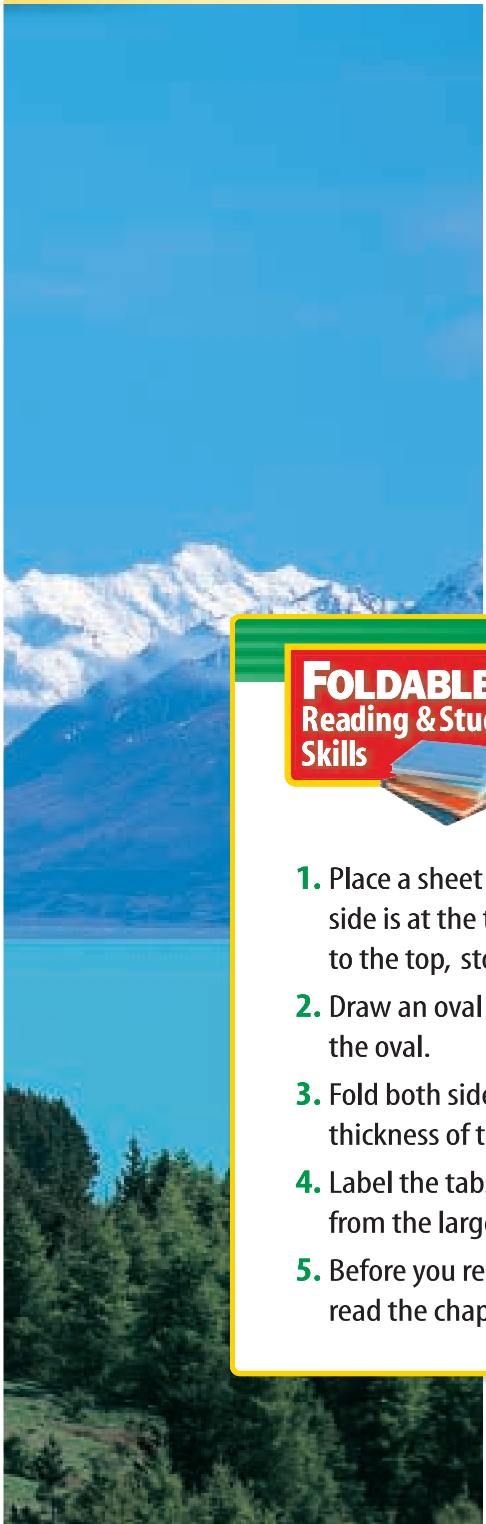
CHAPTER 16

Solids, Liquids, and Gases

If you were traveling on this scenic highway, you couldn't help but notice the lake beside the road and the beautiful, snowcapped mountain in the distance. The clouds you see were formed when water in the air (a gas) came together to form droplets. In this chapter you will learn about the three states of matter—solid, liquid, and gas.

What do you think?

Science Journal Look at the picture below with a classmate. Discuss what you think this might be. Here's a hint: *It may be on your windows on a cold winter day.* Write your answer or best guess in your Science Journal.

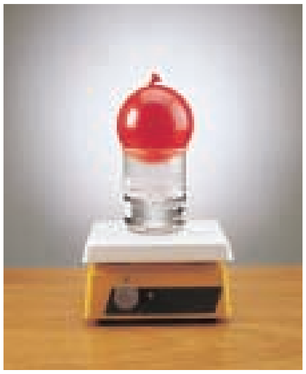


EXPLORE ACTIVITY

Why does the mercury in a thermometer rise? Why do sidewalks have cracks? Many substances expand when heated and contract when cooled as you will see during this activity.

Safety Precautions Use caution when handling hot items.

Observe the expansion and contraction of air



1. Blow up a balloon until it is half filled. Use a tape measure to measure the circumference of the balloon.
2. Pour water into a large beaker until it is half full. Place the beaker on a hotplate and wait for the water to boil.
3. Set the balloon on the mouth of beaker and observe for five minutes. Be careful not to allow the balloon to touch the hotplate. Measure the circumference of the balloon.

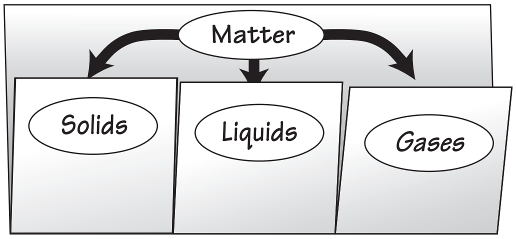
Observe

Write a paragraph in your Science Journal describing the changing size of the balloon's circumference. Infer why the balloon's circumference changed.

Before You Read

FOLDABLES Reading & Study Skills

Making a Concept Map Study Fold **Make the following Foldable to help you organize information by diagramming ideas about solids, liquids, and gases.**



1. Place a sheet of paper in front of you so the long side is at the top. Fold the bottom of the paper to the top, stopping about 4 cm from the top.
2. Draw an oval above the fold. Write *Matter* inside the oval.
3. Fold both sides in and then unfold. Through the top thickness of the paper, cut along each of the fold lines to form three tabs.
4. Label the tabs *Solids, Liquids,* and *Gases* and draw an oval around each word. Draw arrows from the large oval to the smaller ovals.
5. Before you read, list examples of each you already know on the front of the tabs. As you read the chapter, add to your lists.

SECTION 1

Kinetic Theory

As You Read

What You'll Learn

- **Explain** the kinetic theory of matter.
- **Describe** particle movement in the four states of matter.
- **Explain** particle behavior at the melting and boiling points.

Vocabulary

kinetic theory
melting point
heat of fusion
heat of vaporization
boiling point
diffusion
plasma
thermal expansion

Why It's Important

You can use energy that is lost or gained when a substance changes from one state to another.

States of Matter

If you don't finish lunch quickly, you'll be late for practice. The soup is boiling on the stove. You hastily pour the soup into the bowl, but now it's too hot to eat. You add an ice cube and stir. The soup's temperature drops—now you can eat it without burning your tongue. Does this sound familiar? If you look closely at the situation, as shown in **Figure 1,** you can identify two states or phases of matter—solid and liquid. The boiling soup on the stove is in the liquid state. The steam directly above the boiling soup also is in the liquid state. The ice cube you dropped into your soup is in the solid state. Do these states have anything in common? How do they differ? Take a closer look at what is going on at the particle level in the three states of matter.

Kinetic Theory The **kinetic theory** is an explanation of how particles in matter behave. To explain the behavior of particles, it is necessary to make some basic assumptions. The three assumptions of the kinetic theory are as follows:

1. All matter is composed of small particles (atoms, molecules, and ions).
2. These particles are in constant, random motion.
3. These particles are colliding with each other and the walls of their container.

Particles lose some energy during collisions with other particles. But the amount of energy lost is very small and can be neglected in most cases.

To visualize the kinetic theory, think of each particle as a tiny table tennis ball in constant motion. These balls are bouncing and colliding with each other. Mentally visualizing matter in this way can help you understand the movement of particles in matter.

Figure 1
Two states of water are present in this photograph.
Can you identify the solid and liquid states?

Thermal Energy Think about the ice cube in the soup. Does the ice cube appear to be moving? How can a frozen, solid ice cube have motion? Remember to focus on the particles. Atoms in solids are held tightly in place by the attraction between the particles. This attraction between the particles gives solids a definite shape and volume. However, the thermal energy in the particles causes them to vibrate in place. Thermal energy is the total energy of a material's particles, including kinetic—vibrations and movement within and between the particles—and potential—resulting from forces that act within or between particles. When the temperature of the substance is lowered, the particles will have less thermal energy and will vibrate more slowly.

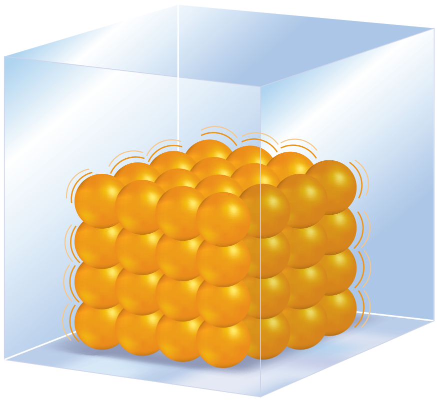


Figure 2
The particles in a solid are packed together tightly and are constantly vibrating in place.

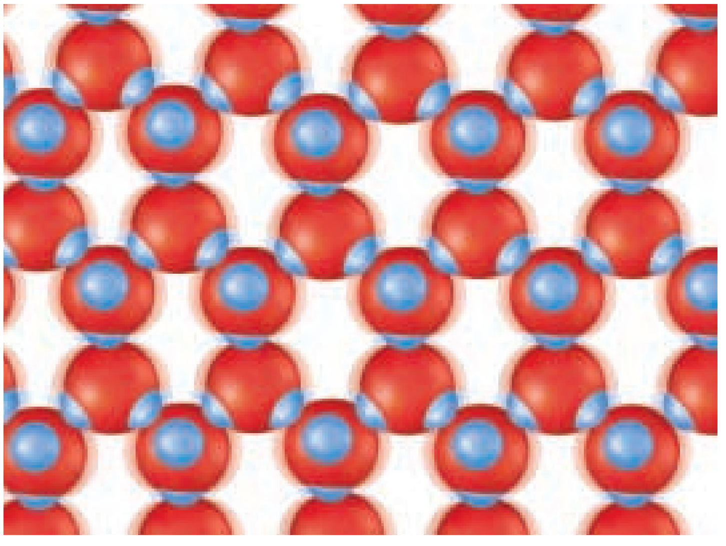
Reading Check *What is thermal energy?*

Average Kinetic Energy Temperature is the term used to explain how hot or cold an object is. In science, temperature means the average kinetic energy in the substance, or how fast the particles are moving. On average, molecules of frozen water at 0°C will move slower than molecules of water at 100°C. Therefore, water molecules at 0°C have lower average kinetic energy than the molecules at 100°C. Molecules will have some movement and kinetic energy at all temperatures, except at absolute zero. Scientists theorize that at absolute zero, or –273.15°C, particle motion is so slow that thermal energy is equal to zero.

Reading Check *How are kinetic energy and temperature related?*

Solid State An ice cube is an example of a solid. The particles of a solid are closely packed together, as shown in **Figure 2.** Most solid materials have a specific type of geometric arrangement in which they form when cooled. The type of geometric arrangement formed by a solid is important. Chemical and physical properties of solids often can be attributed to the type of geometric arrangement that the solid forms. **Figure 3** shows the geometric arrangement of solid water. Notice that the hydrogen and oxygen atoms are alternately spaced in the arrangement.

Figure 3
The particles in water align themselves in an ordered geometric pattern. Even though a solid ice cube doesn't look like it is moving, its molecules are vibrating in place.



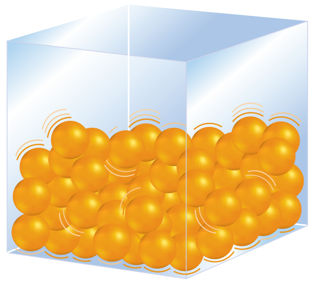


Figure 4
The particles in a liquid are moving more freely than the particles in a solid. They have enough kinetic energy to slip out of the ordered arrangement of a solid.

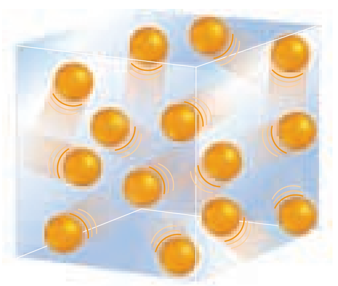


Figure 5
In gases, the particles are far apart and the attractive forces between the particles are overcome. Gases do not have a definite volume or shape.

Liquid State What happens to a solid when thermal energy or heat is added to it? Think about the ice cube in the hot soup. The particles in the hot soup are moving fast and colliding with the vibrating particles in the ice cube. The collisions of the particles transfer energy from the soup to the ice cube. The particles on the surface of the ice cube vibrate faster. These particles collide with and transfer energy to other ice particles. Soon the particles of ice have enough kinetic energy to overcome the attractive forces. The particles of ice gain enough kinetic energy to slip out of their ordered arrangement and the ice melts. This is known as the **melting point,** or the temperature at which a solid begins to liquefy. Energy is required for the particles to slip out of the ordered arrangement. The amount of energy required to change a substance from the solid phase to the liquid phase at its melting point is known as the **heat of fusion.**

Reading Check *What is heat of fusion?*

Liquids Flow Particles in a liquid, shown in **Figure 4,** have more kinetic energy than particles in a solid. This extra kinetic energy allows particles to partially overcome the attractions to other particles. Thus, the particles can slide past each other allowing liquids to flow and take the shape of their container. However, the particles in a liquid have not completely overcome the attractive forces between them. This causes the particles to cling together, giving liquids a definite volume.

Reading Check *Why do liquids flow?*

Gaseous State Particles in the gas state are shown in **Figure 5.** Gas particles have enough kinetic energy to overcome the attractions between them. Gases do not have a fixed volume or shape. Therefore, they can spread far apart or contract to fill the container that they are in. How does a liquid become a gas? The particles in a liquid are constantly moving. Some particles are moving faster and have more kinetic energy than others. The particles that are moving fast enough can escape the attractive forces of other particles and enter the gas phase. This process is called vaporization. Vaporization can occur in two ways—evaporation and boiling. Evaporation is vaporization that occurs at the surface of a liquid and can occur at temperatures below the liquid's boiling point. To evaporate, particles must have enough kinetic energy to escape the attractive forces of the liquid. They must be at the liquid's surface and traveling away from the liquid.

Reading Check *What occurs on a molecular level when a liquid begins to boil?*

Boiling Point A second way that a liquid can vaporize is by boiling. Unlike evaporation, boiling occurs throughout a liquid at a specific temperature depending on the pressure on the surface of the liquid. Boiling is shown in **Figure 6.** The **boiling point** of a liquid is the temperature at which the pressure of the vapor in the liquid is equal to the external pressure acting on the surface of the liquid. This external pressure is a force pushing down upon a liquid, keeping particles from escaping. Particles require energy to overcome this force. **Heat of vaporization** is the amount of energy required for the liquid at its boiling point to become a gas.

Figure 6
Boiling occurs throughout a liquid when the pressure of the vapor in the liquid equals the pressure of the vapor on the surface of the liquid.

Reading Check *How does external pressure affect the boiling point of a liquid?*

Gases Fill Their Container What happens to the attractive forces between the particles in a gas? The gas particles are moving so quickly and are so far apart that they have overcome the attractive force between them. Because the attractive forces between them are overcome, gases do not have a definite shape or a definite volume. The movement of particles and the collisions between them cause gases to diffuse. **Diffusion** is the spreading of particles throughout a given volume until they are uniformly distributed. Diffusion occurs in solids and liquids but occurs most rapidly in gases. For example, if you spray air freshener in one corner of a room, it's not long before you smell the scent all over the room. The particles of gas have moved, collided, and "filled" their container—the room. The particles have diffused. Gases will fill the container that they are in even if the container is a room. The particles continue to move and collide in a random motion within their container.

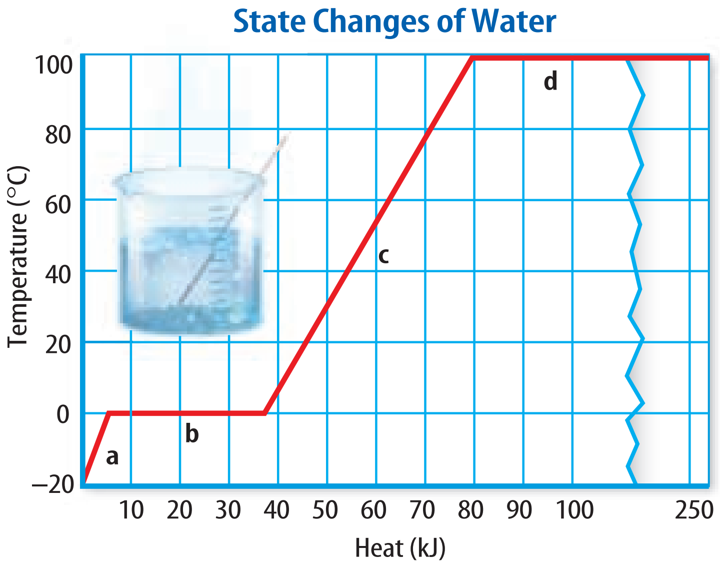


Figure 7
This graph shows the heating curve of water. At A and C the water is increasing in kinetic energy. At B and D the added energy is used to overcome the bonds between the particles.

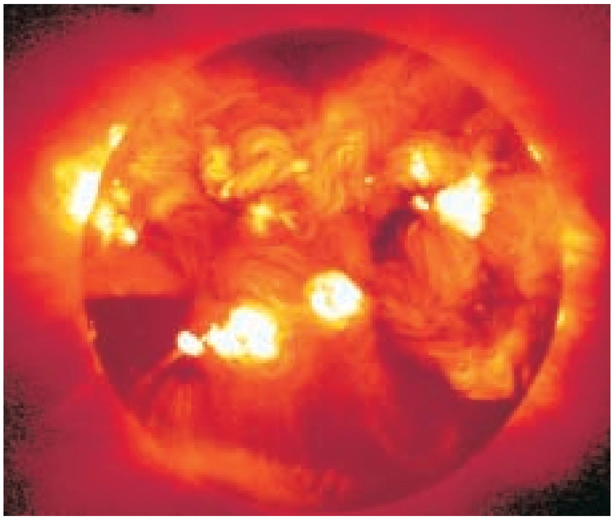
Heating Curve of a Liquid A graph of water being heated from –20°C to 100°C is shown in **Figure 7.** This type of graph is called a heating curve because it shows the temperature change of water as thermal energy or heat is added. Notice the two areas on the graph where the temperature does not change. At 0°C, ice is melting. All of the energy put into the ice at this temperature is used to overcome the attractive forces between the particles in the solid. The temperature remains constant during melting. After the attractive forces are overcome, particles move more freely and their average kinetic energy or temperature increases. At 100°C, water is boiling or vaporizing and the temperature remains constant again. All of the energy that is put into the water goes to overcoming the remaining attractive forces between the water particles. When all of the attractive forces in the water are overcome, the energy goes to increasing the temperature of the particles.

Reading Check *What is occurring at the two temperatures on the heat curve where the graph is a flat line?*

Astronomy INTEGRATION

Plasma State So far, you've learned about the three familiar states of matter—solids, liquids, and gases. But none of these is the most common state of matter in the universe. Scientists estimate that much of the matter in the universe is plasma. **Plasma** is gas consisting of positively and negatively charge particles. Although this high-temperature gas contains positive and negative particles, the overall charge of the gas is neutral because equal numbers of both charges are present. Recall that on average, particles of matter move faster as the matter is heated to higher temperatures. The faster the particles move the greater the force is with which they collide. The forces produced from high-energy collisions are so great that electrons from the atom are stripped off. This state of matter is called plasma. All of the observed stars including the Sun, shown in **Figure 8,** consist of plasma. Plasma also is found in lightning bolts, neon and fluorescent tubes, and auroras.

Figure 8
Stars including the Sun contain matter that is in the plasma phase. Plasma exists where the temperature is extremely high.



Reading Check *What is plasma?*

Thermal Expansion

You have learned how the kinetic theory is used to explain the behavior of particles in different states of matter. The kinetic theory also explains other characteristics of matter in the world around you. Have you noticed the seams in a concrete driveway or sidewalk? A gap often is left between the sections to clearly separate them. These separation lines are called expansion joints. When concrete absorbs heat, it expands. Then when it cools, it contracts. If expansion joints are not used, the concrete will crack when the temperature changes.

Figure 9
As the thermometer is heated, the column of liquid in the thermometer expands. As the temperature cools, the liquid in the thermometer contracts.

Expansion of Matter The kinetic theory can be used to explain this behavior in concrete. Recall that particles move faster and separate as the temperature rises. This separation of particles results in an expansion of the entire object known as thermal expansion. **Thermal expansion** is an increase in the size of a substance when the temperature is increased. The kinetic theory can be used to explain the contraction in objects, too. When the temperature of an object is lowered, particles slow down. The attraction between the particles increases and the particles move closer together. The movements of the particles closer together result in an overall shrinking of the object known as contraction.

Expansion in Liquids Expansion and contraction occur in most solids, liquids, and gases. A common example of expansion in liquids occurs in thermometers, as shown in **Figure 9.** The addition of energy causes the particles of the liquid in the thermometer to move faster. The particles in the liquid in the narrow thermometer tube start to move farther apart as their motion increases. The liquid has to expand only slightly to show a large change on the temperature scale.

Expansion in Gases **Figure 10** is an example of thermal expansion in gases. Hot-air balloons are able to rise due to thermal expansion of air. The air in the balloon is heated, causing the distance between the particles in the air to expand. As the air in the hot-air balloon expands, the number of particles per cubic centimeter decreases. This expansion results in a decreased density of the hot air. Because the density of the air in the hot-air balloon is lower than the density of the cool air outside, the balloon will rise.

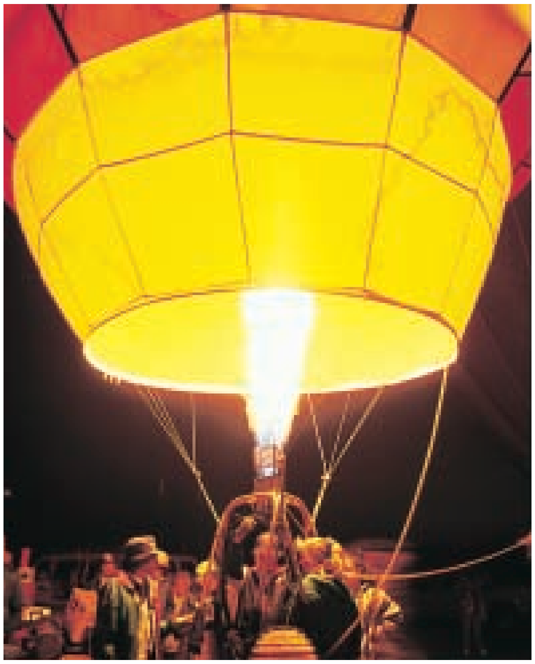


Figure 10
Heating the air in this hot-air balloon causes the particles in the air to separate, creating a lower density inside the balloon.

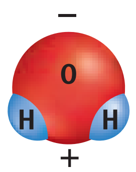


Figure 11
The positively and negatively charged regions on a water molecule interact to create empty spaces in the crystal lattice. These interactions cause water to expand when it is in the solid phase.

The Strange Behavior of Water Normally, substances expand as the temperature rises, because the particles move farther apart. An exception to this rule, however, is water. Water molecules are unusual in that they have highly positive and highly negative areas. **Figure 11** is a diagram of the water molecule showing these charged regions. These charged regions affect the behavior of water. As the temperature of water drops, the particles move closer together. The unlike charges will be attracted to each other and line up so that only positive and negative zones are near each other. Because the water molecules orient themselves according to charge, empty spaces occur in the structure. These empty spaces are larger in ice than in liquid water, so water expands when going from a liquid to a solid state. Solid ice is less dense than liquid water. That is why ice floats on the top of lakes in the winter.

Solid or a Liquid?

There are other substances that have unusual behavior when changing states. Amorphous solids and liquid crystals are two classes of materials that do not react as you would expect when they are changing states.

Amorphous Solids Ice melts at 0°C, gold melts at 1,064°C and lead melts at 327°C. But not all solids have a definite temperature at which they change from solid to liquid. Some solids merely soften and gradually turn into a liquid over a temperature range. There is not an exact temperature like a boiling point where the phase change occurs. These solids lack the highly ordered structure found in crystals. They are known as amorphous solids from the Greek word for "without form."

You are familiar with two amorphous solids—glass and plastics. The particles that make up amorphous solids are typically long, chainlike structures that can get jumbled and twisted instead of being neatly stacked into geometric arrangements. Interactions between the particles occur along the chain, which gives amorphous solids some properties that are very different from crystalline solids.

For example, glass appears to be a solid, but glass windows actually change over time. In old houses if you measure the thickness of the top and bottom of a windowpane, you will find that the top is thinner than the bottom. Because of the gravitational pull and the lack of crystalline structure, the glass in the windowpane will flow to the bottom over time.

Reading Check *What are two examples of amorphous solids?*

Health INTEGRATION

Some liquid crystals can form thin layers that are one molecule thick. These liquid crystals react to tiny temperature changes by changing color making them useful in determining temperature changes over the surface of the skin such as in a thermometer. In your Science Journal, identify other possible uses for this type of liquid crystal.

Liquid Crystals Liquid crystals are another group of materials that do not change states in the usual manner. Normally, the ordered geometric arrangement of a solid is lost when the substance goes from the solid state to the liquid state. Liquid crystals start to flow during the melting phase similar to a liquid, but they do not lose their ordered arrangement completely, as most substances do. Liquid crystals will retain their geometric order in specific directions.

Figure 12
Liquid crystals are used in the displays of watches, clocks, calculators, and some notebook computers because they respond to electric fields.

Liquid crystals are placed in classes depending upon the type of order they maintain when they liquefy. They are highly responsive to temperature changes and electric fields. Scientists use these unique properties of liquid crystals to make liquid crystal displays (LCD) in the displays of watches, clocks, and calculators, as shown in **Figure 12.**

Reading Check *What unusual property do liquid crystals have when they melt?*

Section 1 Assessment

1. What are the three basic assumptions of the kinetic theory?
2. Describe the movement of the particles in solids, liquids, and gases.
3. Describe the movement of the particles at the melting point of a substance.
4. Describe the movement of the particles at the boiling point of a substance.
5. **Think Critically** Would the boiling point of water be higher or lower on the top of a mountain peak? How would the boiling point be affected in a pressurized boiler system? Explain.

Skill Builder Activities

6. **Interpreting Data** Using the graph in **Figure 7,** describe the energy changes that are occurring when water goes from −15°C to 100°C. **For more help, refer to the Science Skill Handbook.**
7. **Making and Using Graphs** The melting point of acetic acid is 16.6°C and the boiling point is 117.9°C. Draw a graph showing the phase changes for acetic acid similar to the graph in **Figure 7.** Clearly mark the three phases, the boiling point, and the melting point on the graph. **For more help, refer to the Science Skill Handbook.**

Activity

How Thermal Energy Affects Matter

The states of matter and its characteristics change as its thermal energy changes.

What You'll Investigate

How does thermal energy affect the state of matter?

Materials

beakers (2)
ring clamp (1)
ring stand
wire mesh
hot plate
ice
thermometer

Goals

- **Explain** the thermal energy changes that occur as matter goes from the solid to gas state.

Safety Precautions

Procedure

1. Set up the equipment as pictured. Prepare a data table in your Science Journal.
2. Gently heat the ice in the lower beaker. Every 3 min record your observations and the temperature of the water in the bottom container. Do not touch the thermometer to the bottom or sides of the container.
3. After the ice in the beaker melts and the water begins to boil, observe the system for several more minutes and record your observations.
4. Turn off the heat and let your system completely cool before you clean up.

Conclude and Apply

1. **Draw** a picture of the system used in this lab in your Science Journal. Label the state the water started at in the lower beaker, the state it changed into in the lower beaker, the state above the lower beaker, and the state on the outside of the upper beaker.
2. Which location on the diagram has the greatest thermal energy and which has the least amount of thermal energy?
3. Make a time-temperature graph using your data for your Science Journal.

Communicating Your Data

Compare your results with other groups in the lab. **For more help, refer to the Science Skill Handbook.**

CONTENTS

SECTION 2

Properties of Fluids

How do ships float?

Some ships are so huge that they are like floating cities. For example, aircraft carriers are large enough to allow airplanes to take off and land on their decks. Despite their weight, these ships are able to float. This is because a greater force pushing up on the ship opposes the weight—or force—of the ship pushing down. What is this force? This supporting force is called the buoyant force. **Buoyancy** is the ability of a fluid—a liquid or a gas—to exert an upward force on an object immersed in it. If the buoyant force is equal to the object's weight, the object will float. If the buoyant force is less than the object's weight, the object will sink.

Archimedes' Principle In the third century B.C., a Greek mathematician named Archimedes made a discovery about buoyancy. Archimedes found that the buoyant force on an object is equal to the weight of the fluid displaced by the object. For example, if you place a block of wood in water, it will push water out of the way as it begins to sink—but only until the weight of the water displaced equals the block's weight. When the weight of water displaced—the buoyant force—becomes equal to the weight of the block, it floats. If the weight of the water displaced is less than the weight of the block, the object sinks. **Figure 13** shows the forces that affect an object in a fluid.

As You Read

What You'll Learn

- **Explain** Archimedes' principle.
- **Explain** Pascal's principle.
- **Explain** Bernoulli's principle and explain how we use it.

Vocabulary

buoyancy
pressure
viscosity

Why It's Important

Properties of fluids determine the design of ships, airplanes, and hydraulic machines.

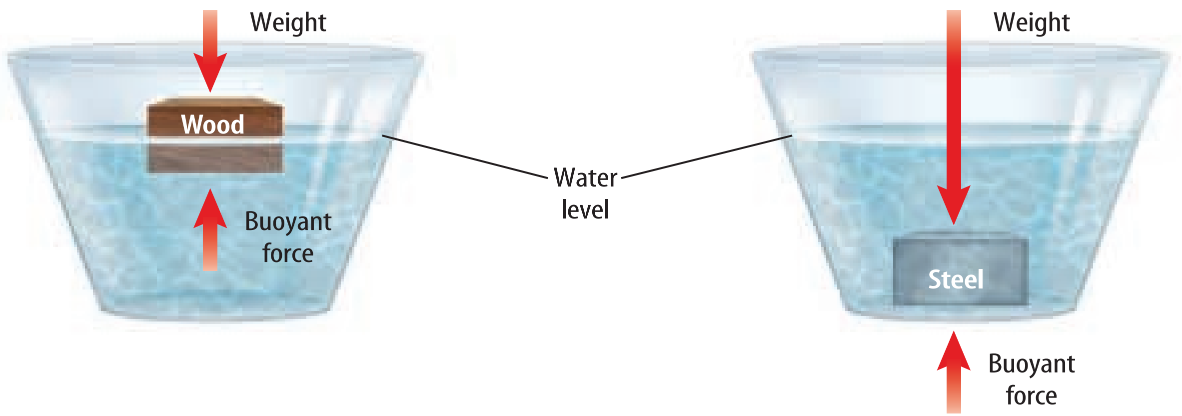
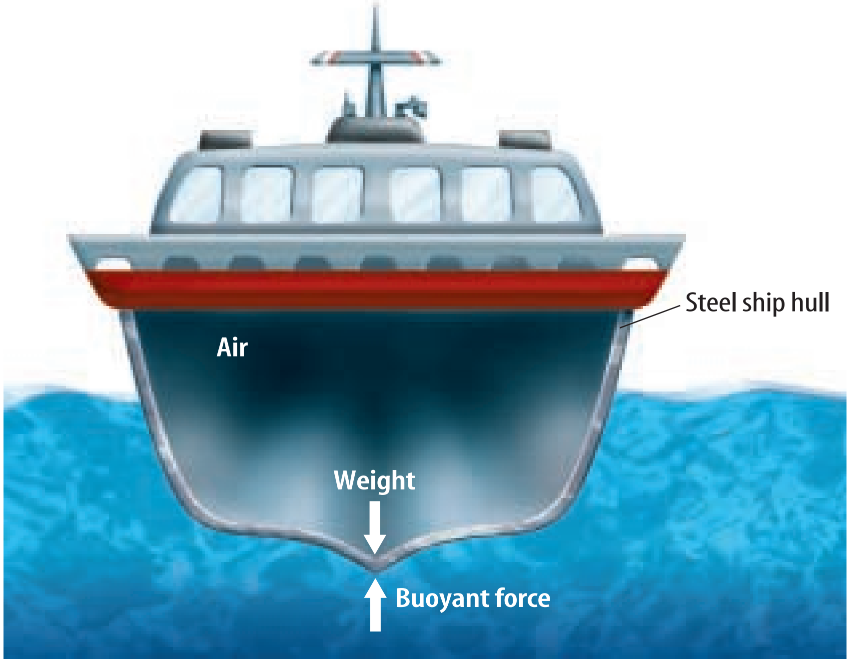


Figure 13
If the buoyant force of the fluid is equal to the weight of the object, the object floats. If the buoyant force of the fluid is less than the weight of the object, the object sinks.

Figure 14
An empty hull of a ship contains mostly air. Its density is much lower than the density of a solid-steel hull. The lower density of the steel and air combination is what allows the ship to float in water.



Mini LAB

Observing Density and Buoyancy of Substances

Procedure

1. Pour 10 mL of **corn syrup** into a 100-mL beaker. In another **beaker,** add 3 to 4 drops of **food coloring** to 10 mL of **water.** Pour the dyed water into the 100-mL beaker containing corn syrup. Add 10 mL of **vegetable oil** to the beaker.
2. Drop a 0.5 cm square piece of **aluminum foil, a steel nut,** and a **whole peppercorn** into the 100-mL beaker.

Analysis

1. Using the concept of density, explain why the contents of the beaker separated into layers.
2. Using the concept of buoyancy, explain why the foil, steel nut, and peppercorn settled in their places.

Density Would a steel block the same size as a wood block float in water? They both displace the same volume and weight of water when submerged. Therefore, the buoyant force on the blocks is equal. Yet the steel block sinks and the wood block floats. What is different? The volume of the blocks and the volume of the water displaced each have different masses. If the three equal volumes have different masses, they must have different densities. Remember that density is mass per unit volume. The density of the steel block is greater than the density of water. The density of the wood block is less than the density of water. An object will float if its density is less than the density of the fluid it is placed in.

Suppose you formed the steel block into the shape of a hull filled with air as in **Figure 14.** Now the same mass takes up a larger volume. The overall density of the steel boat and air is less than the density of water. The boat will now float.

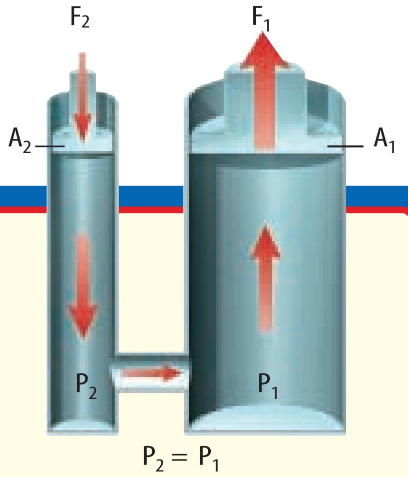
Pascal's Principle

If you are underwater, you can feel the pressure of the water all around you. **Pressure** is force exerted per unit area. Do you realize that Earth's atmosphere is a fluid? Earth's atmosphere exerts pressure all around you.

Blaise Pascal (1623–1662), a French scientist, discovered a useful property of fluids. According to Pascal's principle, pressure applied to a fluid is transmitted throughout the fluid. For example, when you squeeze one end of a balloon, the balloon expands out on the other end. When you squeeze one end of a toothpaste tube, toothpaste emerges from the other end. The pressure has been transmitted through the fluid toothpaste.

Applying the Principle Hydraulic machines are machines that move heavy loads in accordance with Pascal's principle. Maybe you've seen a car raised using a hydraulic lift in an auto repair shop. A pipe that is filled with fluid connects small and large cylinders as shown in **Figure 15.** Pressure applied to the small cylinder is transferred through the fluid to the large cylinder. Because pressure remains constant throughout the fluid, according to Pascal's principle, more force is available to lift a heavy load by increasing the surface area. With a hydraulic machine, you could use your weight to lift something much heavier than you are. Do the Math Skills Activity to see how force, pressure, and area are related.

Figure 15
The pressure remains the same throughout the fluid in a hydraulic lift.



Math Skills Activity

Calculating Forces Using Pascal's Principle

Example Problem

A hydraulic lift is used to lift a heavy machine that is pushing down on a 2.8 m^2 piston (A_1) with a force (F_1) of 3,700 N. What force (F_2) needs to be exerted on a 0.072 m^2 piston (A_2) to lift the machine?

Solution

1 *This is what you know:*

$$\text{pressure} = \frac{\text{Force}}{\text{Area}} = \frac{F}{A}$$

$F_1 = 3{,}700$ N

$A_1 = 2.8\ m^2$

$A_2 = 0.072\ m^2$

2 *This is what you need to find:* Force needed: F_2

3 *Because $P_1 = P_2$, this is the equation that you need to use:*

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

4 *Solve the equation for F_2 and then substitute the known values:*

$$F_2 = \frac{F_1 A_2}{A_1} = \frac{3{,}700\ \text{N} \times 0.072\ m^2}{2.8\ m^2} = 95\ N$$

Check your answer by substituting it and the known values back into the original equation.

Practice Problem

A heavy crate applied a force of 1,500 N on a 25-m^2 piston. What force needs to be exerted on the 0.80-m^2 piston to lift the crate?

For more help, refer to the Math Skill Handbook.

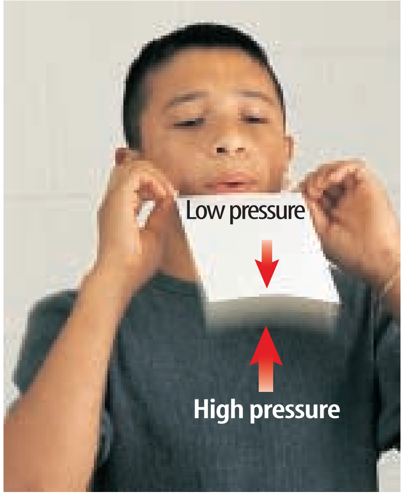


Figure 16
The air above the sheet of paper is moving faster than the air under the paper, creating a low-pressure area above the paper, so the paper rises.

Bernoulli's Principle

It took humans thousands of years to learn to do what birds do instinctively—fly, glide, and soar. It wasn't easy to build a machine that could lift itself off the ground and fly with people aboard. This ability is a property of fluids stated in Bernoulli's principle. Daniel Bernoulli (1700–1782) was a Swiss scientist who studied the properties of moving fluids such as water and air. He published his discovery in 1738. According to Bernoulli's principle, as the velocity of a fluid increases, the pressure exerted by the fluid decreases. One way to demonstrate Bernoulli's principle is to blow across the top surface of a sheet of paper, as in **Figure 16.** The paper will rise. The velocity of the air you blew over the top surface of the paper is greater than that of the quiet air below it. As a result, the air pressure pushing down on the top of the paper is lower than the air pressure pushing up on the paper. The net force below the paper pushes the paper upward.

Now, look at the curvature of the airplane wing in **Figure 17.** As the plane moves forward, the air passing over the top of the wing travels faster than the air passing below it. Thus, the pressure above the wing is less than the pressure below it. The result is a net upward force on the wing. This upward force contributes to the lift of an airplane wing.

Reading Check *How does pressure change as the velocity of a fluid increases?*

Notice that the airflow over the wing is a smooth path. If the wing encounters air that is rotating, the airplane might not have lift and the plane could crash. It is important for the pilot to be aware of any turbulent airflow, especially when an airplane is landing where there is little room for error.

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SCIENCE Online

Research Visit the Glencoe Science Web site at **science.glencoe.com** for information about flying machines. Communicate to your class what you learn.

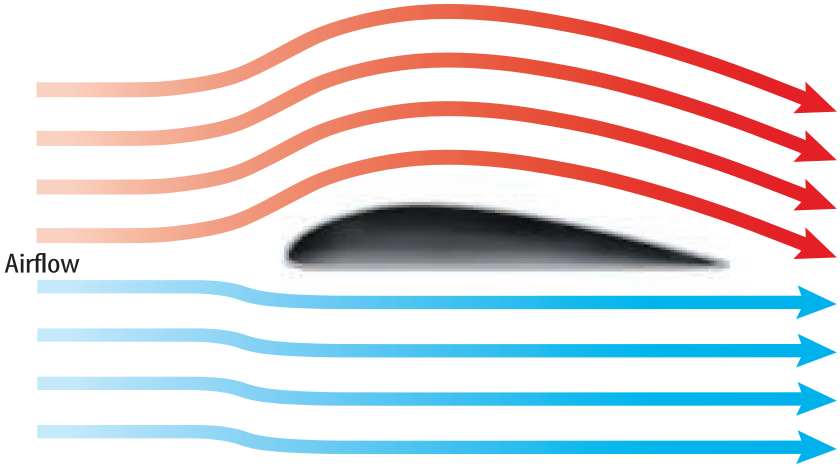


Figure 17
This is a side view of an airplane wing. The air above the wing travels faster over the wing than under it. This creates a low-pressure area above the wing.

Fluid Flow

Another property exhibited by fluid is its tendency to flow. A resistance to flow by a fluid is called **viscosity.** Fluids vary in their tendency to flow. For example, when you take syrup out of the refrigerator and pour it, the flow of syrup is slow. But if this syrup were heated, it would flow much faster. Water has a low viscosity because it flows easily. Cold syrup has a high viscosity because it flows slowly.

Fluids vary in their tendency to flow because their structures differ. When a container of liquid is tilted to allow flow to begin, the flowing particles will transfer energy to the particles that are stationary. In effect, the flowing particles are pulling the other particles, causing them to flow, too. If the flowing particles do not effectively pull the other particles into motion, then the liquid has a high viscosity, or a high resistance to flow. If the flowing particles pull the other particles in motion easily, then the liquid has low viscosity, or a low resistance to flow.

A rise in temperature increases the movement of particles in any substance. In substances that are heated, such as the syrup mentioned above, the particles move much faster. If the particles are moving faster, then energy transfer occurs much faster. Heating the syrup causes the particles to interact more, resulting in a faster energy transfer and a lower viscosity or a lower resistance to flow.

Reading Check *How does temperature affect viscosity?*

Earth Science INTEGRATION

Magma, or liquefied rock from a volcano, is an example of a liquid with varying viscosity. The viscosity of magma depends upon its composition. The viscosity of the magma flow determines the shape of the volcanic cone. In your Science Journal, infer the type of volcano cone that is created with high- and low-viscosity lava flows.

Section 2 Assessment

1. Explain what two opposing forces are acting on an object floating in water.
2. What is Archimedes' principle? Explain how it enables heavy ships to float.
3. What is Pascal's principle? Explain how it works in a plastic mustard bottle.
4. Using Bernoulli's principle, explain how roofs are lifted off building in tornados.
5. **Think Critically** If you fill a balloon with air, tie it off, and release it, it will fall to the floor. Why does it fall instead of float? What if the balloon contained helium?

Skill Builder Activities

6. **Measuring in SI** The density of water is 1.0 g/cm^3. How many kilograms of water does a submerged 120-cm^3 block displace? One kilogram weighs 9.8 N. What is the buoyant force on the block? **For more help, refer to the Science Skills Handbook.**
7. **Solving One-Step Equations** If you wanted to lift an object weighing 20,000 N, how much force would you need to exert on the small piston in **Figure 15?** **For more help, refer to the Math Skills handbook.**

SECTION

3 Behavior of Gases

As You Read

What You'll Learn

- **Explain** how a gas exerts pressure on its container.
- **Explain** how a gas is affected when pressure, temperature, or volume is changed.

Vocabulary

pascal

Why It's Important

Being able to explain and to predict the behavior of gases is useful because you live in a sea of air.

Pressure

Relax and take a deep breath. If the air is clean and fresh, it is primarily a mixture of nitrogen, oxygen, argon, and carbon dioxide. Small amounts of hydrogen, water vapor, and a few other elements are present also. The atmosphere is held in place by the gravitational force on these tiny gas particles. Without the force of gravity acting on these particles, they would escape into space. More information about the atmosphere is on the next page in **Figure 19.**

Particle Collisions You learned from kinetic theory that gas particles are constantly moving and colliding with anything in their path. The collisions of these particles in the air result in atmospheric pressure. Pressure is the amount of force exerted per unit of area, or $P = F/A$. It is measured in units called **pascals** (Pa), the SI unit of pressure. Because pressure is the amount of force divided by area, one pascal of pressure is one Newton per square meter or 1 N/m^2. This is a small pressure unit, so most pressures are given in kilopascals (kPa) or 1,000 pascals. At sea level, atmospheric pressure is 101.3 kPa. This means that at Earth's surface, the atmosphere exerts a force of about 101,300 N on every square meter—about the weight of a large truck.

Often, gases are confined within containers. A balloon and a bicycle tire are considered to be containers. They remain inflated because of collisions the air particles have with the walls of their container, as shown in **Figure 18.** This collection of forces, caused by the collisions of the particles, pushes the walls of the container outward. If more air is pumped into the balloon, the number of air particles is increased. This causes more collisions with the walls of the container, which causes it to expand. Since the bicycle tire can't expand much, its pressure increases.

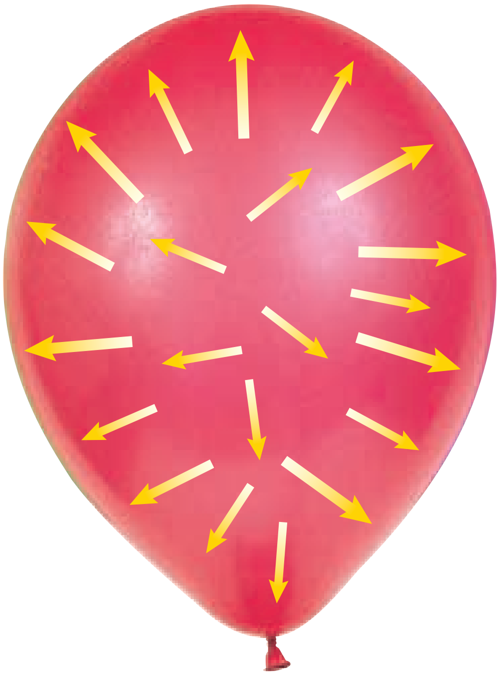


Figure 18
The force created by the many particles in air striking the balloon's walls forces them outward, keeping the balloon inflated.

Reading Check *How are force, area, and pressure related?*

VISUALIZING ATMOSPHERIC LAYERS

Figure 19

Earth's atmosphere is divided into five layers. The air gets thinner as distance from Earth's surface increases. Temperature is variable, however, due to differences in the way the layers absorb incoming solar energy.

The Hubble Space Telescope

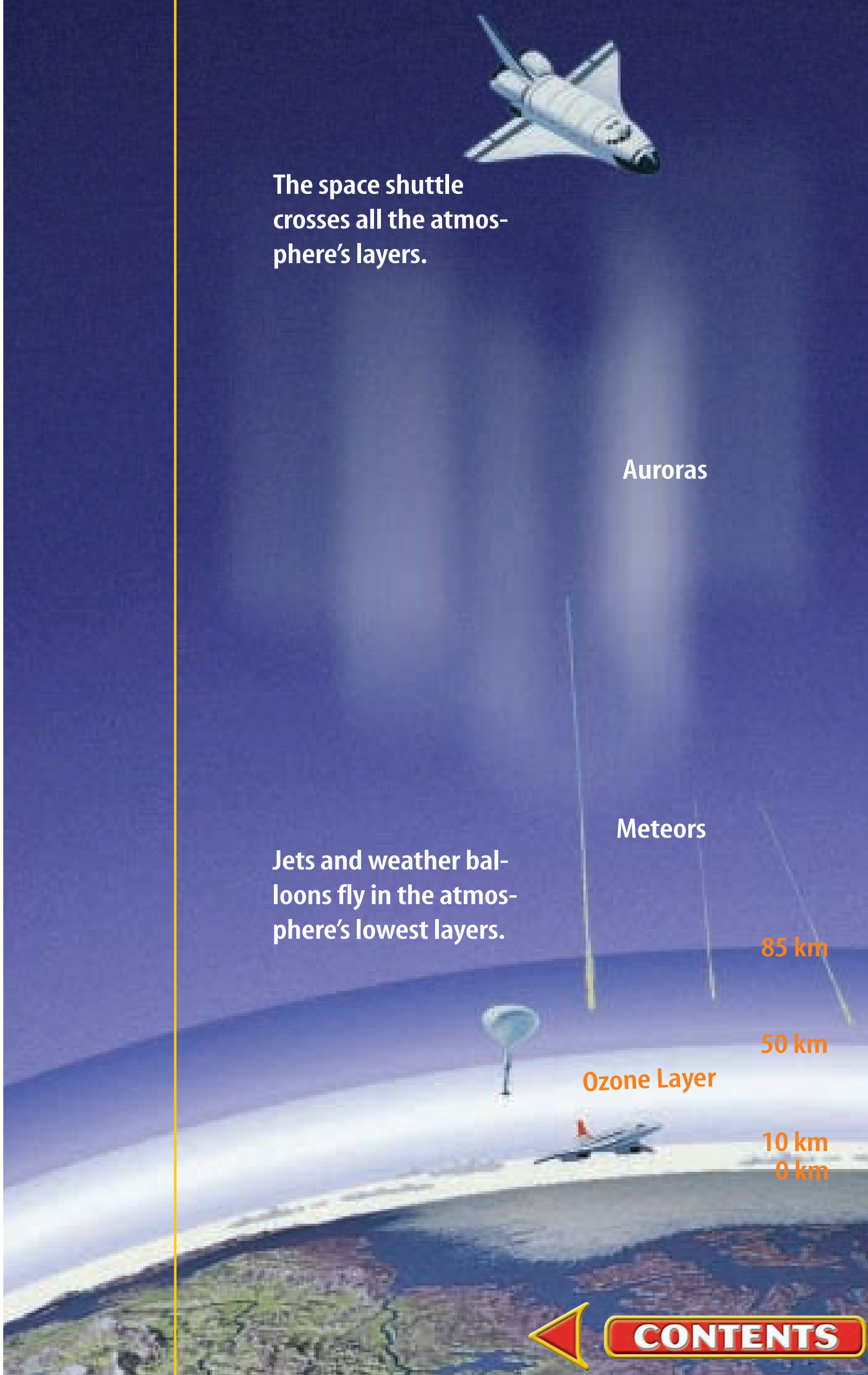
Exosphere (on average, 1,100°C; pressure negligible)

Gas molecules are sparse in the exosphere (beyond 500 km). The Landsat 7 satellite and the Hubble Space Telescope orbit in this layer, at an altitude of about 700 km and 600 km respectively. Beyond the exosphere there is nothing but the vacuum of interplanetary space.

Thermosphere (−80°C to 1,000°C; pressure negligible)

Compared to the exosphere, gas molecules are slightly more concentrated in the thermosphere (85–500 km). Air pressure is still very low, however, and temperatures range widely. Light displays called auroras form in this layer over polar regions.

The temperature drops dramatically in the mesosphere (50–85 km), the coldest layer. The stratosphere (10–50 km) contains a belt of ozone, a gas that absorbs most of the Sun's harmful ultraviolet rays. Clouds and weather systems form in the troposphere (1–10 km), the only layer in which air-breathing organisms typically can survive.



The space shuttle crosses all the atmosphere's layers.

Jets and weather balloons fly in the atmosphere's lowest layers.

Mesosphere (−80°C to −25°C; 0.3 to 0.01 kPa)

Stratosphere (−55°C to −20°C; 27 to 0.3 kPa)

Troposphere (−55°C to 15°C; 100 to 27 kPa)

Figure 20
Balloons are used to measure the weather conditions at high altitudes. These balloons expand as they rise due to decreased pressure.

Boyle's Law

You now know how gas creates pressure in a container. What happens to the gas pressure if you decrease the size of the container? You know that the pressure of a gas depends on how often its particles strike the walls of the container. If you squeeze gas into a smaller space, its particles will strike the walls more often—giving an increased pressure. The opposite is true, too. If you give the gas particles more space, they will hit the walls less often—gas pressure will be reduced. Robert Boyle (1627–1691), a British scientist, described this property of gases. According to Boyle's law, if you decrease the volume of a container of gas and hold the temperature constant, the pressure of the gas will increase. An increase in the volume of the container causes the pressure to drop, if the temperature remains constant.

The behavior of weather balloons, as shown in **Figure 20,** can be explained using Boyle's law. Rubber or neoprene weather balloons are used to carry sensing instruments to high altitudes to detect weather information. The balloons are inflated near Earth's surface with a low-density gas. As the balloon rises, the atmospheric pressure decreases. The balloon gradually expands to a volume of 30 to 200 times its original size. At some point the expanding balloon ruptures. Boyle's law states that as pressure is decreased the volume increases, as demonstrated by the weather balloon. The opposite also is true, as shown by the graph in **Figure 21.** As the pressure is increased, the volume will decrease.

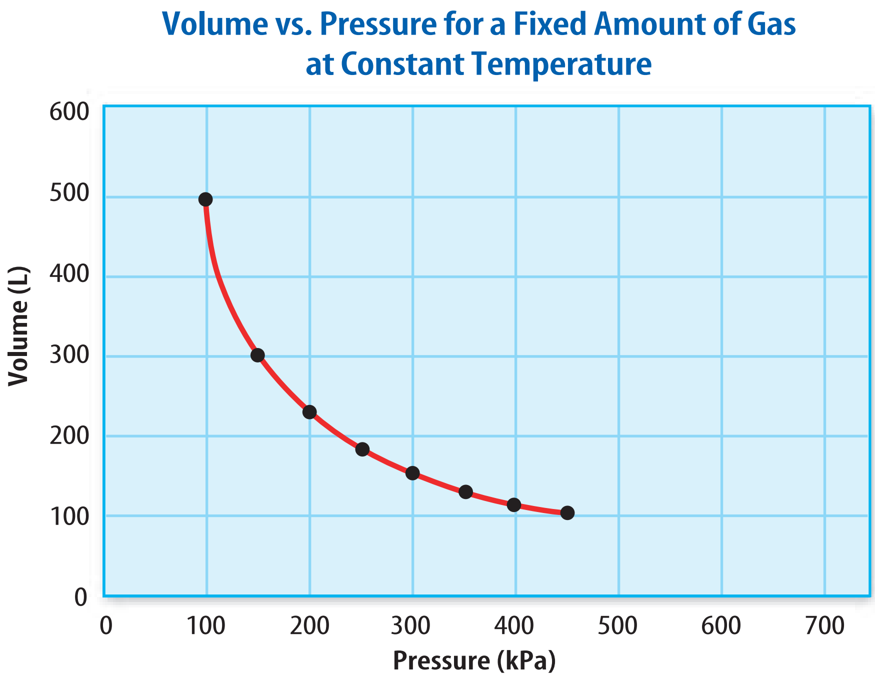


Figure 21
As you can see from the graph, as pressure increases, volume decreases; as pressure decreases, volume increases. *What is the volume of the gas at 100 kPa?*

Boyle's Law in Action When Boyle's law is applied to a real life situation, we find that the pressure multiplied by the volume is always equal to a constant if the temperature is constant. As the pressure and volume change indirectly, the constant will remain the same. You can use the equations $P_1V_1 = \text{constant} = P_2V_2$ to express this mathematically. This shows us that the product of the initial pressure and volume—designated with the subscript 1—is equal to the product of the final pressure and volume—designated with the subscript 2. Using this equation, you can find one unknown value, as shown in the example problem below.

Reading Check *What is $P_1V_1 = P_2V_2$ known as?*

SCIENCE Online

Research Visit the Glencoe Science Web site at **science.glencoe.com** for various industrial uses for compressed gases. Communicate to your class what you learn.

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Math Skills Activity

Using Boyle's Law

Example Problem

A balloon has a volume of 10.0 L at a pressure of 101 kPa. What will be the new volume when the pressure drops to 43 kPa?

Solution:

1. *This is what you know:* initial pressure: $P_1 = 101$ kPa; initial volume: $V_1 = 10.0$ L; final pressure: $P_2 = 43$ kPa
2. *This is what you need to find:* final volume: V_2
3. *This is the equation you need to use:* $P_1V_1 = P_2V_2$
4. *Solve the equation for V_2:* $V_2 = \dfrac{P_1V_1}{P_2}$

Substitute the known values: $V_2 = \dfrac{(101\ \text{kPa})(10.0\ \text{L})}{43\ \text{kPa}} = 23\ \text{L}$

Check your answer by substituting 23 L back into the original equation and solving for P_1. Does the result reflect the theory of Boyle's law—volume increased as the pressure decreased?

Practice Problem

A volume of helium occupies 11.0 L at 98.0 kPa. What is the new volume if the pressure drops to 86.2 kPa?

For more help, refer to the Math Skill Handbook.

TRY AT HOME Mini LAB

Observing Pressure

Safety Precautions

Procedure

1. Blow up a **balloon** to about half its maximum size.
2. Place the balloon on a **beaker** filled with **ice water.**

Analysis

1. Explain what happened to the balloon when you placed it on the beaker.
2. If the volume of the half-filled balloon was 0.5 L at a temperature of 298 K, what would the volume of the balloon be if the temperature increased to 358 K?

The Pressure-Temperature Law

Have you ever read the words "keep away from heat" on a pressurized spray canister? What happens if you heat an enclosed gas? The particles of gas will strike the walls of the canister more often. Because this canister is rigid, its volume cannot increase. Instead, its pressure increases. If the pressure becomes greater than the canister can hold, it will explode. After the container explodes, the pressure is released and the gas expands.

Reading Check *How does temperature affect pressure at constant volume?*

Charles's Law

If you've watched a hot air balloon being inflated, you know that gases expand when they are heated. Because particles in the hot air are further apart than particles in the cool air, the hot air is less dense than the cool air. This difference in density allows the hot air balloon to rise. Jacques Charles (1746–1823) was a French scientist who studied gases. According to Charles's law, the volume of a gas increases with increasing temperature, as long as pressure does not change. As with Boyle's law, the reverse is true, also. The volume of a gas shrinks with decreasing temperature, as shown in **Figure 22.**

Charles's law can be explained using the kinetic theory of matter. As a gas is heated, its particles move faster and faster and its temperature increases. Because the gas particles move faster, they begin to strike the walls of their container more often and with more force. In the hot air balloon, the walls have room to expand so instead of increased pressure, the volume increases.

Temperature v. Volume for a Fixed Amount of Gas at Constant Pressure

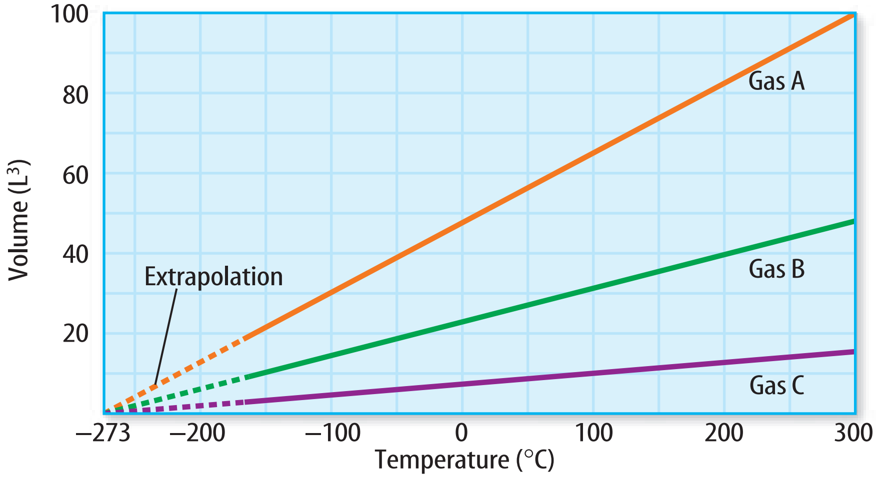


Figure 22
The volume of a gas increases when the temperature increases at constant pressure. Notice that when the graphs are extended to absolute zero, the volume is theoretically zero.

Using Charles's Law The formula that relates the variables of temperature to volume shows a direct relationship, $V_1/T_1 = V_2/T_2$, when temperature is given in Kelvin. When using Charles's law, the pressure must be kept constant. What would be the resulting volume of a 2.0-L balloon at 25.0°C that was placed in a container of ice water at 3.0°C, as shown in **Figure 23?**

$V_1 = 2.0\ \text{L} \qquad T_1 = 25.0°\text{C} + 273 = 298\ \text{K}$

$V_2 = ? \qquad T_2 = 3.0°\text{C} + 273 = 276\ \text{K}$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{2.0\ \text{L}}{298\ \text{K}} = \frac{V_2}{276\ \text{K}}$$

$$V_2 = \frac{(2.0\ \text{L})(276\ \text{K})}{298\ \text{K}}$$

$$V_2 = 1.9\ \text{L}$$

As Charles's law predicts, the volume decreased as the temperature of the trapped gas decreased. This assumed no changes in pressure.

Reading Check *According to Charles's law, what happens to the volume of a gas if the temperature increases?*

Figure 23
Charles's law states that as the temperature is lowered, the volume decreases. *If the balloon in the text was placed in a freezer at 5°C, what would be the new volume?*

Section 3 Assessment

1. Why does a gas have pressure?
2. What is the pressure of Earth's atmosphere at sea level?
3. Explain Boyle's law. Give an example of Boyle's law at work.
4. Explain Charles's law. Give an example of Charles's law at work.
5. **Think Critically** Labels on cylinders of compressed gases state the highest temperature to which the cylinder may be exposed. Give a reason for this warning.

Skill Builder Activities

6. **Forming Hypotheses** A bottle of ammonia begins to leak. An hour later, you can smell ammonia almost everywhere, especially near the bottle. State a hypothesis to explain your observations. **For more help, refer to the Science Skill Handbook.**
7. **Solving One-Step Equations** If a 5-L balloon at 25°C was gently heated to 30°C, what new volume would the balloon have? **For more help, refer to the Math Skill Handbook.**

Activity

Testing the Viscosity of Common Liquids

The resistance to flow of a liquid is called viscosity, and it can be measured and compared. One example of the importance of a liquid's viscosity is motor oil in car engines. The viscosity of motor oil in your family car is very important because it keeps the engine lubricated. It must cling to the moving parts and not run off leaving the parts dry and unlubricated. If the engine is not properly lubricated, it will be damaged eventually. The motor oil must maintain its viscosity in all types of weather from extreme heat in the summer to freezing cold in the winter.

What You'll Investigate

How can you compare the resistance to flow, or viscosity, of common household liquids?

Materials

room temperature household liquids such as:
- dish detergent
- corn syrup
- pancake syrup
- shampoo
- vegetable oil
- vinegar
- molasses
- water

spheres such as glass marbles or steel balls
100-mL graduated cylinders
150-mL beaker
ruler
stopwatch

Goals

- Observe and compare the viscosity of common liquids.

Safety Precautions

Dispose of wastes as directed by your teacher.

CONTENTS

Procedure

1. Measure equal amounts of the liquids to be tested into the graduated cylinders.
2. Measure the depth of the liquid.
3. Copy the data chart into your Science Journal.
4. Place the sphere on the surface of the liquid. Using a stopwatch, measure and record how long it takes for it to travel to the bottom of the liquid.
5. Remove the sphere and repeat step 4 two more times for the same liquid.
6. Rinse and dry the sphere.
7. Repeat steps 4, 5, and 6 for two more liquids.

Sample Data

Viscosity of Common Liquids

Substance	Depth of Liquid (cm)	Time (s)	Velocity (cm/s)
honey	6.0	9.65	0.62
conditioning shampoo	6.0	6.19	0.97
mint shampoo	6.0	4.01	1.50
hand soap	6.0	4.15	1.45
syrup	6.0	2.44	2.46
corn oil	6.0	0.21	28.13

Conclude and Apply

1. **Graph** the average speed of the sphere for each liquid on a bar graph.
2. In which liquid did the sphere move the fastest? Would that liquid have a high or low viscosity? Explain.
3. Would it matter if you dropped or threw the sphere into the liquid instead of placing it there? Explain your answer.
4. What effect does temperature play in the viscosity of a liquid? What would happen to the viscosity of your slowest liquid if you made it colder? Explain.

Communicating Your Data

Compare your results with other groups and discuss differences noted. Why might these differences have occurred? **For more help, refer to the Science Skill Handbook.**

Science Stats

Hot and Cold

Did you know...

. . . The world's coldest substance, liquid helium, is about −269°C. It's used in cryogenics research, which is the study of extremely low temperatures. Cryogenics has enabled physicians to freeze and preserve body parts, such as corneas from human eyes. The freezing keeps cells alive until they are needed.

Cryogenics Laboratory

Hot Springs National Park, Arkansas

. . . Hot springs—also called thermal springs—are a popular tourist attraction. Thousands of people visit Hot Springs National Park in Arkansas each year. The average water temperature of the hot springs at the park is about 62°C.

Oxyacetylene Torch

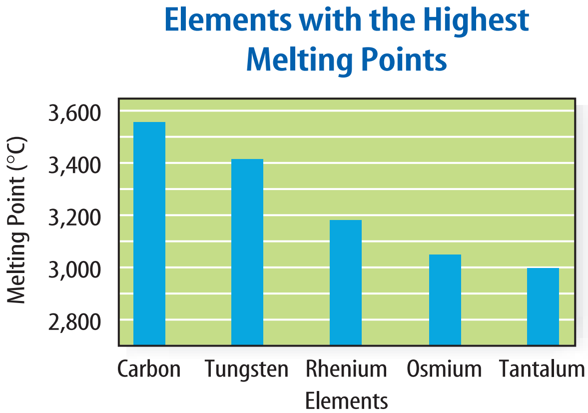
. . . The hottest known flame is made by burning a mixture of oxygen and acetylene. The flame of an oxyacetylene torch can become as hot as 3,300°C. That's more than two times hotter than the melting point of steel.

. . . The hottest temperature in the universe occurs during a supernova—the explosion of a giant star. Temperatures can reach 3,500,000,000 Kelvin. The temperature of the surface of the Sun, by comparison, is about 5,600 K and the temperature of molten lava is 2,000 K.

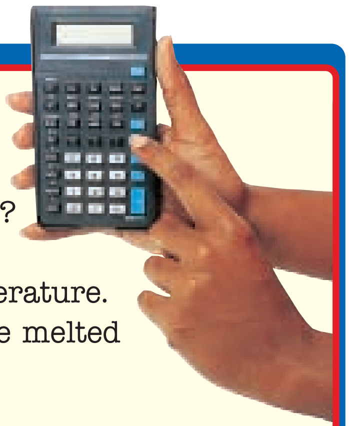
Supernova

. . . Air becomes a liquid at −195°C. Scientists use liquid air to extract liquid oxygen, which is used in high-energy fuels for rocket engines.

. . . The ideal serving temperature of ice cream is between −14°C and −12°C. In this temperature range, the ice cream is firm enough to hold its shape and deliver flavor.



Do the Math



1. In 1983, the temperature dropped to −89°C in Vostok, Antarctica. How many more degrees Celsius would the temperature need to drop for the air to become a liquid?
2. Make a bar graph that compares the temperature of liquid helium, liquid air, and ice cream at serving temperature.
3. Look at the graph above. List the elements that could be melted by an oxyacetylene torch.

Go Further

Go to **science.glencoe.com** to research the melting points of six metals. Make a bar graph showing the data you find.

CLICK HERE

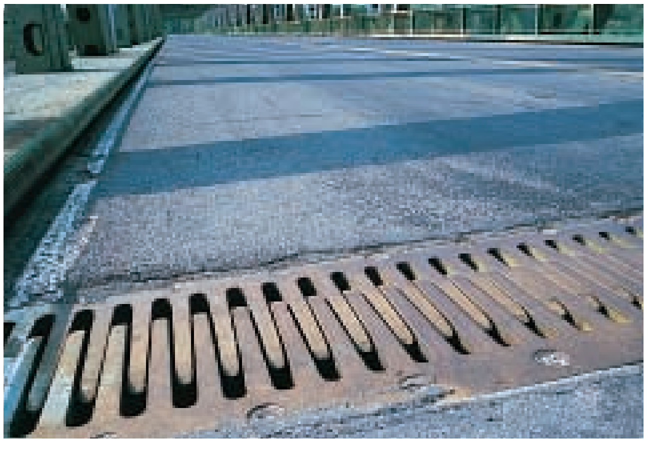
CONTENTS

Chapter 16 Study Guide

Reviewing Main Ideas

Section 1 Kinetic Theory

1. Four states of matter exist: solid, liquid, gas, and plasma.
2. According to the kinetic theory, all matter is made of constantly moving particles that collide without losing energy.
3. Most matter expands when heated and contracts when cooled. *Why is the expansion joint needed in this concrete bridge shown below?*



4. Changes of state can be interpreted in terms of the kinetic theory of matter.

Section 2 Properties of Fluids

1. Archimedes' principle states that the buoyant force of an object in a fluid is equal to the weight of the fluid displaced. *In the photograph on the right, explain why the penny sank in the beaker of water.*

2. Pascal's principle states that pressure applied to a fluid is transmitted unchanged throughout the fluid.
3. Bernoulli's principle states that the pressure exerted by a fluid decreases as its velocity increases.

Section 3 Behavior of Gases

1. Gas pressure results from moving particles colliding with the inside walls of the container.
2. Boyle's law states that the volume of a gas decreases when the pressure increases at constant temperature.
3. Charles's law states that the volume of a gas increases when the temperature increases at constant pressure.
4. At constant volume, as the temperature of a gas increases, so does the pressure of a gas. *What happens to the pressure in this cylinder as the temperature outdoors rises?*

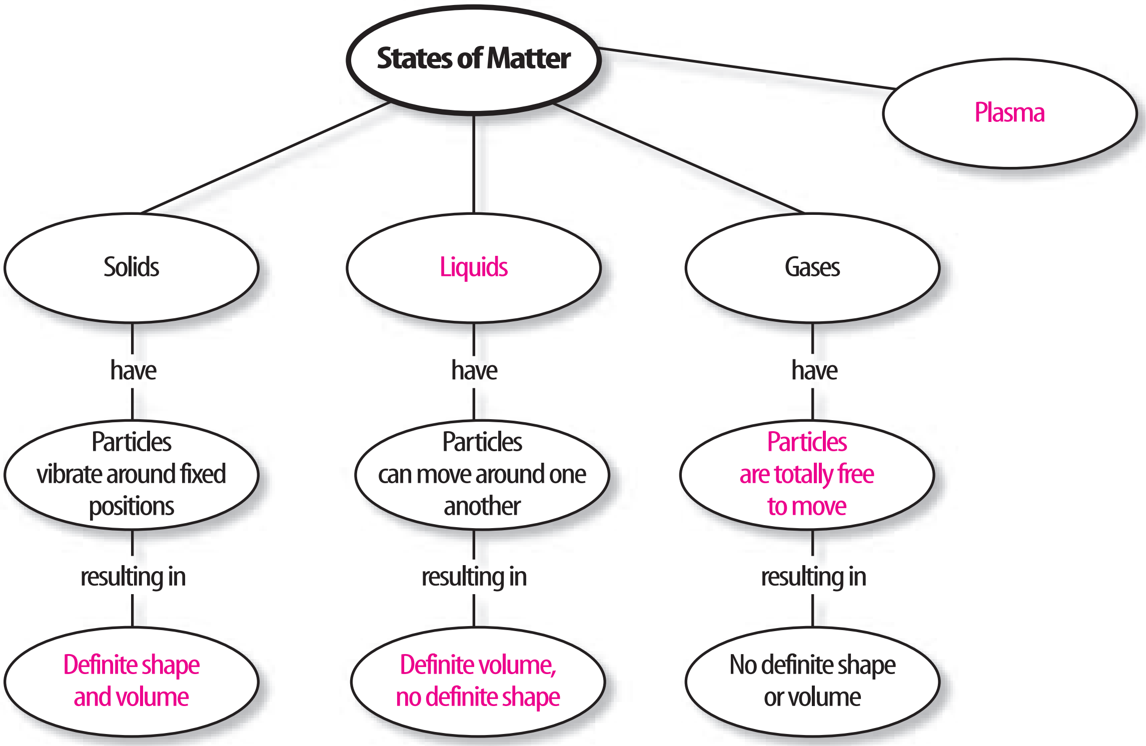
FOLDABLES Reading & Study Skills

After You Read

Under the tabs of your Foldable, write and explain the characteristics of solids, liquids, and gases.

Visualizing Main Ideas

Complete the following concept map on states of matter.



Vocabulary Review

Vocabulary Words

a. boiling point
b. buoyancy
c. diffusion
d. heat of fusion
e. heat of vaporization
f. kinetic theory
g. melting point
h. pascal
i. plasma
j. pressure
k. thermal expansion
l. viscosity

Using Vocabulary

Answer the following questions using complete sentences.

1. What is the property of a fluid that represents its resistance to flow?
2. What is the SI unit of pressure?
3. What term is used to describe the amount of force exerted per unit of area?
4. What is the temperature when a solid begins to liquefy?
5. What theory is used to explain the behavior of particles in matter?
6. What is the ability of a fluid to exert an upward force on an object?

THE PRINCETON REVIEW **Study Tip**

Make flashcards for new vocabulary words. Put the word on one side and the definition on the other. Use them to quiz yourself.

Chapter 16 Assessment

Checking Concepts

Choose the word or phrase that best answers the question.

1. What is the temperature at which all particle motion of matter ceases?
   A) absolute zero **C)** boiling point
   B) melting point **D)** heat of fusion
2. What is the state of matter that has a definite volume and a definite shape?
   A) solid **C)** gas
   B) liquid **D)** plasma
3. What is the most common state of matter in the universe?
   A) solid **C)** gas
   B) liquid **D)** plasma
4. Which of the following would be used to measure pressure?
   A) gram **C)** kilopascals
   B) newtons **D)** kilograms
5. Which of the following uses Pascal's principle?
   A) aerodynamics **C)** buoyancy
   B) hydraulics **D)** changes of state
6. Which of the following uses Bernoulli's principle?
   A) airplanes **C)** boats
   B) pistons **D)** snowboards
7. The particles in which of the following are farthest from each other?
   A) gas **C)** liquid
   B) solid **D)** plasma
8. In which state would a material fill a room at the quickest rate?
   A) solid **C)** water
   B) liquid **D)** gas
9. What is the upward force in a liquid?
   A) pressure **C)** buoyancy
   B) kinetic theory **D)** diffusion
10. What is the amount of energy needed to change a solid to a liquid at its melting point called?
    A) heat of fusion
    B) heat of vaporization
    C) temperature
    D) absolute zero

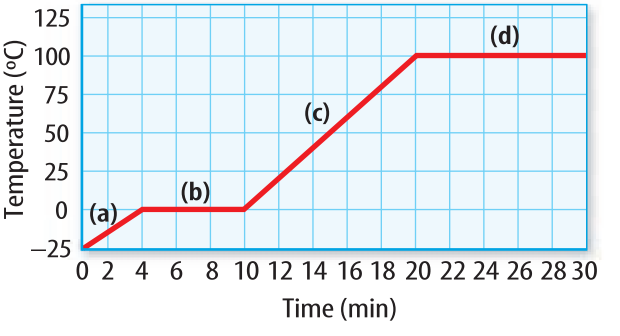
Thinking Critically

11. Use the Temperature-Pressure law to explain why you should check your tire pressure when the temperature changes.
12. Describe the changes that occur inside a helium balloon as it rises from sea level.
13. Why do aerosol cans have a "do not incinerate" warning?
14. The Dead Sea is a solution that is so dense that you float on it easily. Explain why you are able to float easily, using the terms *density* and *buoyant force.*

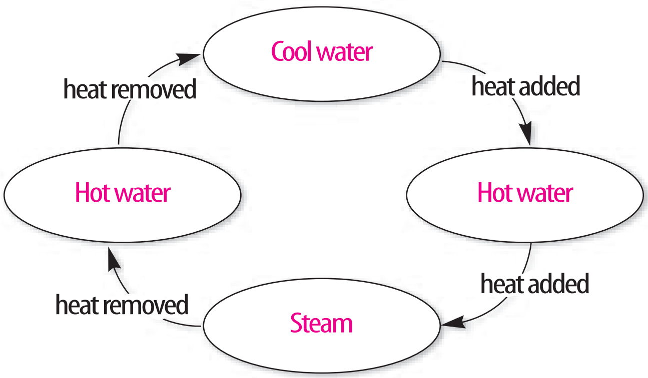
Developing Skills

15. **Making and Using Graphs** A group of students heated ice until it turned to steam. They measured the temperature each minute. Their graph is provided below. Explain what is happening at each letter (a, b, c, d) in the graph.

Temperature v. Time for Heating Water



16. Concept Mapping Use a cycle map to show the changes in particles as cool water boils, changes to steam, and then changes back to cool water.



17. Interpreting Data As elevation increases, boiling point decreases. List each of the following locations as *at sea level, above sea level,* or *below sea level.* (Boiling point of water is given in parenthesis.)

Death Valley (100.3°C), Denver (94°C), Madison (99°C), Mt. Everest (76.5°C), Mt. McKinley (79°C), New York City (100°C), Salt Lake City (95.6°C)

Performance Assessment

18. Researching Research the effects of pressure changes on the human body and write a report. Include in your report any precautions that must be taken in dealing with pressure changes in space and when deep-sea diving.

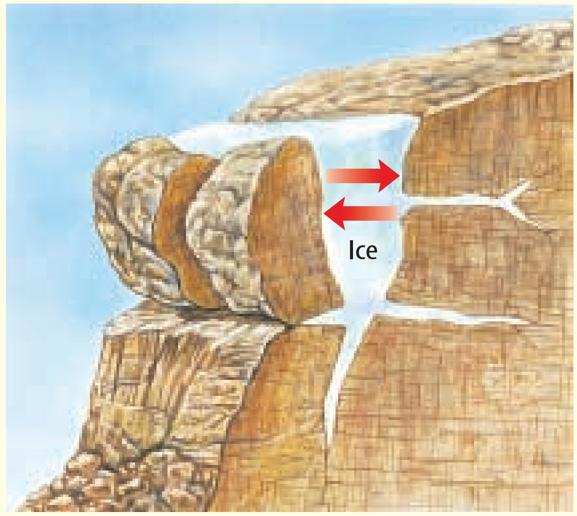
Technology

Go to the Glencoe Science Web site at **science.glencoe.com** or use the **Glencoe Science CD-ROM** for additional chapter assessment.

THE PRINCETON REVIEW

Test Practice

A geologist was investigating the effects of the change in seasons on rock formations. One of his observations is shown in the diagram below.



Study the picture and answer the following questions.

1. Which of these is the most likely cause of the rocks being wedged apart?

A) Water contains dissolved chemicals that eat away at rocks.
B) Cold water is more acidic than warm water.
C) Ice is more dense than water.
D) Water expands when it freezes.

2. The ice pushes outward in this manner in response to _____.

F) atmospheric pressure
G) temperature changes
H) glacial movement
J) gravity

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