Section
2

Changes of State

Terms to Learn

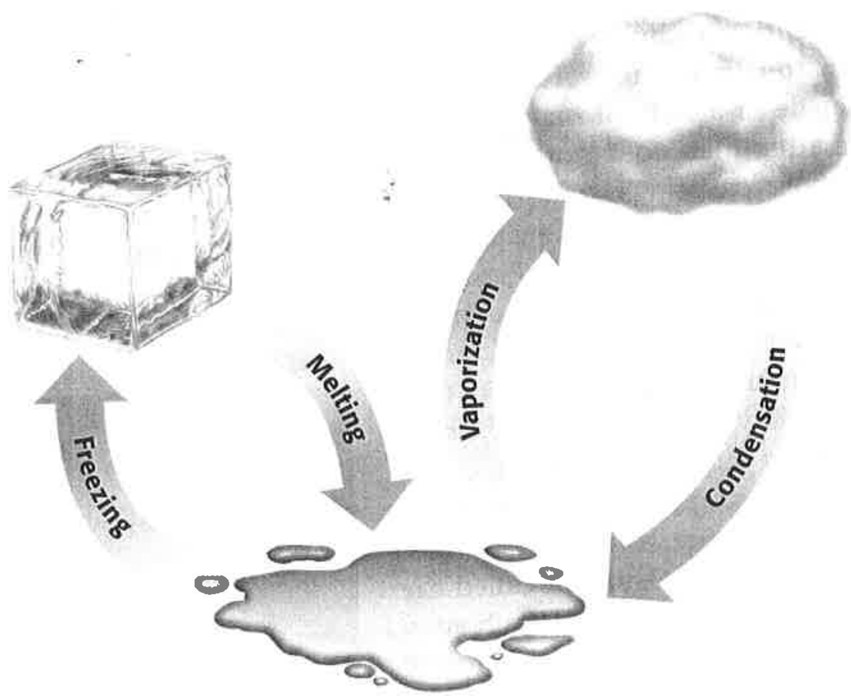
change of state
melting
freezing
vaporization
boiling
evaporation
condensation
sublimation

What You'll Do

- Describe how substances change from state to state.
- Explain the difference between an exothermic change and an endothermic change.
- Compare the changes of state.

A **change of state** is the conversion 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 13**, the ice, liquid water, and steam are all the same substance—water. In this section, you will learn about the four changes of state illustrated in Figure 13 as well as a fifth change of state called *sublimation* (SUHB li MAY shuhn).

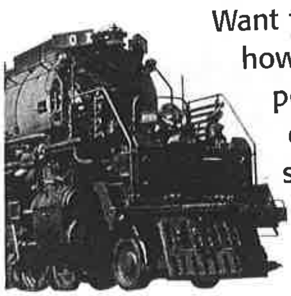
Figure 13 *The terms in the arrows are changes of state. Water commonly goes through the changes of state shown here.*



Energy and Changes of State

During a change of state, the energy of a substance changes. The *energy* of a substance is related to the motion of its particles. The molecules in the liquid water in Figure 13 move faster than the molecules in the ice. Therefore, the liquid water has more energy than the ice.

If energy is added to a substance, its particles move faster. If energy is removed, its particles move slower. The *temperature* of a substance is a measure of the speed of its particles and therefore is a measure of its energy. For example, steam has a higher temperature than liquid water, so particles in steam have more energy than particles in liquid water. A transfer of energy, known as *heat,* causes the temperature of a substance to change, which can lead to a change of state.



Want to learn how to get power from changes of state? Steam ahead to page 79.

Melting: Solids to Liquids

Melting is the change of state from a solid to a liquid. This is what happens when an ice cube melts. **Figure 14** shows a metal called gallium melting. What is unusual about this metal is that it melts at around 30°C. Because your normal body temperature is about 37°C, gallium will melt right in your hand!

The *melting point* of a substance is the temperature at which the substance changes from a solid to a liquid. Melting points of substances vary widely. The melting point of gallium is 30°C. Common table salt, however, has a melting point of 801°C.

Most substances have a unique melting point that can be used with other data to identify them. Because the melting point does not change with different amounts of the substance, melting point is a *characteristic property* of a substance.

Figure 14 *Even though gallium is a metal, it would not be very useful as jewelry!*

Absorbing 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 it absorbs increases the motion of its atoms or molecules until they overcome the attractions that hold them in place. Melting is an *endothermic* change because energy is absorbed by the substance as it changes state.

Freezing: Liquids to Solids

Freezing is the change of state from a liquid to a solid. The temperature at which a liquid changes into a solid is its *freezing point*. Freezing is the reverse process of melting, so freezing and melting occur at the same temperature, as shown in **Figure 15.**

Removing Energy For a liquid to freeze, the motion of its atoms or molecules must slow to the point where attractions between them overcome their motion. If a liquid is at its freezing point, removing more energy causes the particles to begin locking into place. Freezing is an *exothermic* change because energy is removed from, or taken out of, the substance as it changes state.

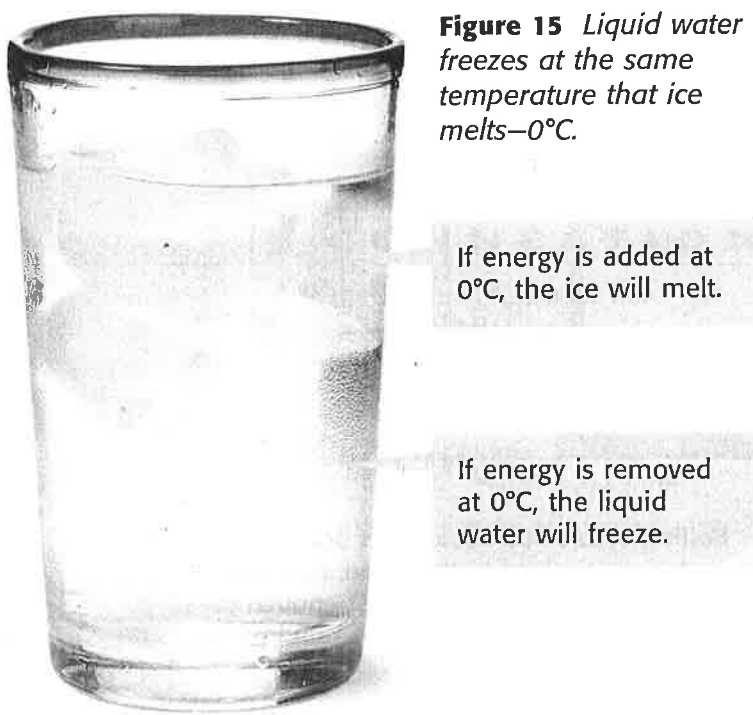


Figure 15 *Liquid water freezes at the same temperature that ice melts—0°C.*

Vaporization: Liquids to Gases

One way to experience vaporization (VAY puhr i ZAY shuhn) is to iron a shirt—carefully!—using a steam iron. You will notice steam coming up from the iron as the wrinkles are eliminated. This steam results from the vaporization of liquid water by the iron. **Vaporization** is simply the change of state from a liquid to a gas.

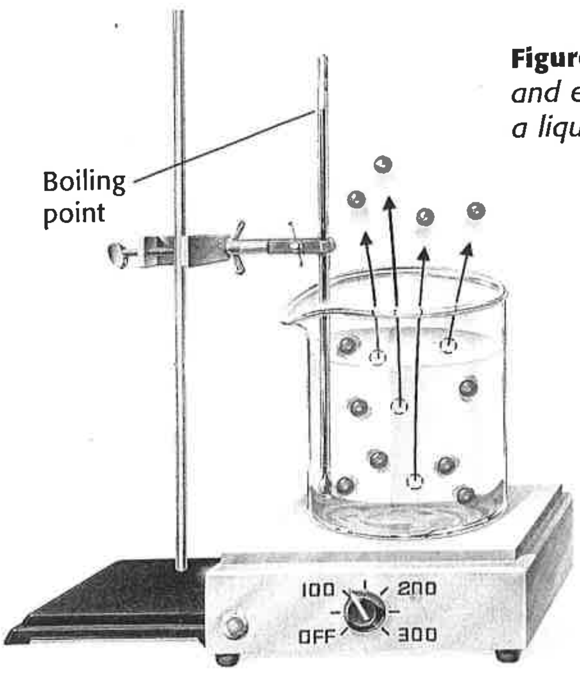
Boiling is vaporization that occurs throughout a liquid. The temperature at which a liquid boils is called its *boiling point.* Like the melting point, the boiling point is a characteristic property of a substance. The boiling point of water is 100°C, whereas the boiling point of liquid mercury is 357°C. **Figure 16** illustrates the process of boiling and a second form of vaporization—evaporation (ee VAP uh RAY shuhn).

Evaporation is vaporization that occurs at the surface of a liquid below its boiling point, as shown in Figure 16. When you perspire, your body is cooled through the process of evaporation. Perspiration is mostly water. Water absorbs energy from your skin as it 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.

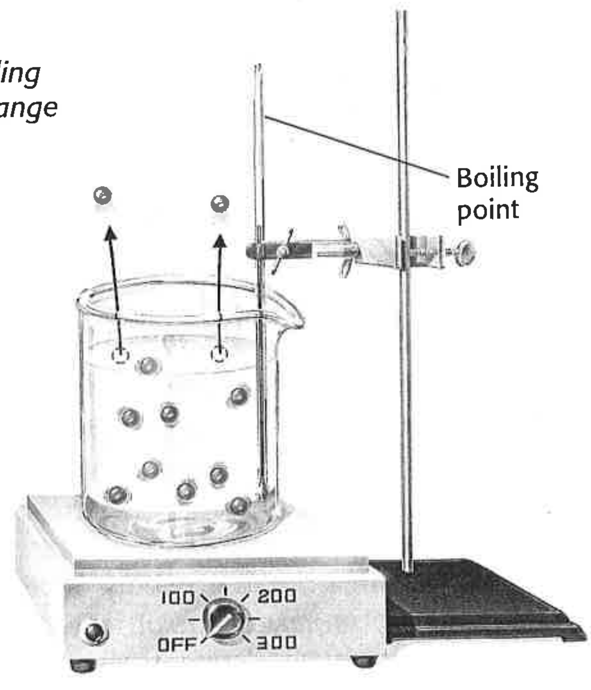
Self-Check

Is vaporization an endothermic or exothermic change? *(See page 724 to check your answer.)*

Figure 16 *Both boiling and evaporation change a liquid to a gas.*



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



Evaporation occurs 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.

Pressure Affects Boiling Point Earlier you learned that water boils at 100°C. In fact, water only boils at 100°C 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 less air there is above you, and the lower the atmospheric pressure is. If you were to boil water at the top of a mountain, the boiling point would be lower than 100°C. For example, Denver, Colorado, is 1.6 km (1 mi) above sea level and water boils there at about 95°C. You can make water boil at an even lower temperature by doing the QuickLab at right.

Condensation: Gases to Liquids

Look at the cool glass of lemonade in **Figure 17.** Notice the beads of water on the outside of the glass. These form as a result of condensation. **Condensation** is the change of state from a gas to a liquid. The *condensation point* of a substance is the temperature at which the gas becomes a liquid and is the same temperature as the boiling point at a given pressure. Thus, at sea level, steam condenses to form water at 100°C—the same temperature at which water boils.

For a gas to become a liquid, large numbers of atoms or molecules must clump together. Particles clump together when the attraction between them overcomes their motion. For this to occur, energy must be removed from the gas to slow the particles down. Therefore, condensation is an exothermic change.

Figure 17 *Gaseous water in the air will become liquid when it contacts a cool surface.*

QuickLab

Boiling Water Is Cool

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

Meteorology CONNECTION

The amount of gaseous water that air can hold decreases as the temperature of the air decreases. As the air cools, some of the gaseous water condenses to form small drops of liquid water. These drops form clouds in the sky and fog near the ground.

Sublimation: Solids Directly to Gases

Look at the solids shown in **Figure 18.** The solid on the left is ice. Notice the drops of liquid collecting as it melts. On the right, you see carbon dioxide in the solid state, also called dry ice. It is called dry ice because instead of melting into a liquid, it goes through a change of state called sublimation. **Sublimation** is the change of state from a solid directly into a gas. Dry ice is colder than ice, and it doesn't melt into a puddle of liquid. It is often used to keep food, medicine, and other materials cold without getting them wet.

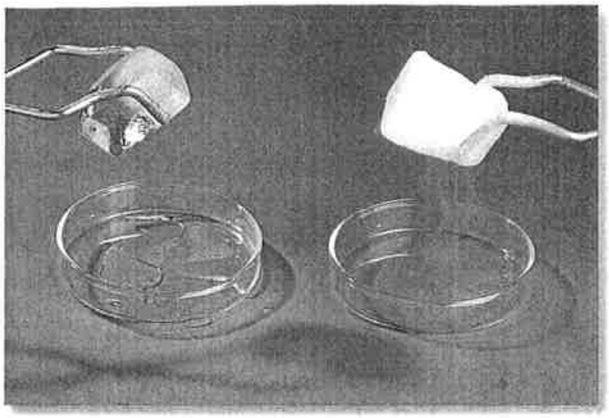


Figure 18 *Ice melts, but dry ice, on the right, turns directly into a gas.*

For a solid to change directly into a gas, the atoms or molecules must move from being very tightly packed to being very spread apart. The attractions between the particles must be completely overcome. Because this requires the addition of energy, sublimation is an endothermic change.

Comparing Changes of State

As you learned in Section 1 of this chapter, the state of a substance depends on how fast its atoms or molecules move and how strongly they are attracted to each other. A substance may undergo a physical change from one state to another by an endothermic change (if energy is added) or an exothermic change (if energy is removed). The table below shows the differences between the changes of state discussed in this section.

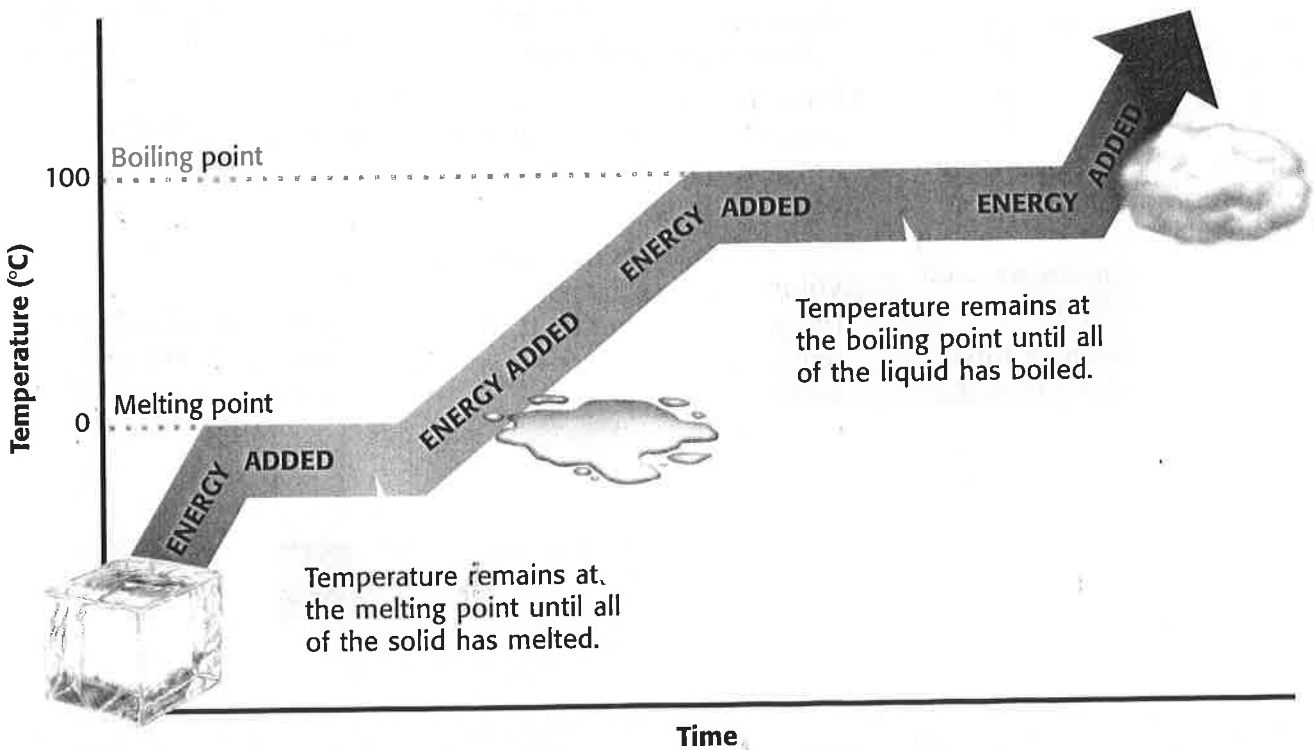
Summarizing the Changes of State

Change of state	Direction	Endothermic or exothermic?	Example
Melting	solid → liquid	endothermic	Ice melts into liquid water at 0°C.
Freezing	liquid → solid	exothermic	Liquid water freezes into ice at 0°C.
Vaporization	liquid → gas	endothermic	Liquid water vaporizes into steam at 100°C.
Condensation	gas → liquid	exothermic	Steam condenses into liquid water at 100°C.
Sublimation	solid → gas	endothermic	Solid dry ice sublimes into a gas at –78°C.

Temperature Change Versus Change of State

When most substances lose or absorb energy, one of two things happens to the substance: its temperature changes or its state changes. Earlier in the chapter, you learned that the temperature of a substance is a measure of the speed of the particles. This means that when the temperature of a substance changes, the speed of the particles also changes. But while a substance changes state, its temperature does not change until the change of state is complete, as shown in **Figure 19.**

Figure 19 Changing the State of Water



REVIEW

1. Compare endothermic and exothermic changes.
2. Classify each change of state (melting, freezing, vaporization, condensation, and sublimation) as endothermic or exothermic.
3. Describe how the motion and arrangement of particles change as a substance freezes.
4. **Comparing Concepts** How are evaporation and boiling different? How are they similar?

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