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?**

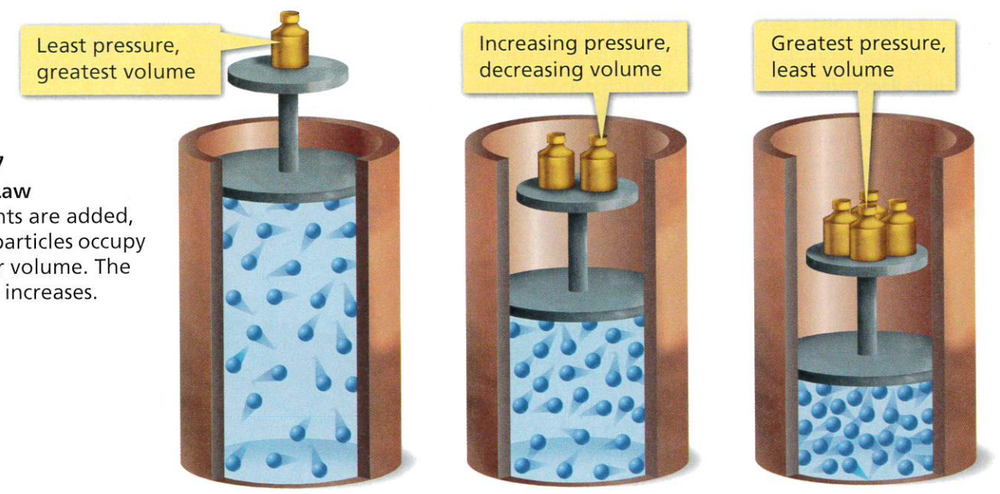

FIGURE 17
Boyle's Law
As weights are added, the gas particles occupy a smaller volume. The pressure increases.

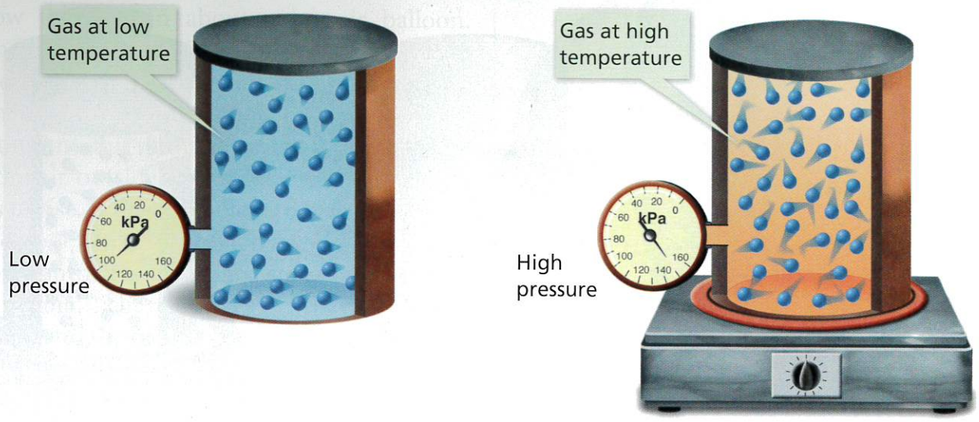

FIGURE 18
Gas Pressure and Temperature
When a gas is heated, the particles move faster and collide more often with each other and with the walls of their container. The pressure of the gas increases.

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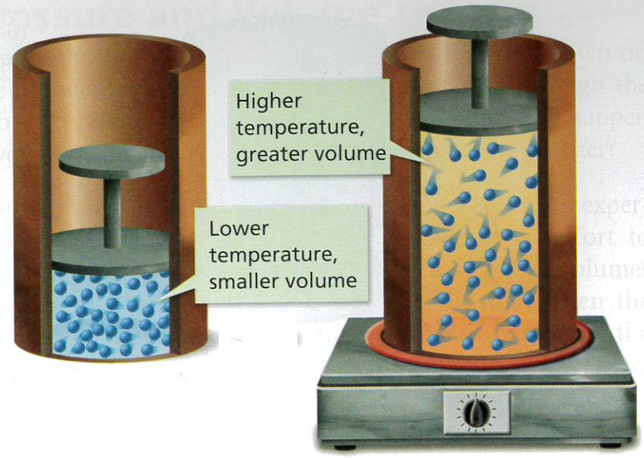
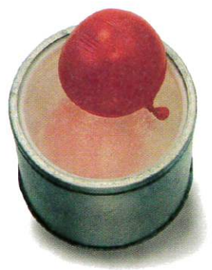
FIGURE 19
Charles's Law
Changing the temperature of a gas at constant pressure changes its volume in a similar way.
Inferring *What happens to the gas particles in the balloon as the gas is warmed?*




▲ 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.

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.


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


▲ The balloon is at room temperature again.

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?**

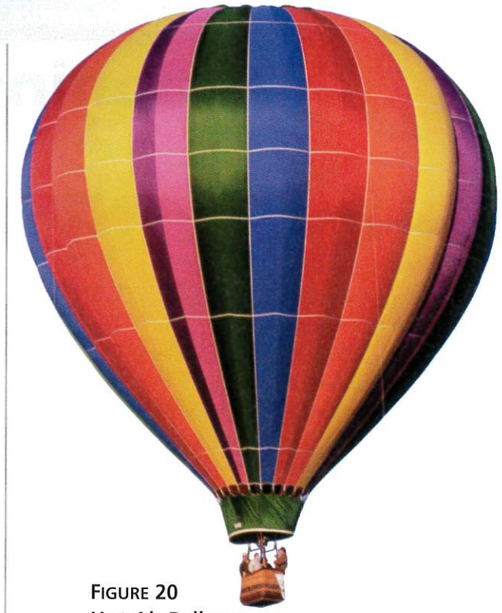


FIGURE 20
Hot-Air Balloon
Balloonists often use a propane burner to heat the air in a balloon.

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?