Section 1

States of Matter

Reading Preview

Key Concepts

- What are the characteristics of a solid?
- What are the characteristics of a liquid?
- What are the characteristics of a gas?

Key Terms

- solid
- crystalline solid
- amorphous solid
- liquid
- fluid
- surface tension
- viscosity
- gas

Target Reading Skill

Building Vocabulary A definition states the meaning of a word or phrase by telling about its most important feature or function. After you read the section, reread the paragraphs that contain definitions of Key Terms. Use all the information you have learned to write a definition of each Key Term in your own words.

Lab zone Discover Activity

What Are Solids, Liquids, and Gases?

1. Break an antacid tablet (fizzing type) into three or four pieces. Place them inside a large, uninflated balloon.
2. Fill a 1-liter plastic bottle about halfway with water. Stretch the mouth of the balloon over the top of the bottle, taking care to keep the tablet pieces inside the balloon.
3. Jiggle the balloon so that the pieces fall into the bottle. Observe what happens for about two minutes.
4. Remove the balloon and examine its contents.

Think It Over

Forming Operational Definitions Identify examples of the different states of matter—solids, liquids, and gases—that you observed in this activity. Define each of the three states in your own words.

It's a bitter cold January afternoon. You are practicing ice hockey moves on a frozen pond. Relaxing later, you close your eyes and recall the pond in July, when you and your friends jumped into the refreshing water on a scorching hot day. Was the water in July made of the same water you skated on this afternoon? Perhaps, but you're absolutely certain that solid water and liquid water do not look or feel the same. Just imagine trying to swim in an ice-covered pond in January or play hockey on liquid water in July!

FIGURE 1
A Wintry Solid
As a solid, water makes a great surface for ice hockey.
Observing *What useful property does the frozen water have here?*

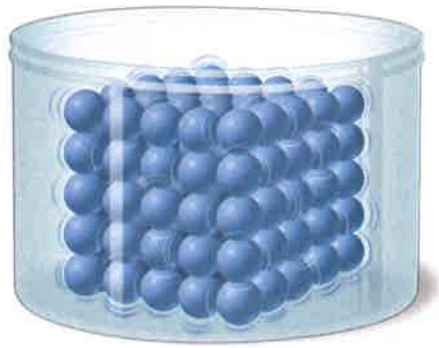
Your everyday world is full of substances that can be classified as solids, liquids, or gases. (You will read about a less familiar form of matter, called plasma, in a later chapter.) Solids, liquids, and gases may be elements, compounds, or mixtures. Gold is an element. Water is a compound you've seen as both a solid and a liquid. Air is a mixture of gases. Although it's easy to list examples of these three states of matter, defining them is more difficult. To define solids, liquids, and gases, you need to examine their properties. The familiar states of matter are defined not by what they are made of but mainly by whether or not they hold their volume and shape.

Solids

What would happen if you were to pick up a solid object, such as a pen or a comb, and move it from place to place around the room? What would you observe? Would the object ever change in size or shape as you moved it? Would a pen become larger if you put it in a bowl? Would a comb become flatter if you placed it on a tabletop? Of course not. A **solid** has a definite shape and a definite volume. If your pen has a cylindrical shape and a volume of 6 cubic centimeters, then it will keep that shape and volume in any position and in any container.

FIGURE 2
Liquid Lava, Solid Rock
Hot, liquid lava flows from a volcano. When it cools to a solid, new rock will be formed.

Figure 3
Behavior of Solid Particles
Particles of a solid vibrate back and forth but stay in place.



Particles in a Solid The particles that make up a solid are packed very closely together. In addition, each particle is tightly fixed in one position. **This fixed, closely packed arrangement of particles causes a solid to have a definite shape and volume.**

Are the particles in a solid completely motionless? No, not really. The particles vibrate, meaning that they move back and forth slightly. This motion is similar to a group of people running in place. The particles that make up a solid stay in about the same position, but they vibrate in place.

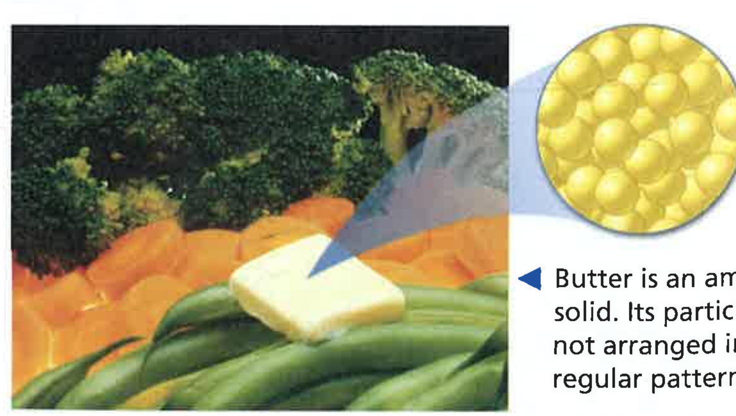
Types of Solids In many solids, the particles form a regular, repeating pattern. These patterns create crystals. Solids that are made up of crystals are called **crystalline solids** (KRIS tuh lin). Salt, sugar, and snow are examples of crystalline solids. When a crystalline solid is heated, it melts at a specific temperature.

In **amorphous solids** (uh MAWR fus), the particles are not arranged in a regular pattern. Plastics, rubber, and glass are amorphous solids. Unlike a crystalline solid, an amorphous solid does not melt at a distinct temperature. Instead, it may become softer and softer or change into other substances.

Reading Checkpoint How do crystalline and amorphous solids differ?

Figure 4
Types of Solids
Solids are either crystalline or amorphous.

◀ Quartz is a crystalline solid. Its particles are arranged in a regular pattern.



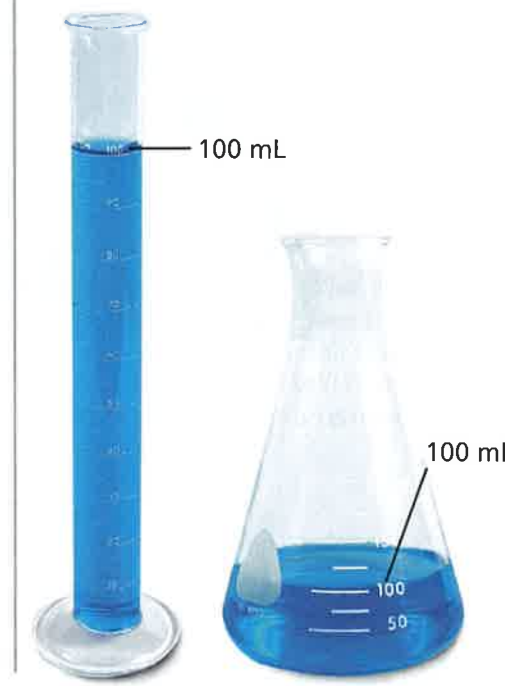
◀ Butter is an amorphous solid. Its particles are not arranged in a regular pattern.

Liquids

A **liquid** has a definite volume but no shape of its own. Without a container, a liquid spreads into a wide, shallow puddle. Like a solid, however, a liquid does have a constant volume. If you gently tried to squeeze a water-filled plastic bag, for example, the water might change shape, but its volume would not decrease or increase. Suppose that you have 100 milliliters of milk in a pitcher. If you pour it into a tall glass, you still have 100 milliliters. The milk has the same volume no matter what shape its container has.

Particles in a Liquid In general, the particles in a liquid are packed almost as closely as in a solid. However, the particles in a liquid move around one another freely. You can compare this movement to the way you might move a group of marbles around in your hand. In this comparison, the solid marbles serve as models for the particles of a liquid. The marbles slide around one another but stay in contact. **Because its particles are free to move, a liquid has no definite shape. However, it does have a definite volume.** These freely moving particles allow a liquid to flow from place to place. For this reason, a liquid is also called a **fluid,** meaning "a substance that flows."

Figure 5
Equivalent Volumes
A liquid takes the shape of its container but its volume does not change.



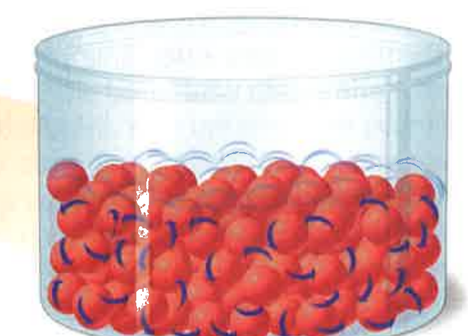


Figure 6
Behavior of Liquid Particles
Particles in a liquid are packed close together but move freely, allowing liquids to flow.
Comparing and Contrasting *How are liquids and solids alike? How do they differ?*

Figure 7
Surface Tension
Water beads up on a leaf due to attractions between the water molecules. Surface tension in water is strong enough to support the weight of an insect.

Lab zone Try This **Activity**

As Thick as Honey

You can compare the viscosity of two liquids.

1. Place on a table a clear plastic jar almost filled with honey and another clear plastic jar almost filled with vegetable oil. Make sure that the tops of both jars are tightly closed.
2. Turn the jars upside down at the same time. Observe what happens.
3. Turn the two jars right-side up and again watch what happens.

Drawing Conclusions Which fluid has a greater viscosity? What evidence leads you to this conclusion?

Properties of Liquids One characteristic property of liquids is surface tension. **Surface tension** is the result of an inward pull among the molecules of a liquid that brings the molecules on the surface closer together. Perhaps you have noticed that water forms droplets and can bead up on many surfaces, such as the leaf shown in Figure 7. That's because water molecules attract one another strongly. These attractions cause molecules at the water's surface to be pulled slightly toward the water molecules beneath the surface.

Due to surface tension, the surface of water can act like a sort of skin. For example, a sewing needle floats when you place it gently on the surface of a glass of water, but it quickly sinks if you push it below the surface. Surface tension enables the water strider in Figure 7 to "walk" on the calm surface of a pond.

Another property of liquids is **viscosity** (vis KAHS uh tee)—a liquid's resistance to flowing. A liquid's viscosity depends on the size and shape of its particles and the attractions between the particles. Some liquids flow more easily than others. Liquids with high viscosity flow slowly. Honey is an example of a liquid with a particularly high viscosity. Liquids with low viscosity flow quickly. Water and vinegar have relatively low viscosities.

Reading Checkpoint **What property of liquids causes water to form droplets?**

Gases

Like a liquid, a gas is a fluid. Unlike a liquid, however, a **gas** can change volume very easily. If you put a gas in a closed container, the gas particles will either spread apart or be squeezed together as they fill that container. Take a deep breath. Your chest expands, and your lungs fill with air. Air is a mixture of gases that acts as one gas. When you breathe in, air moves from your mouth to your windpipe to your lungs. In each place, the air has a different shape. When you breathe out, the changes happen in reverse.

What about the volume of the air? If you could see the particles that make up a gas, you would see them moving in all directions. The particles are no longer limited by the space in your body, so they move throughout the room. **As they move, gas particles spread apart, filling all the space available. Thus, a gas has neither definite shape nor definite volume.** You will read more about the behavior of gases in Section 3.

Reading Checkpoint **How does breathing demonstrate that gases are fluids?**

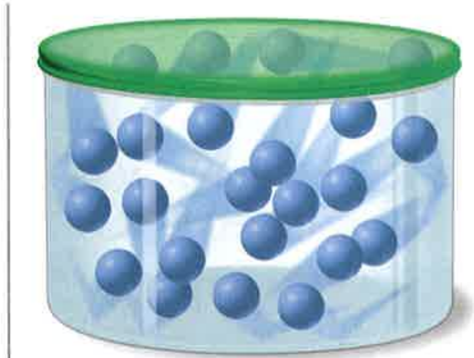


Figure 8
Modeling Gas Particles
The particles of a gas can be squeezed into a small volume.
Predicting *What will happen if the container lid is removed?*

Section 1 Assessment

Target Reading Skill

Building Vocabulary Use your definitions to help answer the questions below.

Reviewing Key Concepts

1. a. **Listing** What are the general characteristics of solids?
   b. **Comparing and Contrasting** How do crystalline solids differ from amorphous solids?
   c. **Drawing Conclusions** A glass blower can bend and shape a piece of glass that has been heated. Is glass a crystalline or an amorphous solid? Explain.
2. a. **Describing** How may liquids be described in terms of shape and volume?
   b. **Explaining** How do the positions and movements of particles in a liquid help to explain the shape and volume of the liquid?
   c. **Relating Cause and Effect** Explain why a sewing needle can float on the surface of water in a glass.
3. a. **Reviewing** What determines the shape and volume of a gas inside a container?
   b. **Applying Concepts** Use what you know about the particles in a gas to explain why a gas has no definite shape and no definite volume.

Lab zone At-Home **Activity**

Squeezing Liquids and Gases Show your family how liquids and gases differ. Fill the bulb and cylinder of a turkey baster with water. Seal the end with your finger and hold it over the sink. Have a family member squeeze the bulb. Now empty the turkey baster. Again, seal the end with your finger and have a family member squeeze the bulb. Did the person notice any difference? Use what you know about liquids and gases to explain your observations.

Section 2

Changes of State

Reading Preview

Key Concepts

- What happens to a substance during changes between solid and liquid?
- What happens to a substance during changes between liquid and gas?
- What happens to a substance during changes between solid and gas?

Key Terms

- melting
- melting point
- freezing
- vaporization
- evaporation
- boiling
- boiling point
- condensation
- sublimation

Target Reading Skill

Outlining As you read, make an outline about changes of state. Use the red headings for the main ideas and the blue headings for the supporting ideas.

Changes in State

I. Changes Between Solid and Liquid
  A. Melting
  B.
II. Changes Between Liquid and Gas

Lab zone Discover Activity

What Happens When You Breathe on a Mirror?

1. Obtain a hand mirror. Clean it with a dry cloth. Describe the mirror's surface.
2. Hold the mirror about 15 cm away from your face. Try to breathe against the mirror's surface.
3. Reduce the distance until breathing on the mirror produces a visible change. Record what you observe.

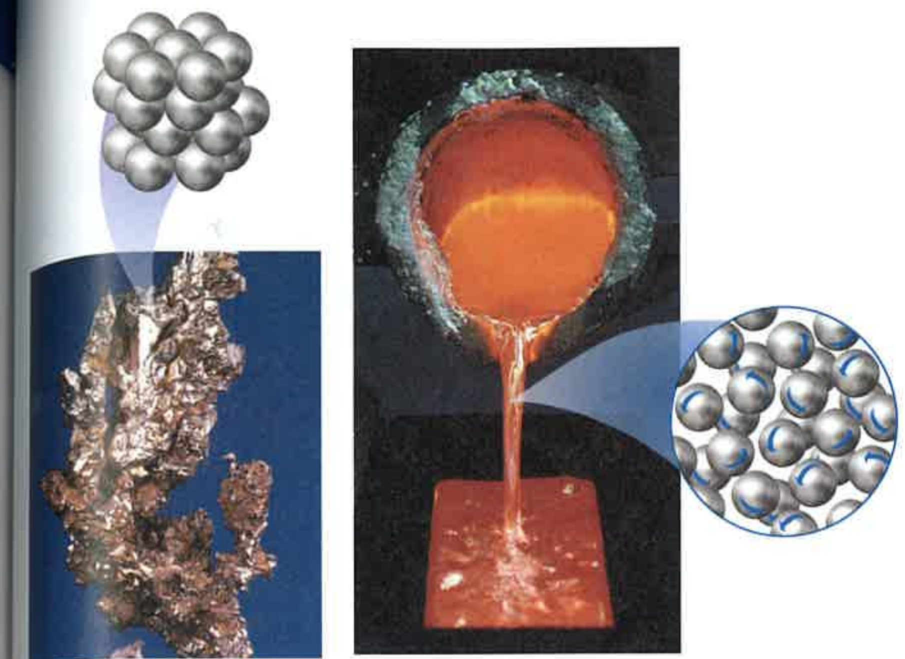
Think It Over

Developing Hypotheses What did you observe when you breathed on the mirror held close to your mouth? How can you explain that observation? Why did you get different results when the mirror was at greater distances from your face?

Picture an ice cream cone on a hot summer day. The ice cream quickly starts to drip onto your hand. You're not surprised. You know that ice cream melts if it's not kept cold. But why does the ice cream melt?

Particles of a substance at a warmer temperature have more thermal energy than particles of that same substance at a cooler temperature. You may recall that thermal energy always flows as heat from a warmer substance to a cooler substance. So, when you take ice cream outside on a hot summer day, it absorbs thermal energy from the air and your hand. The added energy changes the ice cream from a solid to a liquid.

Increased thermal energy turns an ice cream cone into a gooey mess! ▶



Solid silver

Liquid silver

FIGURE 9
Solid to Liquid
In solid silver, atoms are in a regular, cubic pattern. Atoms in liquid (molten) silver have no regular arrangement.
Applying Concepts *How can a jewelry maker take advantage of changes in the state of silver?*

Changes Between Solid and Liquid

How does the physical state of a substance relate to its thermal energy? Particles of a liquid have more thermal energy than particles of the same substance in solid form. As a gas, the particles of this same substance have even more thermal energy. A substance changes state when its thermal energy increases or decreases sufficiently. A change from solid to liquid involves an increase in thermal energy. As you can guess, a change from liquid to solid is just the opposite: It involves a decrease in thermal energy.

Melting

The change in state from a solid to a liquid is called **melting.** In most pure substances, melting occurs at a specific temperature, called the **melting point.** Because melting point is a characteristic property of a substance, chemists often compare melting points when trying to identify an unknown material. The melting point of pure water, for example, is 0°C.

What happens to the particles of a substance as it melts? Think of an ice cube taken from the freezer. The energy to melt the ice comes mostly from the air in the room. At first, the added thermal energy makes the water molecules vibrate faster, raising their temperature. **At its melting point, the particles of a solid substance are vibrating so fast that they break free from their fixed positions.** At 0°C, the temperature of the ice stops increasing. Any added energy continues to change the arrangement of the water molecules from ice crystals into liquid water. The ice melts.

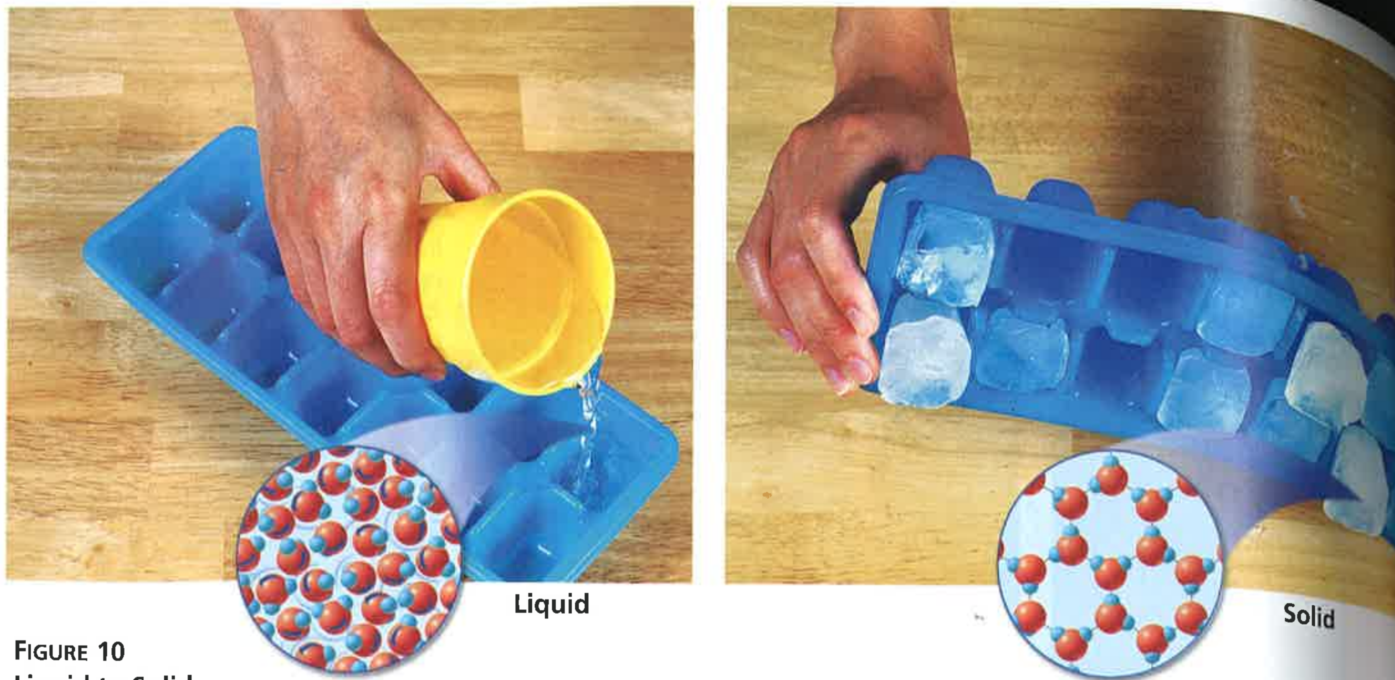


FIGURE 10
Liquid to Solid
Just a few hours in a freezer will change liquid water into a solid.

> **Lab zone** **Try This Activity**
>
> ### Keeping Cool
>
> 1. Wrap the bulbs of two alcohol thermometers with equal amounts of gauze.
> 2. Lay the thermometers on a paper towel on a table.
> 3. Use a medicine dropper to put 10 drops of water on the gauze surrounding the bulb of one thermometer.
> 4. Using rubbing alcohol rather than water, repeat step 3 with the second thermometer.
> 5. Read the temperatures on the two thermometers for several minutes.
>
> **Interpreting Data** Which liquid evaporates faster? Explain your answer.

Freezing The change of state from liquid to solid is called **freezing.** It is just the reverse of melting. **At its freezing temperature, the particles of a liquid are moving so slowly that they begin to form regular patterns.**

When you put liquid water into a freezer, for example, the water loses energy to the cold air in the freezer. The water molecules move more and more slowly as they lose energy. Over time, the water becomes solid ice. When water begins to freeze, its temperature remains at 0°C until freezing is complete. The freezing point of water, 0°C, is the same as its melting point.

Reading Checkpoint **What happens to the particles of a liquid as they lose more and more energy?**

Changes Between Liquid and Gas

Have you ever wondered how clouds form, or why rain falls from clouds? And why do puddles dry up after a rain shower? To answer these questions, you need to look at what happens when changes occur between the liquid and gas states.

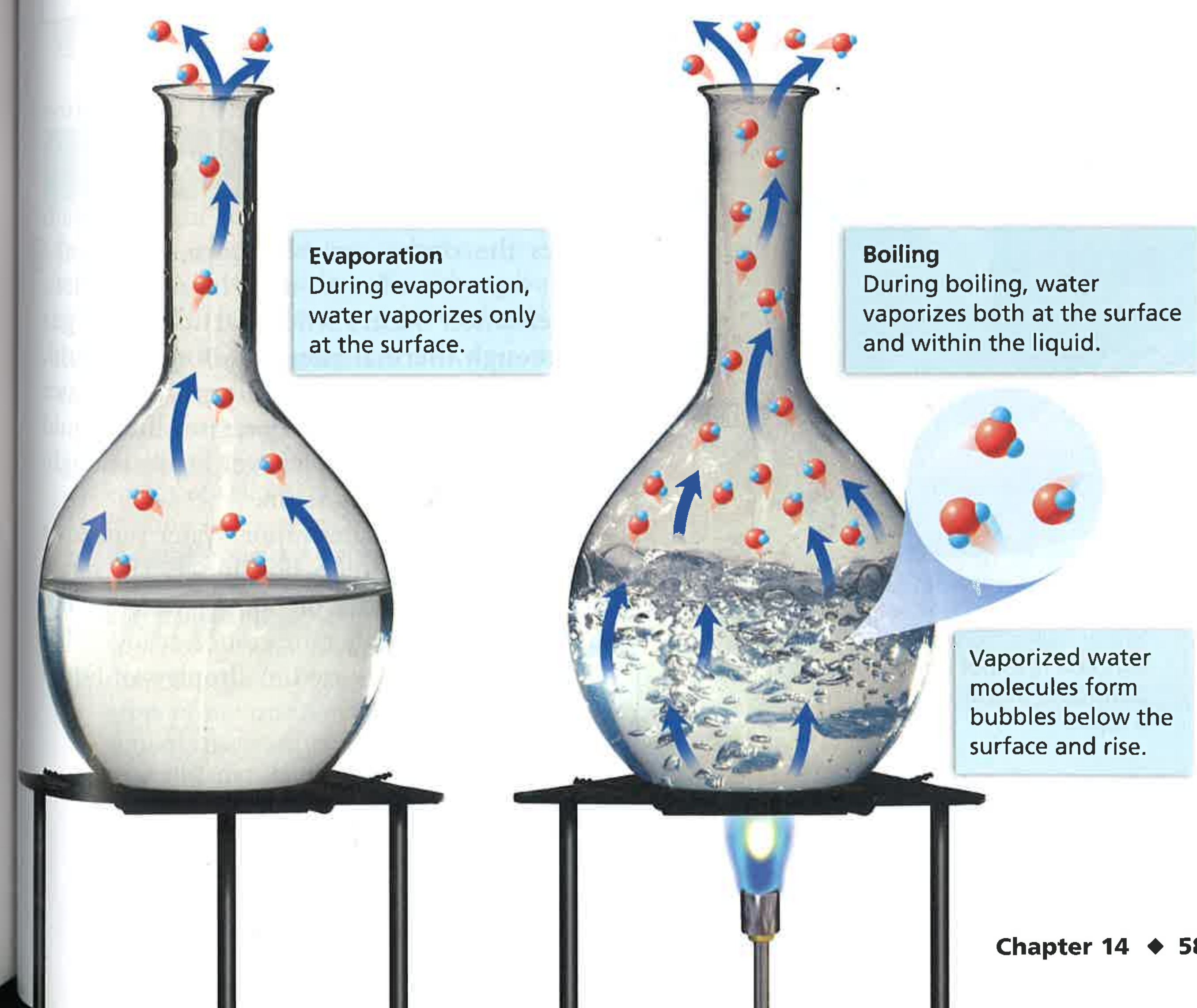
The change from a liquid to a gas is called **vaporization** (vay puhr ih ZAY shun). **Vaporization takes place when the particles in a liquid gain enough energy to form a gas.** There are two main types of vaporization—evaporation and boiling.

Evaporation Vaporization that takes place only on the surface of a liquid is called **evaporation** (ee vap uh RAY shun). A shrinking puddle is an example. Water in the puddle gains energy from the ground, the air, or the sun. The added energy enables some of the water molecules on the surface of the puddle to escape into the air, or evaporate.

Boiling Another kind of vaporization is called boiling. **Boiling** occurs when a liquid changes to a gas below its surface as well as at the surface. You see the results of this process when the boiling liquid bubbles. The temperature at which a liquid boils is called its **boiling point.** As with melting points, chemists use boiling points to help identify an unknown substance.

Boiling Point and Air Pressure The boiling point of a substance depends on the pressure of the air above it. The lower the pressure, the less energy needed for the particles of the liquid to escape into the air. In places close to sea level, the boiling point of water is 100°C. In the mountains, however, air pressure is lower and so is water's boiling point. In Denver, Colorado, where the elevation is 1,600 meters above sea level, water boils at 95°C.

FIGURE 11
Evaporation and Boiling
Liquids can vaporize in two ways.
Interpreting Diagrams *How do these processes differ?*



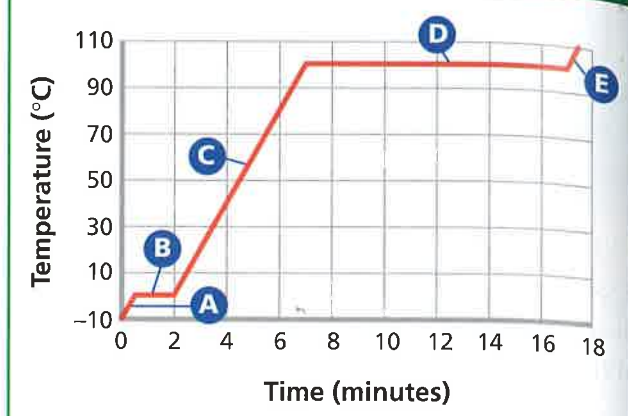
Math Analyzing Data

Temperature and Changes of State

A beaker of ice at −10°C was slowly heated to 110°C. The changes in the temperature of the water over time were recorded. The data were plotted on the graph shown here.

1. **Reading Graphs** What two variables are plotted on the graph?
2. **Reading Graphs** What is happening to the temperature of the water during segment C of the graph?
3. **Interpreting Data** What does the temperature value for segment B represent? For segment D?
4. **Drawing Conclusions** What change of state is occurring during segment B of the graph? During segment D?

Changes of State for Water



5. **Inferring** In which segment, A or E, do the water molecules have more thermal energy? Explain your reasoning.

FIGURE 12
Condensation of Water
Water vapor from a hot shower contacts the cool surface of a bathroom mirror and condenses into a liquid.

Condensation The opposite of vaporization is called **condensation.** One way you can observe condensation is by breathing onto a mirror. When warm water vapor in your breath reaches the cooler surface of the mirror, the water vapor condenses into liquid droplets. **Condensation occurs when particles in a gas lose enough thermal energy to form a liquid.** For example, clouds typically form when water vapor in the atmosphere condenses into liquid droplets. When the droplets get heavy enough, they fall to the ground as rain.

You cannot see water vapor. Water vapor is a colorless gas that is impossible to see. The steam you see above a kettle of boiling water is not water vapor, and neither are clouds or fog. What you see in those cases are tiny droplets of liquid water suspended in air.

Reading Checkpoint How do clouds typically form?

Changes Between Solid and Gas

If you live where the winters are cold, you may have noticed that snow seems to disappear even when the temperature stays well below freezing. This change is the result of sublimation. **Sublimation** occurs when the surface particles of a solid gain enough energy that they form a gas. **During sublimation, particles of a solid do not pass through the liquid state as they form a gas.**

One example of sublimation occurs with dry ice. Dry ice is the common name for solid carbon dioxide. At ordinary atmospheric pressures, carbon dioxide cannot exist as a liquid. So instead of melting, solid carbon dioxide changes directly into a gas. As it changes state, the carbon dioxide absorbs thermal energy. This property helps keep materials near dry ice cold and dry. For this reason, using dry ice is a way to keep temperature low when a refrigerator is not available. When dry ice becomes a gas, it cools water vapor in the nearby air. The water vapor then condenses into a liquid, forming fog around the dry ice.

Reading Checkpoint What physical state is skipped during the sublimation of a substance?

FIGURE 13
Dry Ice
When solid carbon dioxide, called "dry ice," sublimates, it changes directly into a gas. **Predicting** *If you allowed the dry ice to stand at room temperature for several hours, what would be left in the glass dish? Explain.*

Section 2 Assessment

Target Reading Skill **Outlining** Use the information in your outline about changes of state to help you answer the questions below.

Reviewing Key Concepts

1. a. **Reviewing** What happens to the particles of a solid as it becomes a liquid?
   b. **Applying Concepts** How does the thermal energy of solid water change as it melts?
   c. **Making Judgments** You are stranded in a blizzard. You need water to drink, and you're trying to stay warm. Should you melt snow and then drink it, or just eat snow? Explain.
2. a. **Describing** What is vaporization?
   b. **Comparing and Contrasting** Name the two types of vaporization. Tell how they are similar and how they differ.
   c. **Relating Cause and Effect** Why does the evaporation of sweat cool your body on a warm day?
3. a. **Identifying** What process occurs as pieces of dry ice gradually get smaller?
   b. **Interpreting Photos** What is the fog you see in the air around the dry ice in Figure 13? Why does the fog form?

Writing in Science

Using Analogies Write a short essay in which you create an analogy to describe particle motion. Compare the movements and positions of people dancing with the motions of water molecules in liquid water and in water vapor.