14.1 Properties of Gases

Connecting to Your World In organized soccer, there are rules about equipment. For international competitions, the ball's mass must be not more than 450 grams and not less than 410 grams. The pressure of the air inside the ball must be no lower than 0.6 atmospheres and no higher than 1.1 atmospheres at sea level. A ball that is properly inflated will rebound faster and travel farther than a ball that is under-inflated. If the pressure is too high, the ball may burst when it is kicked. In this section, you will study variables that affect the pressure of a gas.

Guide for Reading

Key Concepts

- Why are gases easier to compress than solids or liquids are?
- What are the three factors that affect gas pressure?

Vocabulary

compressibility

Reading Strategy

Relating Cause and Effect A cause makes something happen. As you read, write down three possible causes for an increase in gas pressure.

Compressibility

When a car comes to a sudden stop, the people in the car will continue to move forward unless they are restrained. The driver and any passengers are more likely to survive a collision if they are wearing seat belts to restrict their forward movement. Cars also contain air bags as a second line of defense. A sudden reduction in speed triggers a chemical reaction inside an air bag. One product of the reaction is nitrogen gas, which causes the bag to inflate. An inflated air bag keeps the driver from colliding with the steering wheel, as shown in Figure 14.1. An inflated air bag keeps a passenger from colliding with the dashboard or windshield.

Recall that a gas can expand to fill its container, unlike a solid or liquid. The reverse is also true. Gases are easily compressed, or squeezed into a smaller volume. **Compressibility** is a measure of how much the volume of matter decreases under pressure. Why does a collision with an inflated air bag cause much less damage than a collision with a steering wheel or dashboard? When a person collides with an inflated air bag, the impact forces the molecules of gas in the bag closer together. The compression of the gas absorbs the energy of the impact.

Figure 14.1 A crash dummy can be used to test the effectiveness of an air bag. Because gases can be compressed, the air bag absorbs some of the energy from the impact of a collision. Air bags work best when combined with seat belts.

Section Resources

Print

- **Guided Reading and Study Workbook,** Section 14.1
- **Core Teaching Resources,** Section 14.1 Review
- **Transparencies,** T150–T151

Technology

- **Interactive Textbook with ChemASAP,** Assessment 14.1
- **Go Online,** Section 14.1
- **Virtual Chemistry Labs,** Lab 15

14.1

1 FOCUS

Objectives

14.1.1 Explain why gases are easier to compress than solids or liquids are.

14.1.2 Describe the three factors that affect gas pressure.

Guide for Reading

Build Vocabulary L2

Word Parts Have students look up the meanings of the prefix *com-* (together), the word *press* (to act on with a steady force or weight), and the suffix *-ibility* (ability or tendency). Have them use these meanings to define *compressibility*.

Reading Strategy L2

Identify Main Ideas For each paragraph in this section, have students identify the main idea. They can use their list as a study guide.

2 INSTRUCT

Connecting to Your World

Ask students to examine the photograph that opens the section. Ask, **What factors affect the pressure of the air inside the ball?** *(the temperature of the air in the ball; and the volume of the ball)*

Compressibility

Discuss L2

Point out that in this chapter students will build upon their knowledge of kinetic theory to describe the behavior of gases. Ask, **What is kinetic energy?** *(energy of motion)* Ask, **How are temperature and kinetic energy related?** *(Temperature is a measure of average kinetic energy.)*

FYI

You may want to use the T&S feature on air bags in Chapter 12 on p. 376.

Use Visuals **L1**

Figure 14.2 This figure illustrates the amount of space in a gas under ordinary conditions. Ask, **Estimate the amount of space occupied by the molecules in the figure.** *(Students are likely to say less than 5%.)* Explain that, for practical reasons, in most drawings, the particles will be too close together for their depicted size. Remind students how small the actual particles are, and how many particles there are in a small volume of gas.

Factors Affecting Gas Pressure

Discuss **L2**

To assess students' knowledge of the kinetic theory, ask, **How can you describe gas pressure?** *(Gas pressure is the result of collisions of particles with their container.)* Ask, **How does increasing the number of particles in a gas affect the pressure?** *(The more particles colliding with the walls of a container, the higher the pressure.)*

Relate **L2**

Lead the class in a discussion of the four variables—volume, temperature, pressure, and number of moles—used to describe a gas. Discuss how the properties of gases lead to some unique uses of them. For example, because the particles in a gas are relatively far apart, gases are poor thermal conductors and are used for insulation between the glass panes in double-paned windows.

FYI

In this section, students look at the relationships between the variables *P*, *V*, *T*, and *n* qualitatively before addressing these relationships quantitatively in Section 14.2.

Go Online NSTA SCILINKS

Download a worksheet on **Gases** for students to complete, and find additional teacher support from NSTA SciLinks.

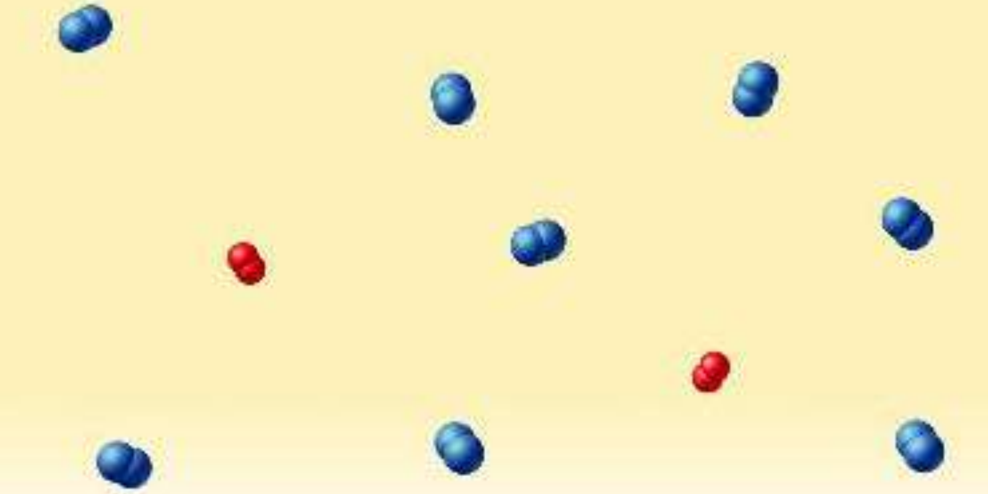

Figure 14.2 There are only a few nitrogen and oxygen molecules in this model of air. At room temperature, the distance between molecules in a container of air at standard pressure is about 10 times the diameter of a molecule.

Kinetic theory can explain why gases are compressed more easily than liquids or solids. **Gases are easily compressed because of the space between the particles in a gas.** Remember that the volume of the particles in a gas is small compared to the overall volume of the gas. So the distance between particles in a gas is much greater than the distance between particles in a liquid or solid. Under pressure, the particles in a gas are forced closer together, or compressed.

At room temperature, the distance between particles in an enclosed gas is about 10 times the diameter of a particle. Figure 14.2 is a model of an air sample at room temperature. Only oxygen and nitrogen—the two main gases in air—are represented. Note how few particles can fit in this relatively large space when the distance between particles is reasonable for the size of the particles. It isn't practical to represent the actual distances between particles in all the molecular drawings of gases in this book. The drawings would be too large to easily fit on a page. For the drawings to fit on a page, the particles must be drawn closer together.

Checkpoint ***How does the volume of the particles in a gas compare to the overall volume of the gas?***

Factors Affecting Gas Pressure

Kinetic theory can help explain other properties of gases, such as their ability to expand and take the shape and volume of their containers. Recall these assumptions about the particles in a gas. The particles move along straight-line paths until they collide with other particles or the walls of their container. The motion of the particles is constant and random. Because there are no significant forces of attraction or repulsion among particles in a gas, particles in a gas can move freely.

Four variables are generally used to describe a gas. The variables and their common units are pressure (P) in kilopascals, volume (V) in liters, temperature (T) in kelvins, and the number of moles (n). **The amount of gas, volume, and temperature are factors that affect gas pressure.**

Go Online NSTA SCILINKS

For: Links on Gases
Visit: www.SciLinks.org
Web Code: cdn-1141

Differentiated Instruction

Less Proficient Readers **L1**

Help students make a list of assumptions about gases in the kinetic theory. Review the list and ask for a behavior of gases related to each assumption.

Amount of Gas An air-filled raft blasts through a narrow opening between rocks and plummets over a short waterfall into churning white water below. The raft bends and twists, absorbing some of the pounding energy of the river. The strength and flexibility of the raft are impressive and rely on the pressure of the gas inside the raft. The raft must be made of a material that is strong enough to withstand the pressure of the air inside the raft. The material must also keep air from leaking out of the raft. The volume of the inflated raft in Figure 14.3 is dramatically larger than the volume of the raft before it is inflated. As air is added, the raft expands to its intended volume. The pressure of the air inside the raft keeps the raft inflated.

You can use kinetic theory to predict and explain how gases will respond to a change of conditions. If you inflate an air raft, for example, the pressure inside the raft will increase. Collisions of particles with the inside walls of the raft result in the pressure that is exerted by the enclosed gas. By adding gas, you increase the number of particles. Increasing the number of particles increases the number of collisions, which explains why the gas pressure increases.

Figure 14.3 The volume of this air-filled raft is much larger than its volume before it was inflated. Using a pump to force air into a raft increases the pressure of the air inside the raft. The increased pressure causes the raft to inflate to its intended size.

Figure 14.4 shows what happens when gas is added to an enclosed, rigid container. Because the container is rigid, the volume of the gas is constant. Assume also that the temperature of the gas does not change. Under these conditions, doubling the number of particles of gas doubles the pressure. Tripling the number of particles triples the pressure, and so on. With a powerful pump and a strong container, you can generate very high pressures by adding more and more gas. However, once the pressure exceeds the strength of the container, the container will burst. Removing gas from a rigid container has the opposite effect. As the amount of gas is reduced, the pressure inside the container is reduced.

Figure 14.4 When a gas is pumped into a closed rigid container, the pressure increases as more particles are added. If the number of particles is doubled, the pressure will double. **Predicting** ***What would happen to the pressure in the container if the number of particles were tripled? If the number of particles were cut in half?***

Use Visuals L1

Figures 14.3 and 14.4 Make sure students understand the difference between a container with a volume that can vary (within limits), such as a balloon or raft, and a rigid container with a constant volume.

TEACHER Demo

Pressure and Particle Size L2

Purpose Students use an analogy to infer the effect of particle size on gas pressure.

Materials 2 identical glass containers, 2 different sizes of beads

Procedure Add small beads to a glass container until it is approximately one-eighth full. Add the same number of larger beads to an identical container. Have the students assume that the beads represent particles of gases in sealed containers at the same temperature. Ask students to compare the pressures in the two containers.

Expected Outcome The pressures will be identical because both gases contain the same number of particles with the same average kinetic energy in the same volume.

Differentiated Instruction

Special Needs L1

Inflate a deflated object with a pump. During the process, ask students to describe and explain what is happening. Ask students to predict what will happen when you remove air from the inflated object. Then deflate the object.

Answers to...

Figure 14.4 The pressure would triple; the pressure would be cut in half.

Checkpoint The volume of the particles is much smaller than the overall volume of the gas.

Discuss **L2**

Ask students to think about why the instructions on an aerosol say to hold the can upright while spraying. Ask, **If the can is not held upright, what material will come out of the can?** *(the propellant)* **How would the loss of propellant affect the use of the can when it is later held upright and sprayed?** *(The amount of propellant is reduced, so there is less pressure to force the paint out of the can.)*

Use Visuals **L1**

Figure 14.6 Figure 14.6 is the first of the drawings that show a piston and cylinder. If possible, show students an actual piston and cylinder. Explain how the tight fit of the piston in the cylinder keeps the gas contained and, thus, able to be compressed. Ask, **What will happen to the pressure in the cylinder as the volume is decreased?** *(Pressure will increase.)* Point out that the number of particles in both diagrams is the same. Then ask, **Why does the pressure of a contained gas double when the volume is reduced by one-half?** *(Reducing the volume by one-half doubles the number of simultaneous collisions of particles with the walls of the piston, doubling the pressure.)*

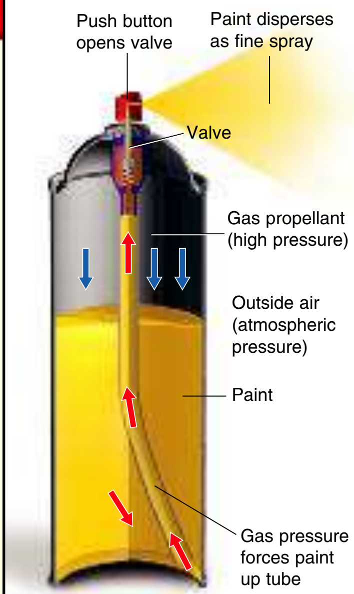

Figure 14.5 The pressure of the gas inside a new can of spray paint is greater than the air pressure outside the can. When gas rushes though an opening in the top of the can, it propels, or forces, paint out of the can. As the can is used, the pressure of the propellant decreases.
Relating Cause and Effect ***What happens when the pressure of the propellant equals the air pressure outside the can?***

If the pressure of the gas in a sealed container is lower than the outside air pressure, air will rush into the container when the container is opened. This movement causes the whoosh you hear when you open a vacuum-packed container. When the pressure of a gas in a sealed container is higher than the outside air pressure, the gas will flow out of the container when the container is unsealed.

Aerosol cans depend on the movement of a gas from a region of high pressure to a region of lower pressure. Aerosol cans may contain whipped cream, hair mousse, or spray paint. Figure 14.5 shows how a can of spray paint works. The can contains a gas stored at high pressure. The air outside the can is at a lower pressure. Pushing the spray button creates an opening between the inside of the can and the air outside. The gas flows through the opening to the lower pressure region outside. The movement of the gas propels, or forces, the paint out of the can. As the gas is depleted, the pressure inside the can decreases until the gas can no longer propel paint from the can.

Volume You can raise the pressure exerted by a contained gas by reducing its volume. The more the gas is compressed, the greater is the pressure that the gas exerts inside the container. When gas is in a cylinder, as in an automobile engine, a piston can be used to reduce its volume. The snug-fitting piston keeps gas from escaping as the cylinder moves down and up.

Figure 14.6 shows a cylinder of gas under two different conditions. When the cylinder has a volume of 1 L, the gas exerts a pressure of 100 kPa. When the volume is halved to 0.5 L, the pressure is doubled to 200 kPa. Increasing the volume of the contained gas has the opposite effect. If the volume is doubled, the particles can expand into a volume that is twice the original volume. With the same number of particles in twice the volume, the pressure of the gas is cut in half.

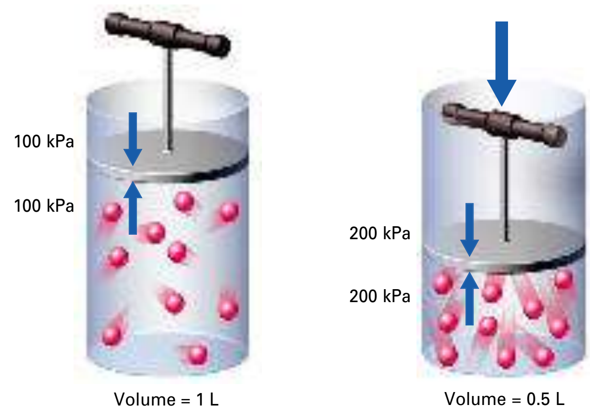

Figure 14.6 A piston can be used to force a gas in a cylinder into a smaller volume. When the volume is decreased, the pressure the gas exerts is increased.
Interpreting Diagrams ***What happens to the gas pressure when the volume is reduced from 1 L to 0.5 L?***

Facts and Figures

Gas and Momentum

The particles in a gas have momentum, the product of their mass and velocity (*mv*). The pressure exerted by a gas in a given volume is proportional to the average kinetic energy of its molecules (1/2 mv^2). The mass of the particles is constant, so any change in momentum is due to a change in velocity. A rise in temperature reflects a rise in average kinetic energy, corresponding to an increase in momentum and pressure.

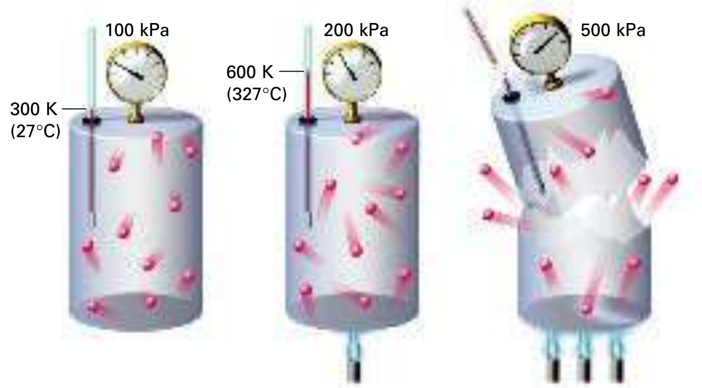

Figure 14.7 An increase in temperature causes an increase in the pressure of an enclosed gas. The container can explode if there is too great an increase in the pressure.

Temperature A sealed bag of potato chips bulges at the seams when placed in a sunny location. The bag bulges because an increase in the temperature of an enclosed gas causes an increase in its pressure. You can use kinetic theory to explain what happens. As a gas is heated, the temperature increases and the average kinetic energy of the particles in the gas increases. Faster-moving particles impact the walls of their container with more energy.

Look at Figure 14.7. The volume of the container and the amount of gas is constant. When the Kelvin temperature of the enclosed gas doubles from 300 K to 600 K, the pressure of the enclosed gas doubles from 100 kPa to 200 kPa. A gas in a sealed container may generate enormous pressure when heated. For that reason, an aerosol can, even an "empty" one, may explode if thrown onto a fire. By contrast, as the temperature of an enclosed gas decreases, the pressure decreases. The particles, on average, move more slowly and have less kinetic energy. They strike the container walls with less force. Halving the Kelvin temperature of a gas in a rigid container decreases the gas pressure by half.

14.1 Section Assessment

1. **Key Concept** Why is a gas easy to compress?
2. **Key Concept** List three factors that can affect gas pressure.
3. Why does a collision with an air bag cause less damage than a collision with a steering wheel?
4. How does a decrease in temperature affect the pressure of a contained gas?
5. If the temperature is constant, what change in volume would cause the pressure of an enclosed gas to be reduced to one quarter of its original value?
6. Assuming the gas in a container remains at a constant temperature, how could you increase the gas pressure in the container a hundredfold?

Writing Activity

Explaining Aerosol Cans Write a paragraph explaining how the compressed gas in an aerosol can force paint out of the can. Describe how the gas pressure inside the can changes as the paint is sprayed, and identify the variable that causes this change. Refer to Figure 14.5.

Interactive Textbook

Assessment 14.1 Test yourself on the concepts in Section 14.1.

with ChemASAP

3 ASSESS

Evaluate Understanding L2

Determine students' understanding of gas pressure. Ask, **What effect would tripling the number of particles of a gas in a closed container have on the pressure exerted?** *(The pressure would triple.)* **What effect would doubling the volume of an enclosed gas have on the pressure?** *(The pressure would decrease by one half.)* **How does the pressure of an enclosed gas change with increasing temperature?** *(The number and force of collisions increase with temperature, and the pressure increases.)*

Reteach L1

Help students make a table to summarize how gas pressure changes as variables increase or decrease. Label the rows *Volume, Temperature,* and *Number of Particles.* Label the columns *Increase* and *Decrease.* Have students use up or down arrows to complete the table.

Writing Activity

The pressure of the gas inside the can is greater than atmospheric pressure. As the gas is used to propel the paint out the can, the number of particles of gas in the can decreases and the pressure of the gas decreases.

Interactive Textbook

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 14.1.

with ChemASAP

Section 14.1 Assessment

1. Gases are easily compressed because of the space between particles in a gas.
2. temperature, pressure, and amount of gas
3. Because the gas in the inflated air bag can be compressed, the bag absorbs some of the energy from the impact of a collision. The solid steering wheel cannot.
4. If the temperature decreases, the pressure will also decrease.
5. The volume would need to increase by a factor of four.
6. Increase the amount of gas in the container one hundredfold.

Answers to...

Figure 14.5 The gas can no longer propel the product out of the can.

Figure 14.6 The pressure is doubled from 100 kPa to 200 kPa.