SECTION 3

Changes of State

It can be tricky to eat a frozen juice bar outside on a hot day. In just minutes, the juice bar will start to melt. Soon the solid juice bar becomes a liquid mess.

As the juice bar melts, it goes through a change of state. In this section, you will learn about the four changes of state shown in **Figure 1** as well as a fifth change of state called *sublimation* (SUHB luh MAY shuhn).

READING WARM-UP

Objectives

- Describe how energy is involved in changes of state.
- Describe what happens during melting and freezing.
- Compare evaporation and condensation.
- Explain what happens during sublimation.
- Identify the two changes that can happen when a substance loses or gains energy.

Terms to Learn

change of state
melting
evaporation
boiling
condensation
sublimation

READING STRATEGY

Mnemonics As you read this section, create a mnemonic device to help you remember the five changes of state.

change of state the change of a substance from one physical state to another

Energy and Changes of State

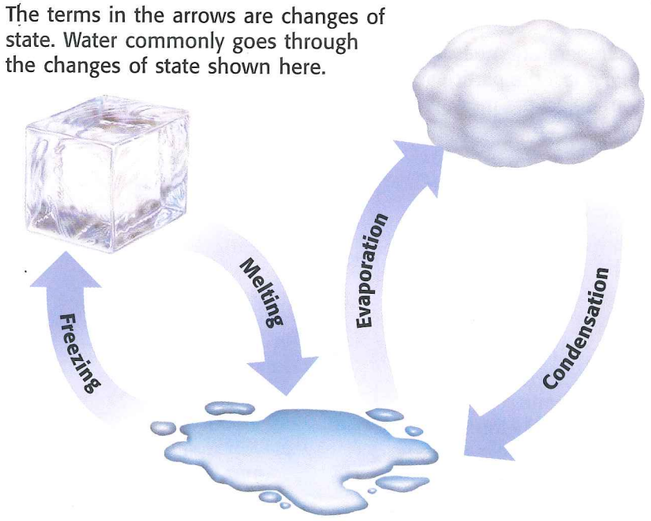
A **change of state** is the change of a substance from one physical form to another. All changes of state are physical changes. In a physical change, the identity of a substance does not change. In **Figure 1,** the ice, liquid water, and steam are all the same substance—water.

The particles of a substance move differently depending on the state of the substance. The particles also have different amounts of energy when the substance is in different states. For example, particles in liquid water have more energy than particles in ice. But particles of steam have more energy than particles in liquid water. So, to change a substance from one state to another, you must add or remove energy.

Reading Check **What is a change of state?** (*See the Appendix for answers to Reading Checks.*)

Figure 1 **Changes of State**

The terms in the arrows are changes of state. Water commonly goes through the changes of state shown here.



Melting: Solid to Liquid

One change of state that happens when you add energy to a substance is melting. **Melting** is the change of state from a solid to a liquid. This change of state is what happens when ice melts. Adding energy to a solid increases the temperature of the solid. As the temperature increases, the particles of the solid move faster. When a certain temperature is reached, the solid will melt. The temperature at which a substance changes from a solid to a liquid is the *melting point* of the substance. Melting point is a physical property. Different substances have different melting points. For example, gallium melts at about 30°C. Because your normal body temperature is about 37°C, gallium will melt in your hand! This is shown in **Figure 2.** Table salt, however, has a melting point of 801°C, so it will not melt in your hand.

Figure 2 *Even though gallium is a metal, it would not be very useful as jewelry!*

melting the change of state in which a solid becomes a liquid by adding energy

Adding Energy

For a solid to melt, particles must overcome some of their attractions to each other. When a solid is at its melting point, any energy added to it is used to overcome the attractions that hold the particles in place. Melting is an *endothermic* (EN doh THUHR mik) change because energy is gained by the substance as it changes state.

Freezing: Liquid to Solid

The change of state from a liquid to a solid is called *freezing*. The temperature at which a liquid changes into a solid is the liquid's *freezing point*. Freezing is the reverse process of melting. Thus, freezing and melting occur at the same temperature, as shown in **Figure 3.**

Removing Energy

For a liquid to freeze, the attractions between the particles must overcome the motion of the particles. Imagine that a liquid is at its freezing point. Removing energy will cause the particles to begin locking into place. Freezing is an *exothermic* (EK so THUHR mik) change because energy is removed from the substance as it changes state.

Figure 3 *Liquid water freezes at the same temperature at which ice melts—0°C.*

Evaporation: Liquid to Gas

One way to experience evaporation is to iron a shirt using a steam iron. You will notice steam coming up from the iron as the wrinkles disappear. This steam forms when the liquid water in the iron becomes hot and changes to gas.

Boiling and Evaporation

evaporation the change of a substance from a liquid to a gas

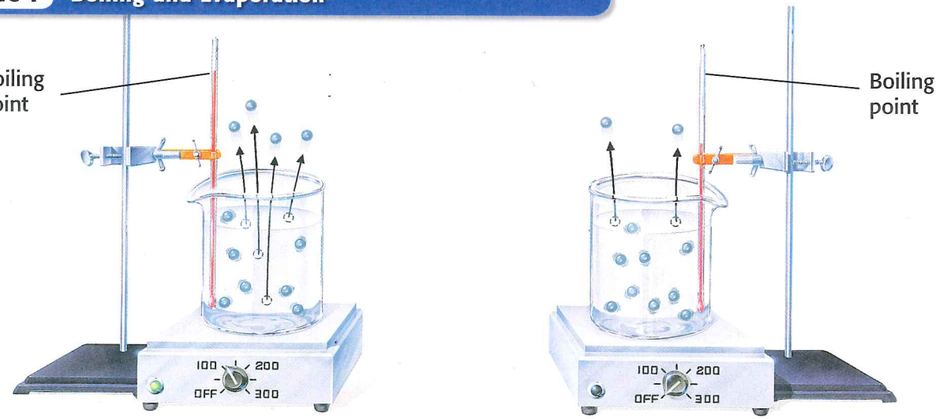
boiling the conversion of a liquid to a vapor when the vapor pressure of the liquid equals the atmospheric pressure

Evaporation (ee VAP uh RAY shuhn) is the change of a substance from a liquid to a gas. Evaporation can occur at the surface of a liquid that is below its boiling point. For example, when you sweat, your body is cooled through evaporation. Your sweat is mostly water. Water absorbs energy from your skin as the water evaporates. You feel cooler because your body transfers energy to the water. Evaporation also explains why water in a glass on a table disappears after several days.

Figure 4 explains the difference between boiling and evaporation. **Boiling** is the change of a liquid to a vapor, or gas, throughout the liquid. Boiling occurs when the pressure inside the bubbles, which is called *vapor pressure*, equals the outside pressure on the bubbles, or atmospheric pressure. The temperature at which a liquid boils is called its *boiling point*. No matter how much of a substance is present, neither the boiling point nor the melting point of a substance change. For example, 5 mL and 5 L of water both boil at 100°C.

Reading Check **What is evaporation?**

Figure 4 Boiling and Evaporation



Boiling occurs in a liquid at its boiling point. As energy is added to the liquid, particles throughout the liquid move faster. When they move fast enough to break away from other particles, they evaporate and become a gas.

Evaporation can also occur in a liquid below its boiling point. Some particles at the surface of the liquid move fast enough to break away from the particles around them and become a gas.

Effects of Pressure on Boiling Point

Earlier, you learned that water boils at 100°C. In fact, water boils at 100°C only at sea level, because of atmospheric pressure. Atmospheric pressure is caused by the weight of the gases that make up the atmosphere.

Atmospheric pressure varies depending on where you are in relation to sea level. Atmospheric pressure is lower at higher elevations. The higher you go above sea level, the fewer air particles there are above you. So, the atmospheric pressure is lower. Imagine boiling water at the top of a mountain. The boiling point would be lower than 100°C. For example, Denver, Colorado, is 1.6 km above sea level. In Denver, water boils at about 95°C.

CONNECTION TO Language Arts

WRITING SKILL **Cooking at High Altitudes** Many times, cake mixes and other prepared foods will have special instructions for baking and cooking at high altitudes. Even poaching an egg at a high attitude requires a different amount of cooking time. Imagine that you got a letter from a cousin in Denver. He is upset that a cake he made turned out poorly, even though he followed the recipe. Do research on cooking at high altitudes. Write a letter to your cousin explaining why he may have had problems baking the cake.

Condensation: Gas to Liquid

Look at the dragonfly in **Figure 5.** Notice the beads of water that have formed on the wings. They form because of condensation of gaseous water in the air. **Condensation** is the change of state from a gas to a liquid. Condensation and evaporation are the reverse of each other. The *condensation point* of a substance is the temperature at which the gas becomes a liquid. And the condensation point is the same temperature as the boiling point at a given pressure.

For a gas to become a liquid, large numbers of particles must clump together. Particles clump together when the attraction between them overcomes their motion. For this to happen, energy must be removed from the gas to slow the movement of the particles. Because energy is removed, condensation is an exothermic change.

condensation the change of state from a gas to a liquid

Figure 5 *Beads of water form when water vapor in the air contacts a cool surface, such as the wings of this dragonfly.*

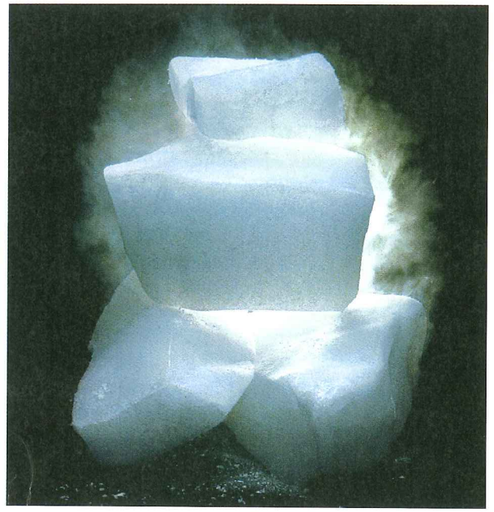


Figure 6 *Dry ice changes directly from a solid to a gas. This change of state is called* sublimation.

Sublimation: Solid to Gas

The solid in **Figure 6** is dry ice. Dry ice is carbon dioxide in a solid state. It is called *dry ice* because instead of melting into a liquid, it goes through sublimation. **Sublimation** is the change of state in which a solid changes directly into a gas. Dry ice is much colder than ice made from water.

For a solid to change directly into a gas, the particles of the substance must move from being very tightly packed to being spread far apart. So, the attractions between the particles must be completely overcome. The substance must gain energy for the particles to overcome their attractions. Thus, sublimation is an endothermic change because energy is gained by the substance as it changes state.

sublimation the process in which a solid changes directly into a gas

Change of Temperature Vs. Change of State

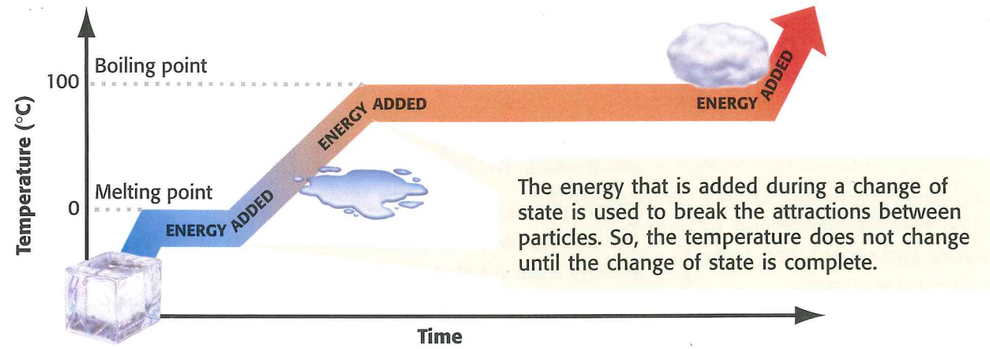
When most substances lose or gain energy, one of two things happens to the substance: its temperature changes or its state changes. The temperature of a substance is related to the speed of the substance's particles. So, when the temperature of a substance changes, the speed of the particles also changes. But the temperature of a substance does not change until the change of state is complete. For example, the temperature of boiling water stays at 100°C until it has all evaporated. In **Figure 7,** you can see what happens to ice as energy is added to the ice.

Reading Check **What happens to the temperature of a substance as it changes state?**

Boiling Water Is Cool

1. Remove the cap from a **syringe.**
2. Place the tip of the syringe in the **warm water** that is provided by your teacher. Pull the plunger out until you have 10 mL of water in the syringe.
3. Tighten the cap on the syringe.
4. Hold the syringe, and slowly pull the plunger out.
5. Observe any changes you see in the water. Record your observations.
6. Why are you not burned by the water in the syringe?

Figure 7 **Changing the State of Water**



The energy that is added during a change of state is used to break the attractions between particles. So, the temperature does not change until the change of state is complete.

SECTION Review

Summary

- A change of state is the conversion of a substance from one physical form to another.
- Energy is added during endothermic changes. Energy is removed during exothermic changes.
- The freezing point and the melting point of a substance are the same temperature.
- Both boiling and evaporation result in a liquid changing to a gas.
- Condensation is the change of a gas to a liquid. It is the reverse of evaporation.
- Sublimation changes a solid directly to a gas.
- The temperature of a substance does not change during a change of state.

Using Key Terms

For each pair of terms, explain how the meanings of the terms differ.

1. *melting* and *freezing*
2. *condensation* and *evaporation*

Understanding Key Ideas

3. The change from a solid directly to a gas is called
   - **a.** evaporation.
   - **b.** boiling.
   - **c.** melting.
   - **d.** sublimation.
4. Describe how the motion and arrangement of particles in a substance change as the substance freezes.
5. Explain what happens to the temperature of an ice cube as it melts.
6. How are evaporation and boiling different? How are they similar?

Math Skills

7. The volume of a substance in the gaseous state is about 1,000 times the volume of the same substance in the liquid state. How much space would 18 mL of water take up if it evaporated?

Critical Thinking

8. **Evaluating Data** The temperature of water in a beaker is 25°C. After adding a piece of magnesium to the water, the temperature increases to 28°C. Is this an exothermic or endothermic reaction? Explain your answer.
9. **Applying Concepts** Solid crystals of iodine were placed in a flask. The top of the flask was covered with aluminum foil. The flask was gently heated. Soon, the flask was filled with a reddish gas. What change of state took place? Explain your answer.
10. **Predicting Consequences** Would using dry ice in your holiday punch cause it to become watery after several hours? Why or why not?