Lab zone **Skills Lab**

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# Melting Ice

## Problem

How does the temperature of the surroundings affect the rate at which ice melts?

## Skills Focus

predicting, interpreting data, inferring

## Materials

- stopwatch or timer
- thermometer or temperature probe
- 2 plastic cups, about 200 mL each
- 2 stirring rods, preferably plastic
- ice cubes, about 2 cm on each side
- warm water, about 40°C–45°C
- water at room temperature, about 20°C–25°C

## Procedure

1. Read Steps 1–8. Based on your own experience, predict which ice cube will melt faster.
2. In your notebook, make a data table like the one below.
3. Fill a cup halfway with warm water (about 40°C to 45°C). Fill a second cup to the same depth with water at room temperature.
4. Record the exact temperature of the water in each cup. If you are using a temperature probe, see your teacher for instructions.
5. Obtain two ice cubes that are as close to the same size as possible.

Data Table

| Cup | Beginning Temperature (°C) | Time to Melt (s) | Final Temperature (°C) |
|---|---|---|---|
| 1 | | | |
| 2 | | | |

6. Place one ice cube in each cup. Begin timing with a stopwatch. Gently stir each cup with a stirring rod until the ice has completely melted.
7. Observe both ice cubes carefully. At the moment one of the ice cubes is completely melted, record the time and the temperature of the water in the cup.
8. Wait for the second ice cube to melt. Record its melting time and the water temperature.

## Analyze and Conclude

1. **Predicting** Was your prediction in Step 1 supported by the results of the experiment? Explain why or why not.
2. **Interpreting Data** In which cup did the water temperature change the most? Explain.
3. **Inferring** When the ice melted, its molecules gained enough energy to overcome the forces holding them together as solid ice. What is the source of that energy?
4. **Communicating** Write a paragraph describing how errors in measurement could have affected your conclusions in this experiment. Tell what you would do differently if you repeated the procedure. (*Hint*: How well were you able to time the exact moment that each ice cube completely melted?)

## Design an Experiment

When a lake freezes in winter, only the top turns to ice. Design an experiment to model the melting of a frozen lake during the spring. *Obtain your teacher's permission before carrying out your investigation.* Be prepared to share your results with the class.



Section 3

# Gas Behavior

## Reading Preview

### Key Concepts

- What types of measurements are useful when working with gases?
- How are the volume, temperature, and pressure of a gas related?

### Key Terms

- pressure
- Boyle's law
- Charles's law

### Target Reading Skill

**Asking Questions** Before you read, preview the red headings. In a graphic organizer like the one below, ask a *what* or *how* question for each heading. As you read, write the answers to your questions.

Gases

| Question | Answer |
|---|---|
| What measurements are useful in studying gases? | Measurements useful in studying gases include . . . |
| | |

Lab zone **Discover Activity**

### How Can Air Keep Chalk From Breaking?

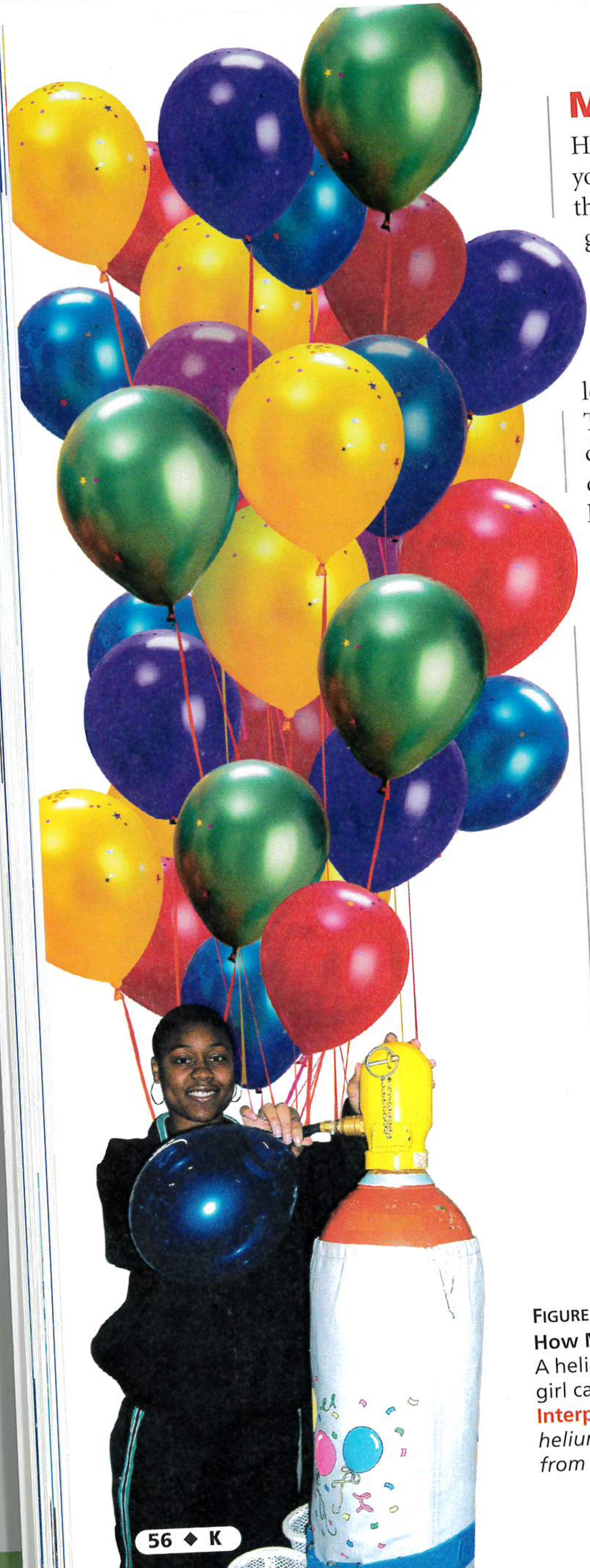
1. Stand on a chair and drop a piece of chalk onto a hard floor. Observe what happens to the chalk.
2. Wrap a second piece of chalk in wax paper or plastic food wrap. Drop the chalk from the same height used in Step 1. Observe the results.
3. Wrap a third piece of chalk in plastic bubble wrap. Drop the chalk from the same height used in Step 1. Observe the results.

**Think It Over**

**Inferring** Compare the results from Steps 1, 2, and 3. What properties of the air in the bubble wrap accounted for the results in Step 3?

How do you prepare a hot-air balloon for a morning ride? First, you inflate the balloon, using powerful air fans. Then you heat the air inside with propane gas burners. But the balloon and its cargo won't begin to rise until the warmer air inside is less dense than the air outside the balloon. How does this change occur? How can you keep the balloon floating safely through the atmosphere? How can you make it descend when you are ready to land? To answer these and other questions, you would need to understand the relationships between the temperature, pressure, and volume of a gas.

Before a flight, a hot-air balloon is filled with air. ▶



## Measuring Gases

How much helium is in the tank in Figure 14? If you don't know the mass of the helium, you may think that measuring the volume of the tank will give you an answer. But gases easily contract or expand. To fill the tank, helium was compressed—or pressed together tightly—to decrease its volume. When you use the helium to fill balloons, it fills a total volume of inflated balloons much greater than the volume of the tank. The actual volume of helium you get, however, depends on the temperature and air pressure that day. **When working with a gas, it is helpful to know its volume, temperature, and pressure.** So what exactly do these measurements mean?

**Volume** You know that volume is the amount of space that matter fills. Volume is measured in cubic centimeters ($cm^3$), milliliters (mL), liters (L), and other units. Because gas particles move and fill the space available, the volume of a gas is the same as the volume of its container.

**Temperature** Hot soup, warm hands, cool breezes—you are familiar with matter at different temperatures. But what does temperature tell you? Recall that the particles within any substance are constantly moving. Temperature is a measure of the average energy of random motion of the particles of a substance. The faster the particles are moving, the greater their energy and the higher the temperature. You might think of a thermometer as a speedometer for molecules.

Even at ordinary temperatures, the average speed of particles in a gas is very fast. At room temperature, or about 20°C, the particles in a typical gas travel about 500 meters per second—more than twice the cruising speed of a jet plane!

FIGURE 14
**How Much Helium?**
A helium tank the height of this girl can fill over 500 balloons!
**Interpreting Photos** *How is the helium in the tank different from the helium in the balloons?*



**Pressure** Gas particles constantly collide with one another and with the walls of their container. As a result, the gas pushes on the walls of the container. The **pressure** of the gas is the force of its outward push divided by the area of the walls of the container. Pressure is measured in units of pascals (Pa) or kilopascals (kPa). (1 kPa = 1,000 Pa.)

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

The firmness of a gas-filled object comes from the pressure of the gas. For example, the air inside a fully pumped basketball has a higher pressure than the air outside. This higher pressure is due to a greater concentration of gas particles inside the ball than in the surrounding air. (Concentration is the number of particles in a given unit of volume.)

When air leaks out of a basketball, the pressure decreases and the ball becomes softer. Why does a ball leak even when it has a tiny hole? The higher pressure inside the ball results in gas particles hitting the inner surface of the ball more often. Therefore, gas particles inside the ball reach the hole and escape more often than gas particles outside the ball reach the hole and enter. Thus, many more particles go out than in. The pressure inside drops until it is equal to the pressure outside.

**Reading Checkpoint** What units are used to measure pressure?

**Math Skills**

### Using Formulas

Pressure can be calculated using the formula below. Force is measured in newtons (N). If area is measured in square meters ($m^2$), pressure is expressed in pascals (Pa).

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

For example, a machine exerts a force of 252 N on a piston having an area of 0.430 $m^2$. What is the pressure on the piston in Pa?

$$\text{Pressure} = \frac{252\ \text{N}}{0.430\ \text{m}^2}$$

$$= 586\ \text{Pa}$$

**Practice Problem** A trash compactor exerts a force of 5,600 N over an area of 0.342 $m^2$. What pressure does the compactor exert in Pa?

FIGURE 15
**A Change in Pressure**
A punctured basketball deflates as the gas particles begin to escape.

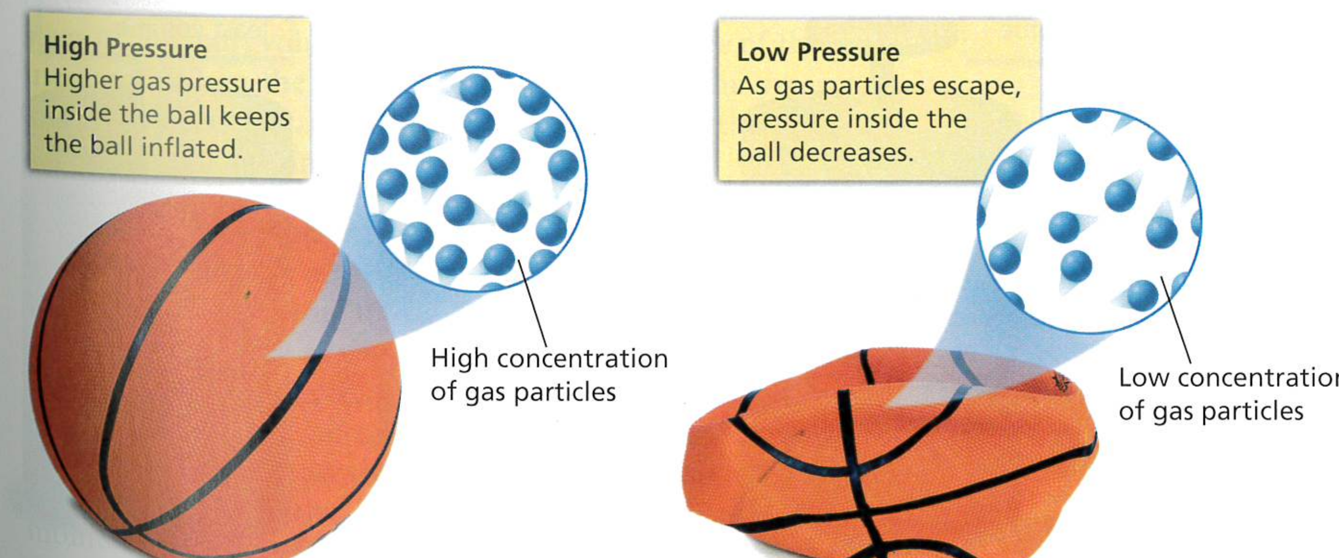


FIGURE 16
**Inflating a Tire**
A bicycle pump makes use of the relationship between the volume and pressure of a gas.

## Pressure and Volume

Suppose you are using a bicycle pump. By pressing down on the plunger, you force the gas inside the pump through the rubber tube and out the nozzle into the tire. What will happen if you close the nozzle and then push down on the plunger?

**Boyle's Law** The answer to this question comes from experiments done by the scientist Robert Boyle in an effort to improve air pumps. In the 1600s, Boyle measured the volumes of gases at different pressures. **Boyle found that when the pressure of a gas at constant temperature is increased, the volume of the gas decreases. When the pressure is decreased, the volume increases.** This relationship between the pressure and the volume of a gas is called **Boyle's law.**

**Boyle's Law in Action** Boyle's law plays a role in research using high-altitude balloons. Researchers fill the balloons with only a small fraction of the helium gas that the balloons can hold. As a balloon rises through the atmosphere, the air pressure around it decreases and the balloon expands. If the balloon were fully filled at takeoff, it would burst before it got very high.

Boyle's law also applies to situations in which the *volume* of a gas is changed. Then the *pressure* changes in the opposite way. A bicycle pump works this way. As you push on the plunger, the volume of air inside the pump cylinder gets smaller and the pressure increases, forcing air into the tire.

**Reading Checkpoint** What could cause a helium balloon to burst as it rises in the atmosphere?

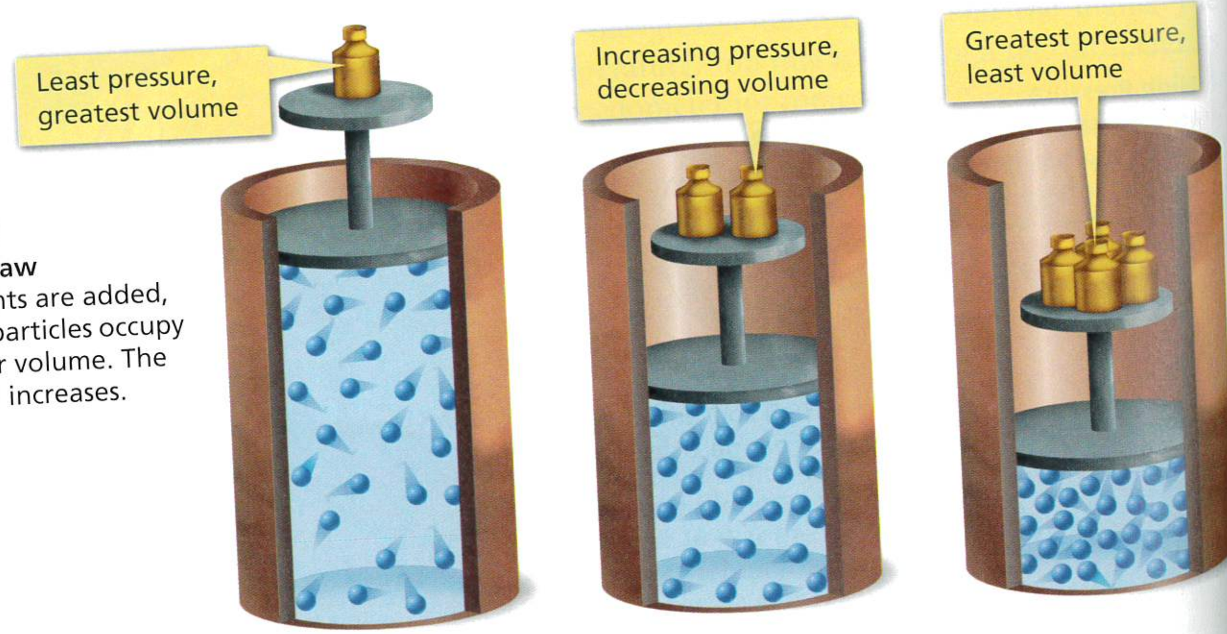



FIGURE 17
**Boyle's Law**
As weights are added, the gas particles occupy a smaller volume. The pressure increases.



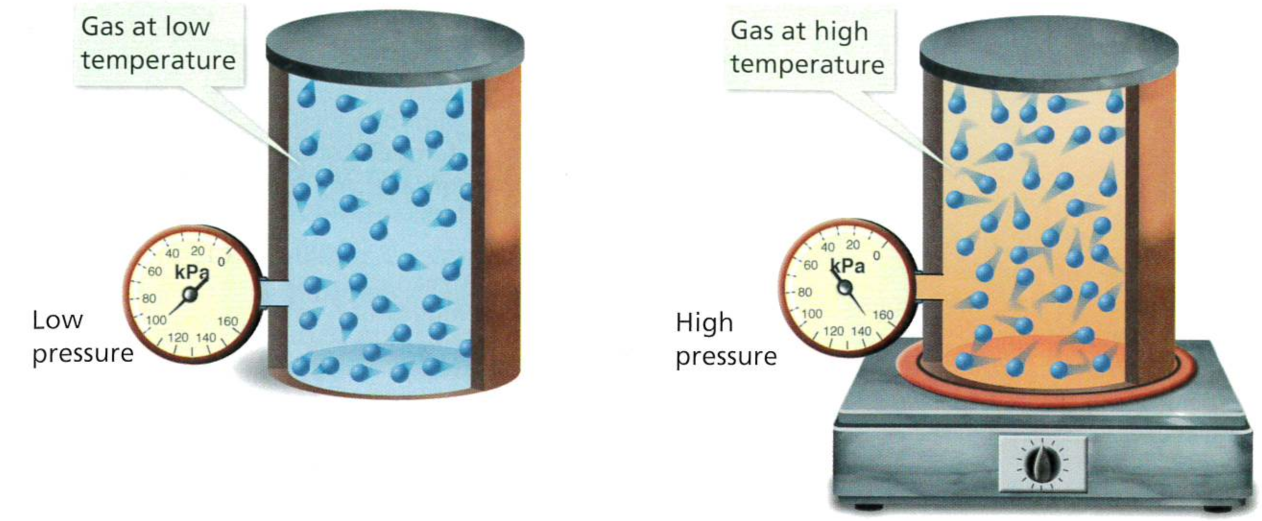



FIGURE 18
**Gas Pressure and Temperature**
When a gas is heated, the particles move faster and collide more often with each other and with the walls of their container. The pressure of the gas increases.

## Pressure and Temperature

If you dropped a few grains of sand onto your hand, you would hardly feel them. But what if you were caught in a sandstorm? Ouch! The sand grains fly around very fast, and they would sting if they hit you. The faster the grains travel, the harder they hit your skin.

Although gas particles are much smaller than sand grains, a sandstorm is a good model for gas behavior. Like grains of sand in a sandstorm, gas particles travel individually and at high speeds (but randomly). The faster the gas particles move, the more frequently they collide with the walls of their container and the greater the force of the collisions.

**Increasing Temperature Raises Pressure** Recall from Section 2 that the higher the temperature of a substance, the faster its particles are moving. Now you can state a relationship between temperature and pressure. **When the temperature of a gas at constant volume is increased, the pressure of the gas increases. When the temperature is decreased, the pressure of the gas decreases.** (*Constant volume* means that the gas is in a closed, rigid container.)

**Pressure and Temperature in Action** Have you ever looked at the tires of an 18-wheel truck? Because the tires need to support a lot of weight, they are large, heavy, and stiff. The inside volume of these tires doesn't vary much. On long trips, especially in the summer, a truck's tires can become very hot. As the temperature increases, so does the pressure of the air inside the tire. If the pressure becomes greater than the tire can hold, the tire will burst. For this reason, truck drivers need to monitor and adjust tire pressure on long trips.

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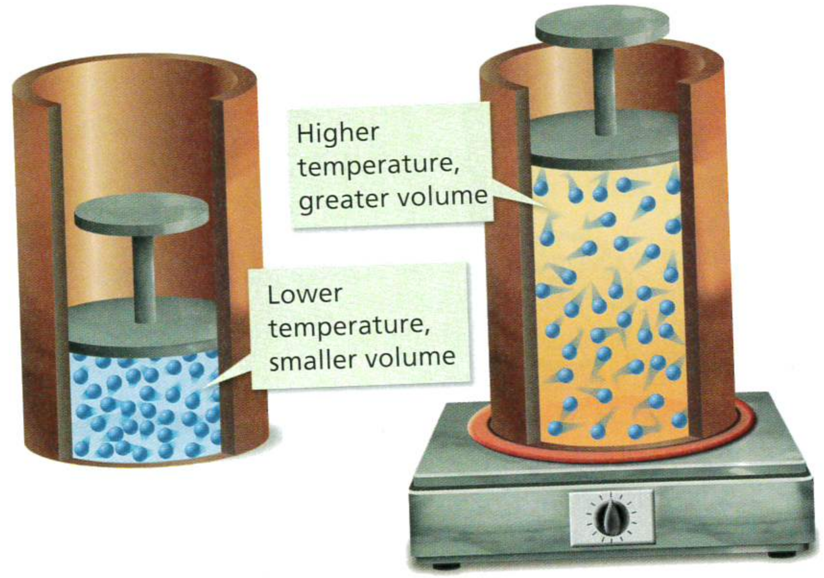
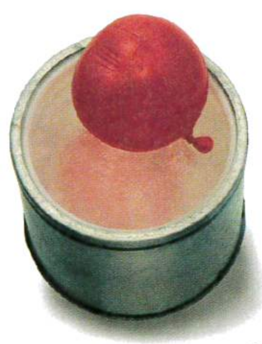
FIGURE 19
### Charles's Law
Changing the temperature of a gas at constant pressure changes its volume in a similar way.
**Inferring** *What happens to the gas particles in the balloon as the gas is warmed?*





▲ A gas-filled balloon is at room temperature.


▲ The balloon is lowered into liquid nitrogen at −196°C.


▲ The balloon shrinks as gas volume decreases.


▲ When removed from the nitrogen, the gas warms and the balloon expands.


▲ The balloon is at room temperature again.

## Volume and Temperature

In the late 1700s, French scientist Jacques Charles helped start a new sport. He and others took to the skies in the first hydrogen balloons. Charles's interest in balloon rides led him to discover how gas temperature and volume are related.

**Charles's Law** Jacques Charles examined the relationship between the temperature and volume of a gas that is kept at a constant pressure. He measured the volume of a gas at various temperatures in a container that could change volume. (A changeable volume allows the pressure to remain constant.) **Charles found that when the temperature of a gas is increased at constant pressure, its volume increases. When the temperature of a gas is decreased at constant pressure, its volume decreases.** This principle is called **Charles's law.**

**Charles's Law in Action** In Figure 19, you can see the effects of Charles's law demonstrated with a simple party balloon. Time-lapse photos show a balloon as it is slowly lowered into liquid nitrogen at nearly −200°C, then removed. The changes to the balloon's volume result from changes in the temperature of the air inside the balloon. The pressure remains more or less constant because the air is in a flexible container.



Now think again about a hot-air balloon. Heating causes the air inside the balloon to expand. Some of the warm air leaves through the bottom opening of the balloon, keeping the pressure constant. But now, the air inside is less dense than the air outside the balloon, so the balloon begins to rise. If the pilot allows the air in the balloon to cool, the reverse happens. The air in the balloon contracts, and more air enters through the opening. The density of the air inside increases, and the balloon starts downward.

Boyle, Charles, and others often described the behavior of gases by focusing on only two factors that vary at a time. In everyday life, however, gases can show the effects of changes in pressure, temperature, and volume all at once. People who work with gases, such as tire manufacturers and balloonists, must consider these combined effects.

**Reading Checkpoint** **What factor is kept unchanged when demonstrating Charles's law?**

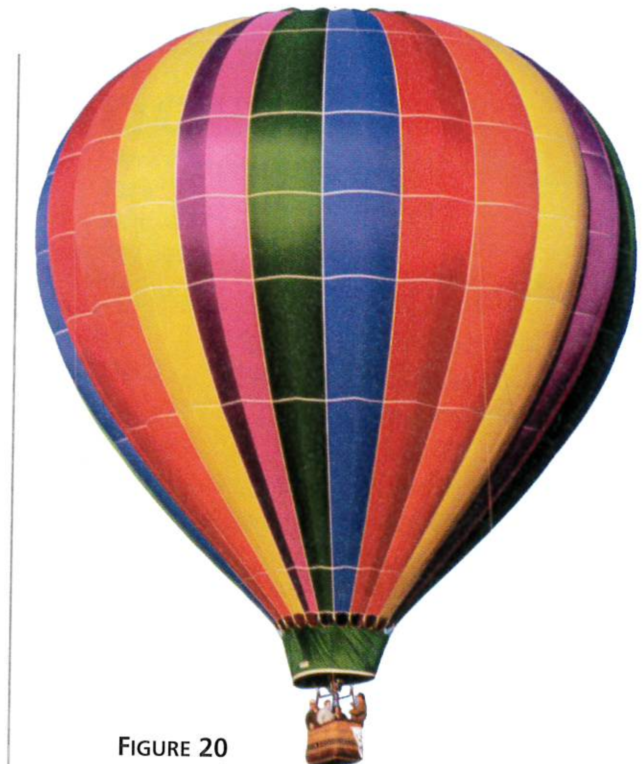


FIGURE 20
**Hot-Air Balloon**
Balloonists often use a propane burner to heat the air in a balloon.

## Section 3 Assessment

**Target Reading Skill** **Asking Questions** Use the answers to the questions you wrote about the headings to help you answer the questions below.

### Reviewing Key Concepts

1. a. **Defining** How is gas pressure defined?
   b. **Describing** Describe how the motions of gas particles are related to the pressure exerted by the gas.
   c. **Relating Cause and Effect** Why does pumping more air into a basketball increase the pressure inside the ball?
2. a. **Reviewing** How does Boyle's law describe the relationship between gas pressure and volume?
   b. **Explaining** Explain why increasing the temperature of a gas in a closed, rigid container causes the pressure in the container to increase.
   c. **Applying Concepts** Suppose it is the night before a big parade, and you are in charge of inflating the parade balloons. You just learned that the temperature will rise 15°C between early morning and the time the parade starts. How will this information affect the way you inflate the balloons?

**Math Practice**

3. **Using Formulas** Suppose the atmosphere exerts a force of 124,500 N on a kitchen table with an area of 1.5 $m^2$. What is the pressure in pascals of the atmosphere on the table?