe Charles's law in action using a few lab supplies.

1. Read and complete a lab safety form.
2. Stretch and blow up a **small balloon** several times.
3. Finally, blow up the balloon to a diameter of about 5 cm. Twist the neck and stretch the mouth of the balloon over the opening of an **ovenproof flask.**
4. Place the flask on a cold **hot plate.** Turn on the hot plate to low, and gradually heat the flask. Record your observations in your Science Journal.
5. ⚠ *Use **tongs** to remove the flask from the hot plate.* Allow the flask to cool for 5 min. Record your observations.
6. Place the flask in a **bowl of ice water.** Record your observations.

Analyze and Conclude

Key Concept What is the effect of temperature changes on the volume of a gas?

Charles's Law in Action

You have probably seen Charles's law in action if you have ever taken a balloon outside on a cold winter day. Why does a balloon appear slightly deflated when you take it from a warm place to a cold place? When the balloon is in cold air, the temperature of the gas inside the balloon decreases. Recall that a decrease in temperature is a decrease in the average kinetic energy of particles. As a result, the gas particles slow down and begin to get closer together. Fewer particles hit the inside of the balloon. The balloon appears partially deflated. If the balloon is returned to a warm place, the kinetic energy of the particles increases. More particles hit the inside of the balloon and push it out. The volume increases.

Reading Check What happens when you warm a balloon?

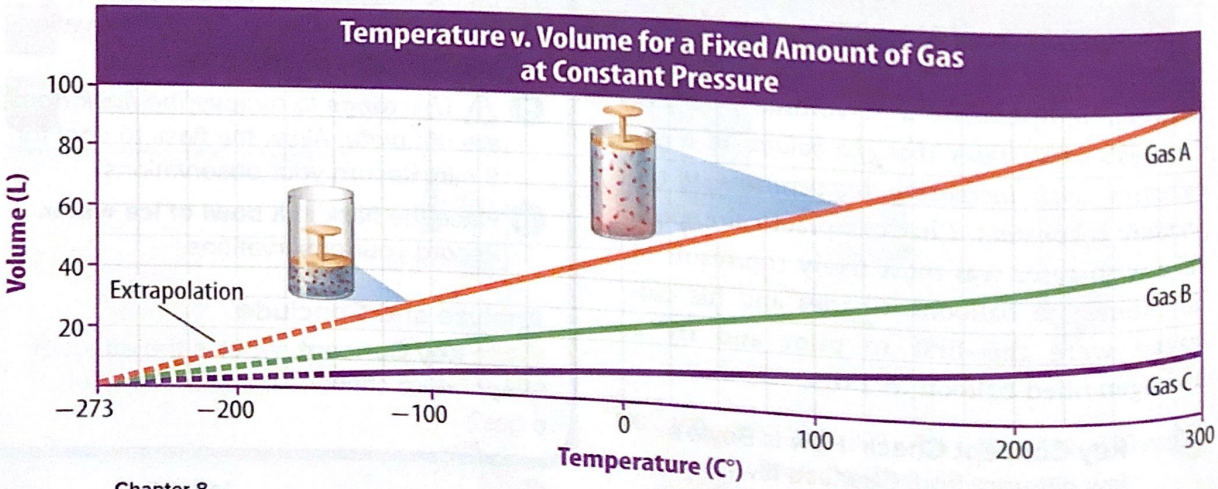
Graphing Charles's Law

The relationship described in Charles's law is shown in the graph of several gases in **Figure 18.** Temperature is on the *x*-axis and volume is on the *y*-axis. Notice that the lines are straight and represent increasing values. Each line in the graph is extrapolated to −273°C. *Extrapolated* means the graph is extended beyond the observed data points. This temperature also is referred to as 0 K (kelvin), or absolute zero. This temperature is theoretically the lowest possible temperature of matter. At absolute zero, all particles are at the lowest possible energy state and do not move. The particles contain a minimal amount of thermal energy (potential energy + kinetic energy).

Key Concept Check Which factors must be constant in Boyle's law and in Charles's law?

Figure 18 The volume of a gas increases when the temperature increases at constant pressure.

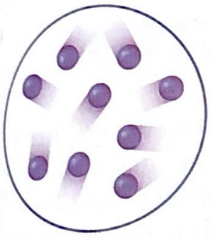
Visual Check What do the dashed lines mean?



Lesson 3 Review

Online Quiz
Virtual Lab

Visual Summary



The explanation of particle behavior in solids, liquids, and gases is based on the kinetic molecular theory.

As volume of a gas decreases, the pressure increases when at constant temperature.

At constant pressure, as the temperature of a gas increases, the volume also increases.

FOLDABLES

Use your lesson Foldable to review the lesson. Save your Foldable for the project at the end of the chapter.

What do you think NOW?

You first read the statements below at the beginning of the chapter.

5. Changes in temperature and pressure affect gas behavior.
6. If the pressure on a gas increases, the volume of the gas also increases.

Did you change your mind about whether you agree or disagree with the statements? Rewrite any false statements to make them true.

Use Vocabulary

1. **List** the basic ideas of the kinetic molecular theory.
2. _____ is force applied per unit area.

Understand Key Concepts

3. Which is held constant when a gas obeys Boyle's law?

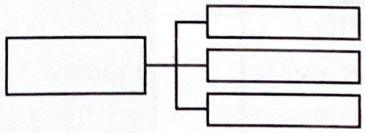
   A. motion **B.** pressure **C.** temperature **D.** volume

4. **Describe** how the kinetic molecular theory explains the behavior of a gas.
5. **Contrast** Charles's law with Boyle's law.
6. **Explain** how temperature, pressure, and volume are related in Boyle's law.

Interpret Graphics

7. **Explain** what happens to the particles to the right when more weights are added.

8. **Identify** Copy and fill in the graphic organizer below to list three factors that affect gas behavior.



Critical Thinking

9. **Describe** what would happen to the pressure of a gas if the volume of the gas doubles while at a constant temperature.

Math Skills

Math Practice

10. **Calculate** The pressure on 400 mL of a gas is raised from 20.5 kPa to 80.5 kPa. What is the final volume of the gas?