Please return

Four States of Matter

Terms to Learn

- states of matter
- solid
- liquid
- gas
- pressure
- Boyle's law
- Charles's law
- plasma

What You'll Do

- Describe the properties shared by particles of all matter.
- Describe the four states of matter discussed here.
- Describe the differences between the states of matter.
- Predict how a change in pressure or temperature will affect the volume of a gas.

Figure 1 shows a model of the earliest known steam engine, invented about A.D. 60 by Hero, a scientist who lived in Alexandria, Egypt. This model also demonstrates the four most familiar states of matter: solid, liquid, gas, and plasma. The **states of matter** are the physical forms in which a substance can exist. For example, water commonly exists in three different states of matter: solid (ice), liquid (water), and gas (steam).

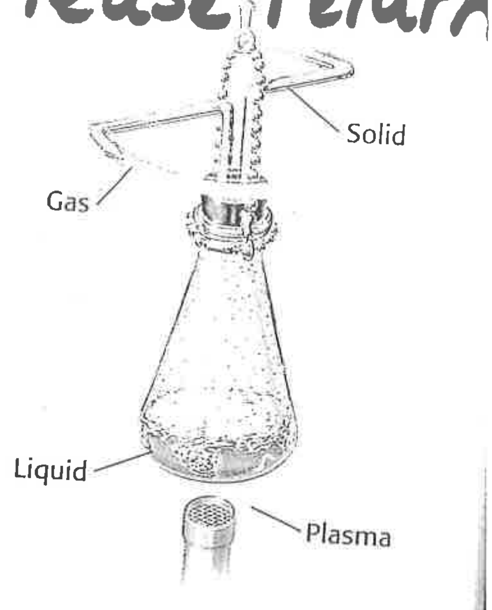


Figure 1 *This model of Hero's steam engine spins as steam escapes through the nozzles.*

Moving Particles Make Up All Matter

Matter consists of tiny particles called atoms and molecules (MAHL i KYOOLZ) that are too small to see without an amazingly powerful microscope. These atoms and molecules are always in motion and are constantly bumping into one another. The state of matter of a substance is determined by how fast the particles move and how strongly the particles are attracted to one another. **Figure 2** illustrates three of the states of matter—solid, liquid, and gas—in terms of the speed and attraction of the particles.

Figure 2 Models of a Solid, a Liquid, and a Gas

Particles of a solid do not move fast enough to overcome the strong attraction between them, so they are held tightly in place. The particles vibrate in place.

Particles of a liquid move fast enough to overcome some of the attraction between them. The particles are able to slide past one another.

Particles of a gas move fast enough to overcome nearly all of the attraction between them. The particles move independently of one another.

Solids Have Definite Shape and Volume

Look at the ship in **Figure 3.** Even in a bottle, it keeps its original shape and volume. If you moved the ship to a larger bottle, the ship's shape and volume would not change. Scientifically, the state in which matter has a definite shape and volume is **solid.** The particles of a substance in a solid are very close together. The attraction between them is stronger than the attraction between the particles of the same substance in the liquid or gaseous state. The atoms or molecules in a solid move, but not fast enough to overcome the attraction between them. Each particle vibrates in place because it is locked in position by the particles around it.

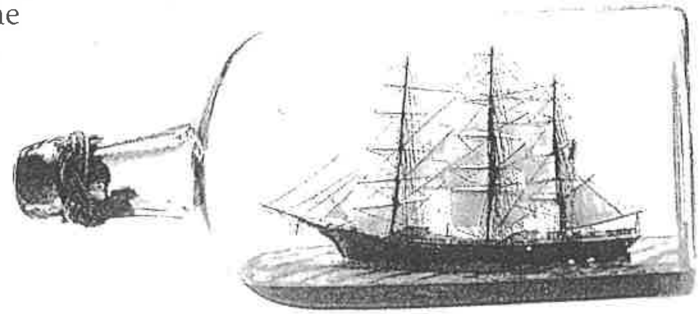


Figure 3 *Because this ship is a solid, it does not take the shape of the bottle.*

Activity

Imagine that you are a particle in a solid. Your position in the solid is your chair. In your ScienceLog, describe the different types of motion that are possible even though you cannot leave your chair.

Two Types of Solids Solids are often divided into two categories—*crystalline* and *amorphous* (uh MOHR fuhs). Crystalline solids have a very orderly, three-dimensional arrangement of atoms or molecules. That is, the particles are arranged in a repeating pattern of rows. Examples of crystalline solids include iron, diamond, and ice. Amorphous solids are composed of atoms or molecules that are in no particular order. That is, each particle is in a particular spot, but the particles are in no organized pattern. Examples of amorphous solids include rubber and wax. **Figure 4** illustrates the differences in the arrangement of particles in these two solids.

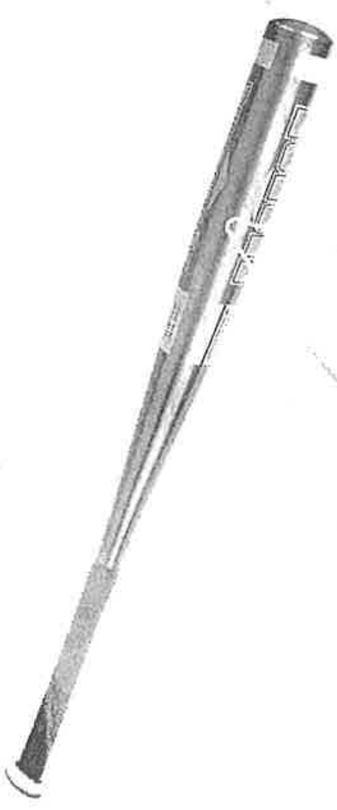
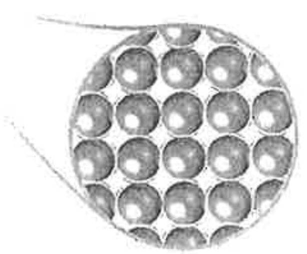
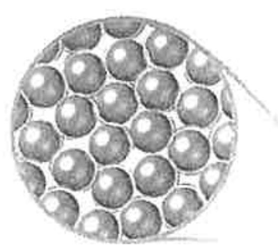


Figure 4 *Differing arrangements of particles in crystalline solids and amorphous solids lead to different properties. Imagine trying to hit a home run with a rubber bat!*

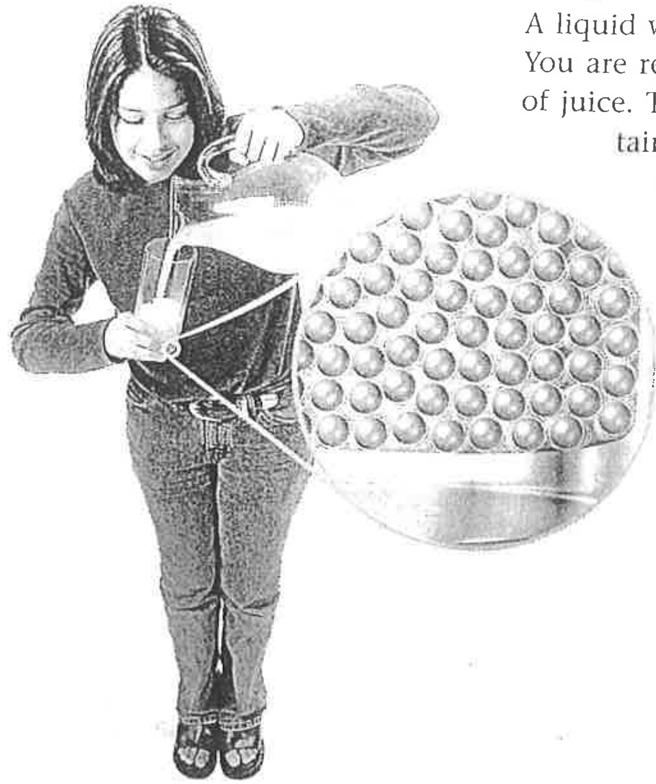


The particles in a **crystalline solid** have a very orderly arrangement.



The particles in an **amorphous solid** do not have an orderly arrangement.

Liquids Change Shape but Not Volume



A liquid will take the shape of whatever container it is put in. You are reminded of this every time you pour yourself a glass of juice. The state in which matter takes the shape of its container and has a definite volume is **liquid.** The atoms or molecules in liquids move fast enough to overcome some of the attractions between them. The particles slide past each other until the liquid takes the shape of its container. **Figure 5** shows how the particles in juice might look if they were large enough to see.

Even though liquids change shape, they do not readily change volume. You know that a can of soda contains a certain volume of liquid regardless of whether you pour it into a large container or a small one. **Figure 6** illustrates this point using a beaker and a graduated cylinder.

Figure 5 *Particles in a liquid slide past one another until the liquid conforms to the shape of its container.*

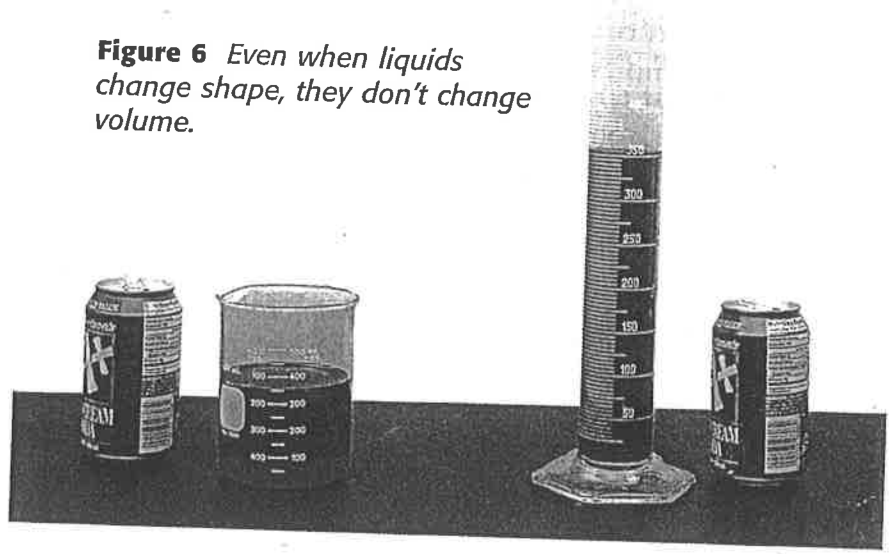


Figure 6 *Even when liquids change shape, they don't change volume.*

BRAIN FOOD

The Boeing 767 Freighter, a type of commercial airliner, has 187 km (116 mi) of hydraulic tubing.

The Squeeze Is On Because the particles in liquids are close to one another, it is difficult to push them closer together. This makes liquids ideal for use in hydraulic (hie DRAW lik) systems. For example, brake fluid is the liquid used in the brake systems of cars. Stepping on the brake pedal applies a force to the liquid. The particles in the liquid move away rather than squeezing closer together. As a result, the fluid pushes the brake pads outward against the wheels, which slows the car.

A Drop in the Bucket Two other important properties of liquids are *surface tension* and *viscosity* (vis KAHS uh tee). Surface tension is the force acting on the particles at the surface of a liquid that causes the liquid to form spherical drops, as shown in **Figure 7.** Different liquids have different surface tensions. For example, rubbing alcohol has a lower surface tension than water, but mercury has a higher surface tension than water.

Viscosity is a liquid's resistance to flow. In general, the stronger the attractions between a liquid's particles are, the more viscous the liquid is. Think of the difference between pouring honey and pouring water. Honey flows more slowly than water because it has a higher viscosity than water.

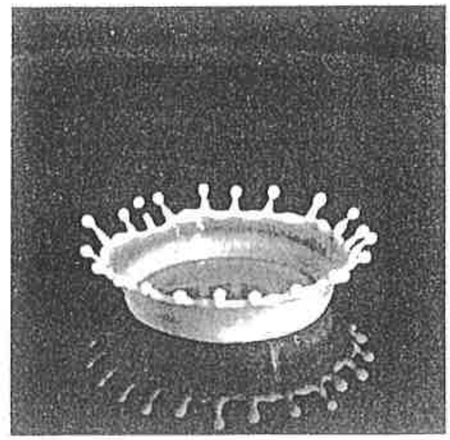


Figure 7 *Liquids form spherical drops as a result of surface tension.*

Gases Change Both Shape and Volume

How many balloons can be filled from a single metal cylinder of helium? The number may surprise you. One cylinder can fill approximately 700 balloons. How is this possible? After all, the volume of the metal cylinder is equal to the volume of only about five inflated balloons.

It's a Gas! Helium is a gas. **Gas** is the state in which matter changes in both shape and volume. The atoms or molecules in a gas move fast enough to break away completely from one another. Therefore, the particles of a substance in the gaseous state have less attraction between them than particles of the same substance in the solid or liquid state. In a gas, there is empty space between particles.

The amount of empty space in a gas can change. For example, the helium in the metal cylinder consists of atoms that have been forced very close together, as shown in **Figure 8.** As the helium fills the balloon, the atoms spread out, and the amount of empty space in the gas increases. As you continue reading, you will learn how this empty space is related to pressure.

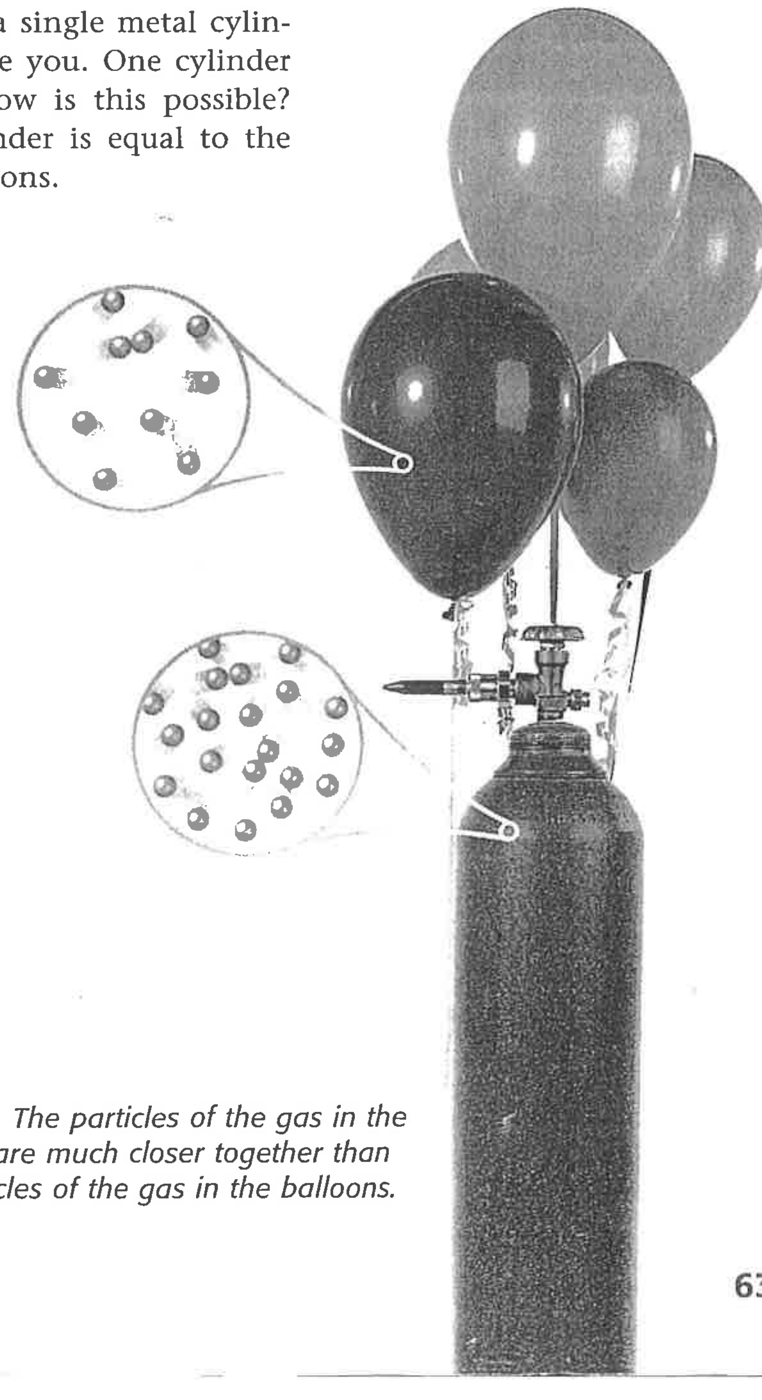


Figure 8 *The particles of the gas in the cylinder are much closer together than the particles of the gas in the balloons.*

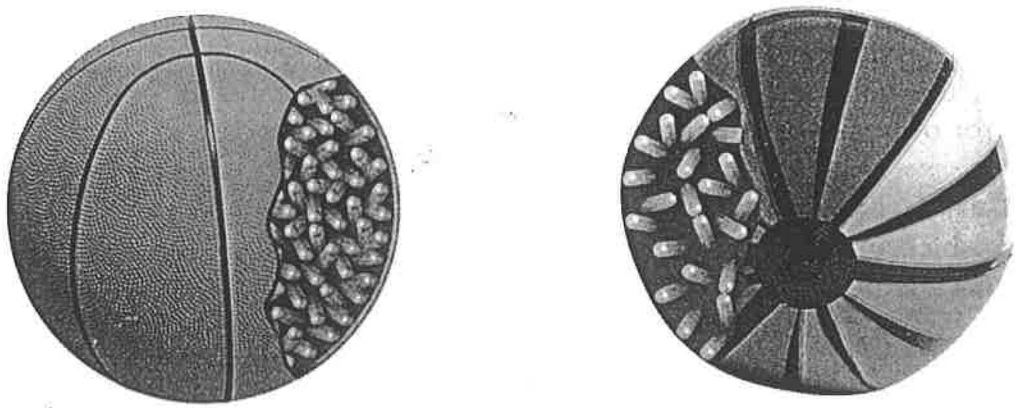
Gas Under Pressure

Pressure is the amount of force exerted on a given area. You can think of this as the number of collisions of particles against the inside of the container. Compare the basketball with the beach ball in **Figure 9.** The balls have the same volume and contain particles of gas (air) that constantly collide with one another and with the inside surface of the balls. Notice, however, that there are more particles in the basketball than in the beach ball. As a result, more particles collide with the inside surface of the basketball than with the inside surface of the beach ball. When the number of collisions increases, the force on the inside surface of the ball increases. This increased force leads to increased pressure.

Self-Check

How would an increase in the speed of the particles affect the pressure of gas in a metal cylinder? *(See page 724 to check your answer.)*

Figure 9 *Both balls shown here are full of air, but the pressure in the basketball is higher than the pressure in the beach ball.*



The basketball has a higher pressure than the beach ball because the greater number of particles of gas are closer together. Therefore, they collide with the inside of the ball at a faster rate.

The beach ball has a lower pressure than the basketball because the lesser number of particles of gas are farther apart. Therefore, they collide with the inside of the ball at a slower rate.

REVIEW

1. List two properties that all particles of matter have in common.
2. Describe solids, liquids, and gases in terms of shape and volume.
3. Why can the volume of a gas change?
4. **Applying Concepts** Explain what happens inside the ball when you pump up a flat basketball.

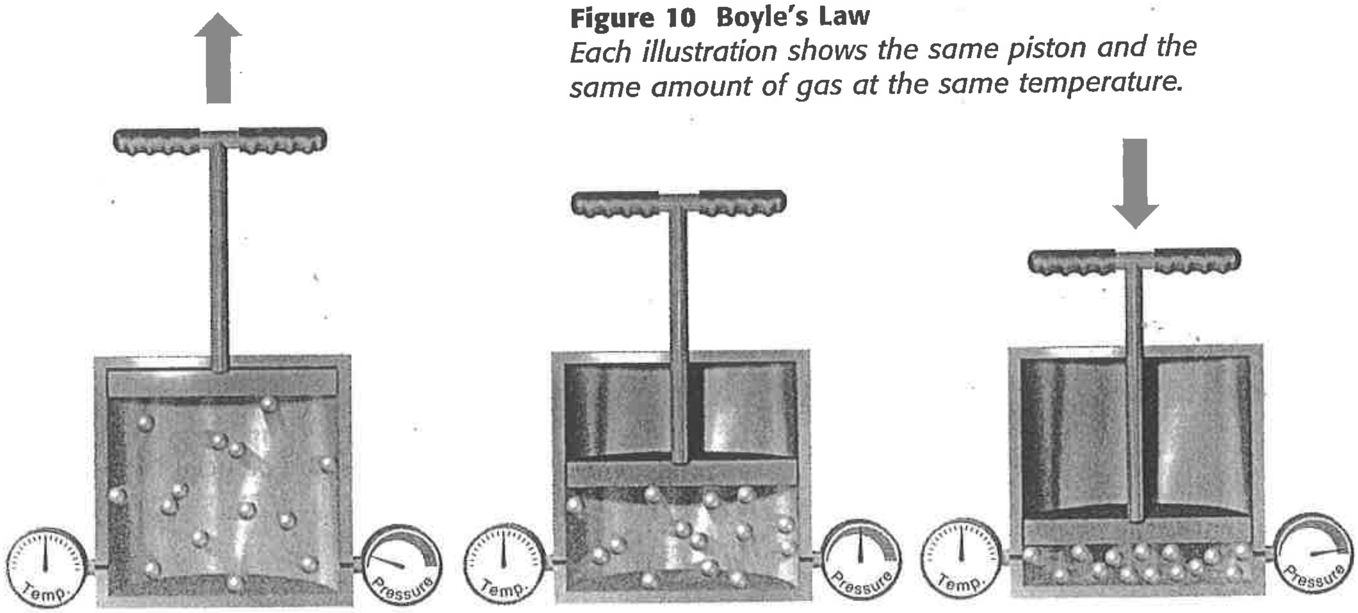
Laws Describe Gas Behavior

Earlier in this chapter, you learned about the atoms and molecules in both solids and liquids. You learned that compared with gas particles, the particles of solids and liquids are closely packed together. As a result, solids and liquids do not change volume very much. Gases, on the other hand, behave differently; their volume can change by a large amount.

It is easy to measure the volume of a solid or liquid, but how do you measure the volume of a gas? Isn't the volume of a gas the same as the volume of its container? The answer is yes, but there are other factors, such as pressure, to consider.

Boyle's Law Imagine a diver at a depth of 10 m blowing a bubble of air. As the bubble rises, its volume increases. By the time the bubble reaches the surface, its original volume will have doubled due to the decrease in pressure. The relationship between the volume and pressure of a gas is known as Boyle's law because it was first described by Robert Boyle, a seventeenth-century Irish chemist. **Boyle's law** states that for a fixed amount of gas at a constant temperature, the volume of a gas increases as its pressure decreases. Likewise, the volume of a gas decreases as its pressure increases. Boyle's law is illustrated by the model in **Figure 10.**

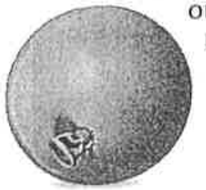
Figure 10 Boyle's Law
Each illustration shows the same piston and the same amount of gas at the same temperature.



Lifting the plunger decreases the pressure of the gas. The particles of gas spread farther apart. The volume of the gas increases as the pressure decreases.

Releasing the plunger allows the gas to change to an intermediate volume and pressure.

Pushing the plunger increases the pressure of the gas. The particles of gas are forced closer together. The volume of the gas decreases as the pressure increases.



See Charles's law in action for yourself using a balloon on page 636 of the LabBook.

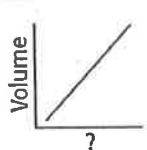
MATH BREAK

Gas Law Graphs

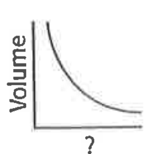
Each graph below illustrates a gas law. However, the variable on one axis of each graph is not labeled. Answer the following questions for each graph:

1. As the volume increases, what happens to the missing variable?
2. Which gas law is shown?
3. What label belongs on the axis?
4. Is the graph linear or nonlinear? What does this tell you?

Graph A



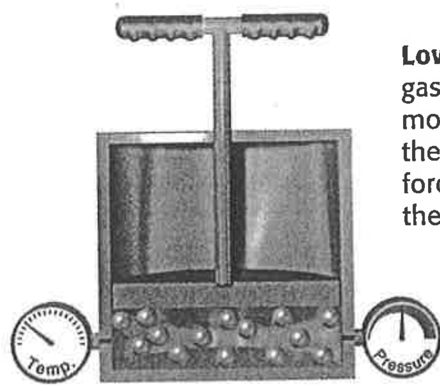
Graph B



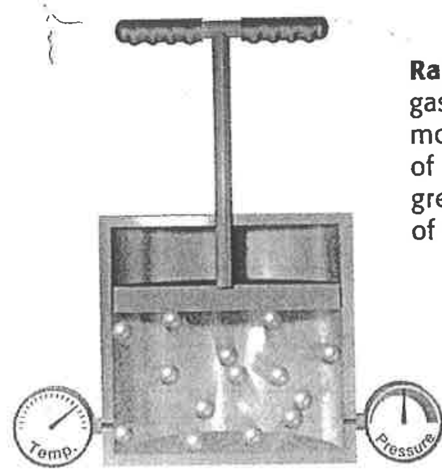
Weather balloons demonstrate a practical use of Boyle's law. A weather balloon carries equipment into the atmosphere to collect information used to predict the weather. This balloon is filled with only a small amount of gas because the pressure of the gas decreases and the volume increases as the balloon rises. If the balloon were filled with too much gas, it would pop as the volume of the gas increased.

Charles's Law An inflated balloon will also pop when it gets too hot, demonstrating another gas law—Charles's law. **Charles's law** states that for a fixed amount of gas at a constant pressure, the volume of the gas increases as its temperature increases. Likewise, the volume of the gas decreases as its temperature decreases. Charles's law is illustrated by the model in **Figure 11.** You can see Charles's law in action by putting an inflated balloon in the freezer. Wait about 10 minutes, and see what happens!

Figure 11 Charles's Law
Each illustration shows the same piston and the same amount of gas at the same pressure.

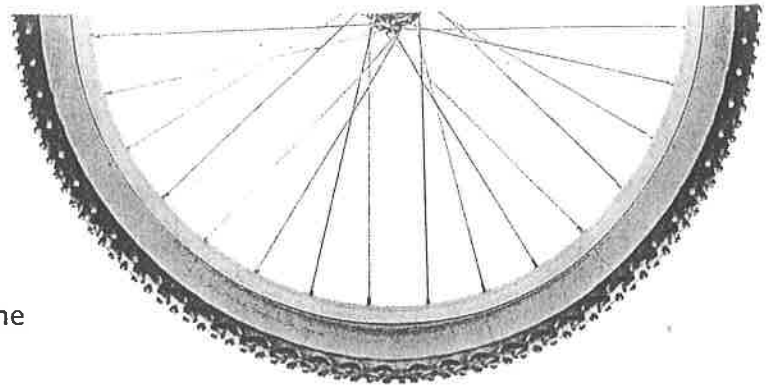


Lowering the temperature of the gas causes the particles to move more slowly. They hit the sides of the piston less often and with less force. As a result, the volume of the gas decreases.



Raising the temperature of the gas causes the particles to move more quickly. They hit the sides of the piston more often and with greater force. As a result, the volume of the gas increases.

APPLY



Charles's Law and Bicycle Tires

One of your friends overinflated the tires on her bicycle. Use Charles's law to explain why she should let out some of the air before going for a ride on a hot day.

Plasmas

Scientists estimate that more than 99 percent of the known matter in the universe, including the sun and other stars, is made of a state of matter called plasma. **Plasma** is the state of matter that does not have a definite shape or volume and whose particles have broken apart.

Plasmas have some properties that are quite different from the properties of gases. Plasmas conduct electric current, while gases do not. Electric and magnetic fields affect plasmas but do not affect gases. In fact, strong magnetic fields are used to contain very hot plasmas that would destroy any other container.

Natural plasmas are found in lightning, fire, and the incredible light show in **Figure 12,** called the aurora borealis (ah ROHR uh BOHR ee AL is). Artificial plasmas, found in fluorescent lights and plasma balls, are created by passing electric charges through gases.

Figure 12 *Auroras, like the aurora borealis seen here, form when high-energy plasma collides with gas particles in the upper atmosphere.*

REVIEW

1. When scientists record the volume of a gas, why do they also record the temperature and the pressure?
2. List two differences between gases and plasmas.
3. **Applying Concepts** What happens to the volume of a balloon left on a sunny windowsill? Explain.

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