Section 3

Thermal Energy and States of Matter

Objectives

After this lesson, students will be able to

M.6.3.1 Name the three states of matter.

M.6.3.2 Identify the cause of changes of state.

M.6.3.3 Describe what happens to a substance as its thermal energy increases.

Target Reading Skill

Building Vocabulary Explain that knowing the definitions of key-concept words helps students understand what they read.

As students read each passage that contains a key term, remind them to write a sentence in their own words. Encourage students to write one or two descriptive phrases to help them remember the key term. Call on students to share their definitions.

Preteach

Build Background Knowledge

L2

Introducing States of Matter

Show students a glass containing water and ice cubes. Ask: **What substance is in this glass?** *(Water)* **What forms of water are in this glass?** *(Liquid water and ice, a solid)* **What will happen to the ice if it sits at room temperature?** *(It will melt and turn into liquid water.)*

Thermal Energy and States of Matter

Reading Preview

Key Concepts

- What are three states of matter?
- What causes matter to change state?
- What happens to a substance as its thermal energy increases?

Key Terms

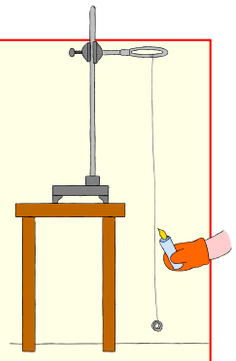
- state
- change of state
- melting
- freezing
- evaporation
- boiling
- condensation
- thermal expansion

Target Reading Skill

Building Vocabulary Using a word in a sentence helps you think about how best to explain the word. After you read the section, reread the paragraphs that contain definitions of Key Terms. Use all the information you have learned to write a meaningful sentence for each Key Term.

Lab zone **Discover Activity**

What Happens to Heated Metal?



1. Wrap one end of a one-meter-long metal wire around a clamp on a ring stand.
2. Tie the other end through several washers. Adjust the clamp so that the washers swing freely, but nearly touch the floor.
3. Light a candle. Hold the candle with an oven mitt, and heat the wire. **CAUTION:** *Be careful near the flame, and avoid dripping hot wax on yourself.* Predict how heat from the candle will affect the wire.
4. With your hand in the oven mitt, swing the wire. Observe any changes in the motion of the washers.
5. Blow out the candle and allow the wire to cool. After several minutes, swing the wire again and observe its motion.

Think It Over

Inferring Based on your observations, what can you conclude about the effect of heating a solid?

Throughout the day, the temperature at an orange grove drops steadily. The anxious farmer awaits the updated weather forecast. The news is not good. The temperature is expected to fall even further during the night. Low temperatures could wipe out the entire crop. He considers picking the crop early, but the oranges are not yet ripe.

◀ **Oranges at 0°C sprayed with water**

Instead, the farmer tells his workers to haul in hoses and spray the orange trees with water. As the temperature drops, the water begins to freeze. The ice keeps the oranges warm!

How can ice possibly keep anything warm? The answer has to do with how thermal energy is transferred as water becomes ice.

Lab zone **Discover Activity**

Skills Focus Inferring L2

Materials 1 m of thin metal wire, clamp, ring stand, 3 or 4 washers, matches, candle, oven mitt

Time 15 minutes

Tips **CAUTION:** *Students should keep loose hair and clothes away from the flame.* In Step 4, suggest that students swing the wire gently.

Expected Outcome As the metal wire is heated, its length increases and the washers drag on the floor. As it cools, the wire returns to its original length and the washers can swing.

Think It Over Sample answer: Solids expand when heated and contract when cooled.

States of Matter

What happens when you hold an ice cube in your hand? It melts. The solid and the liquid are both the same material—water. Water can exist in three different **states,** or forms. **In fact, most matter on Earth can exist in three states—solid, liquid, and gas.** Although the chemical composition of matter remains the same, the arrangement of the particles that make up the matter differs from one state to another.

Solids The particles that make up a solid are packed together in relatively fixed positions. Particles of a solid cannot move out of their positions. They can only vibrate back and forth. This is why solids retain a fixed shape and volume. Because the shape and volume of the plastic helmets shown in Figure 10 do not change, the plastic is a solid.

Liquids The particles that make up a liquid are close together, but they are not held together as tightly as those of a solid. Because liquid particles can move around, liquids don't have a definite shape. But liquids do have a definite volume. In Figure 10, notice how the river water changes shape.

Gases In gases, the particles are moving so fast that they don't even stay close together. Gases expand to fill all the space available. They don't have a fixed shape or volume. Because air is a gas, it can expand to fill the raft in Figure 10 and also take the raft's shape.

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FIGURE 10
Three States of Matter
The plastic helmets, the water in the river, and the air that fills the raft are examples of three states of matter—solid, liquid, and gas.
Classifying *Which state of matter is represented by the plastic oars?*

Differentiated Instruction

English Learners/Beginning L1
Comprehension: Link to Visual Call students' attention to the inset drawings in Figure 10. Have students copy the three inset drawings on a blank sheet of paper. Then have students add the labels *solid, liquid,* and *gas* to the correct drawing.
learning modality: visual

English Learners/Intermediate L2
Comprehension: Link to Visual Call students' attention to the inset drawings in Figure 10. Have students copy the three inset drawings on a blank sheet of paper. Then, have students write a sentence next to each drawing describing the particles in that state of matter, for example, *The particles in a solid are close together*. Model this activity for students before they begin.
learning modality: visual

Instruct

Three States of Matter

Teach Key Skills L2

Solids, Liquids, and Gases

Focus State that almost all matter on Earth exists as a solid, a liquid or a gas.

Teach Write three headings on the board: *solid, liquid, gas*. Ask students to state facts about each state of matter, and list their responses under the correct heading on the board. After the facts have been collected, ask students to list examples of common substances for each state of matter. Record the examples on the board.

Apply Ask: **In which state of matter do substances have a definite shape? Why?** *(Solids, because the particles that make up a solid are not free to move out of their positions.)* **learning modality: logical/mathematical**

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Students can explore internet sources about changes of state.

Independent Practice L2

All in One Teaching Resources
- Guided Reading and Study Worksheet: *Thermal Energy and States of Matter*

Student Edition on Audio CD

Monitor Progress L2

Oral Presentation Have students give a description of the motion of particles in solids, liquids, and gases.

Answer
Figure 10 The plastic oars are an example of a solid.

Changes of State

Teach Key Concepts L2

Thermal Energy Causes Changes of State

Focus Ask: **What happens to an ice cube at room temperature?** *(It melts.)*

Teach Point out that the ice cube melting, like any change of state, is caused by a change in the thermal energy of the substance. Explain that thermal energy flows from the air in the room to the ice cube. When the ice cube absorbs a certain amount of thermal energy, it melts, or changes from a solid to a liquid.

Apply Ask: **What happens to liquid water when it is placed in the freezer? Why?** *(It changes state from a liquid to a solid because it releases thermal energy.)* **learning modality: verbal**

All in One Teaching Resources

- Transparency M55

Lab zone Teacher Demo

Observing the Freezing Point of Paraffin L1

Materials hot plate, two blocks of paraffin, thermometer, saucepan

Time 20 minutes

Focus Tell students that different substances have different freezing points.

Teach Place the paraffin in a saucepan on a hot plate. Gently warm the paraffin over low heat until it is completely melted. Remove the saucepan from the hot plate. Turn off the hot plate. Place a thermometer into the liquid paraffin and record the temperature every minute until the paraffin is once again solid. Note the temperature at which the paraffin begins to solidify.

Apply Ask: **Is the freezing point of paraffin the same as the freezing point of water?** *(No)* **Is it higher or lower?** *(Higher)* **learning modality: visual**

FIGURE 11
Melted Chocolate
Though normally a solid at room temperature, this chocolate has absorbed enough thermal energy to become a liquid.

Changes of State

The physical change from one state of matter to another is called a **change of state.** The state of matter depends on the amount of thermal energy it has. The more thermal energy matter has, the faster its particles move. Since a gas has more thermal energy than a liquid, the particles of a gas move faster than the particles of the same matter in the liquid state.

Matter can change from one state to another when thermal energy is absorbed or released. The graph in Figure 12 shows that as thermal energy increases, matter changes from a solid to a liquid and then to a gas. A gas changes to a liquid and then to a solid as thermal energy is removed from it.

The flat regions of the graph show conditions under which thermal energy is changing but temperature remains the same. Under these conditions, matter is changing from one state to another. During a change of state, the addition or loss of thermal energy changes the arrangement of the particles. However, the average kinetic energy of those particles does not change. Since temperature is a measure of average kinetic energy, temperature does not change as the state of matter changes.

Solid–Liquid Changes of State The change of state from a solid to a liquid is called **melting.** Melting occurs when a solid absorbs thermal energy. As the thermal energy of the solid increases, the structure of its particles breaks down. The particles become freer to move around. The temperature at which a solid changes to a liquid is called the melting point.

The change of state from a liquid to a solid is called **freezing.** Freezing occurs when matter releases thermal energy. The temperature at which matter changes from a liquid to a solid is called its freezing point.

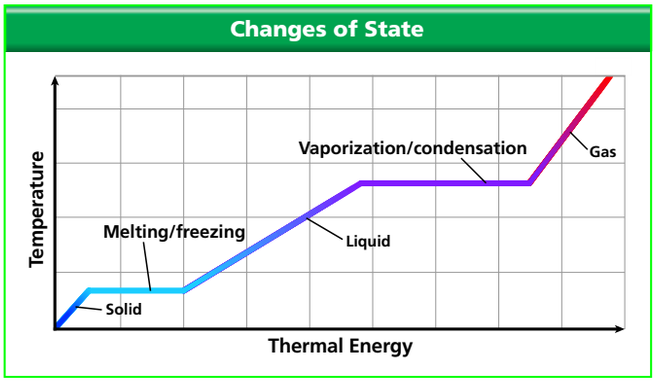

FIGURE 12
Thermal energy and temperature change as matter changes from one state to another.

Differentiated Instruction

Gifted and Talented L3

Researching Have students research the use of road salt to prevent slippery roads in cold climates. Students should relate the use of road salt to freezing point and changes of state. When students have completed their research, they can present their findings to the class. **learning modality: verbal**

Special Needs L1

Displaying Information Have students use drawings or magazine clippings of substances that are solids, liquids, and gases to create a three-part poster. Each part of the poster should have an appropriate label. **learning modality: visual**

For a given type of matter, the freezing point and melting point are the same. The difference between the two is whether the matter is gaining or releasing thermal energy. The farmer had his workers spray the orange trees with water because the freezing water releases thermal energy into the oranges.

Liquid–Gas Changes of State The process by which matter changes from the liquid to the gas state is called vaporization. During this process, particles in a liquid absorb thermal energy and move faster. Eventually they move fast enough to escape the liquid as gas particles. If vaporization takes place at the surface of a liquid, it is called **evaporation.** At higher temperatures, vaporization can occur below the surface of a liquid as well. This process is called **boiling.** When a liquid boils, gas bubbles that form within the liquid rise to the surface. The temperature at which a liquid boils is called its boiling point.

When a gas loses a certain amount of thermal energy, it will change into a liquid. A change from the gas state to the liquid state is called **condensation.** You have probably seen beads of water appear on the outside of a cold drinking glass. This occurs because water vapor that is present in the air loses thermal energy when it comes in contact with the cold glass.

Reading Checkpoint **What change of state occurs in evaporation?**

Lab zone Skills Activity

Observing

Put a teakettle on a stove or a lab burner and bring the water to a boil. Look carefully at the white vapor coming out of the spout. **CAUTION:** *Steam and boiling water can cause serious burns.* In what state of matter is the white vapor that you see? What is present, but not visible, in the small space between the white vapor and the spout?

FIGURE 13
Condensation
Under certain weather conditions, water vapor in the air can condense into fog. Applying Concepts *As it condenses, does water absorb or release thermal energy?*

Lab zone Skills Activity

Skills Focus Observing L2

Materials tea kettle, hot plate, water

Time 10 minutes

Tips **CAUTION:** *Students stand clear of the boiling water and steam.*

Expected Outcome Students will see steam coming from the teakettle. Sample answer: The visible steam is condensation, a liquid. Water vapor, a gas, is present but not visible.

Extend Have students apply what they have observed in this activity to infer the role of condensation in cloud formation. *(Clouds are formed when water vapor undergoes condensation on particulate matter in the air.)* **learning modality: visual**

Help Students Read L1

Word/Part Analysis Tell students that examining word parts can help them determine a word's meaning. Help students understand the key term *thermal expansion* by pointing out the word part *therm-*, a Greek root meaning *heat*. Ask: **In addition to *thermal expansion*, can you think of other words or terms that contain the word part *therm-*?** *(Sample answers: Thermometer, exothermic, thermostat)*

Thermal Expansion

Teach Key Concepts L2

Expansion and Contraction

Focus Remind students that changes in thermal energy affect the motion of the particles in a substance.

Teach Explain that when an object absorbs thermal energy, its particles spread out. This causes the substance to expand. When an object releases thermal energy, its particles move closer together, and the object contracts.

Apply Ask: **If you fill your bike's tires with air on a very hot day, what might you observe when the temperature drops? Why?** *(The tires will appear less full when it is cold outside, because the air in the tires has contracted.)* **learning modality: logical/mathematical**

Monitor Progress L2

Writing Have students write a paragraph comparing evaporation and boiling.

Students can keep their paragraphs in their portfolios. Portfolio

Answers

Figure 13 Water releases thermal energy during condensation.

Reading Checkpoint Liquid to gas

Thermal Energy and Heat

Show the Video Field Trip to let students understand how thermal expansion affects bridges. Discussion question: **Why is knowledge of heat transfer important in the construction of bridges?** *(Sample answer: The materials used to construct bridges are subject to expansion and contraction as the surrounding temperature changes. Engineers and bridge designers must consider possible expansion or contraction of bridge materials so the bridge is safe at all temperatures.)*

Assess

Reviewing Key Concepts

1. a. Solids, liquids, and gases **b.** Only solids have definite shapes. Solids and liquids have definite volumes. Gases have neither definite shapes nor definite volumes.
2. a. At certain temperatures, matter changes from one state to another when thermal energy is absorbed or released. **b.** The addition or loss of thermal energy changes the arrangement of the particles, not their average kinetic energy. **c.** Melting occurs when a solid absorbs enough thermal energy to reach its melting point.
3. a. A liquid can expand without changing state if the thermal energy it absorbs does not cause it to reach the temperature at which it vaporizes. **b.** The water in the potato will change state as the potato is baked. The holes allow the water vapor and steam to escape. **c.** A thermostat uses a bimetallic strip. When the strip is heated, one side expands more than the other, operating the switch that turns the heating system on and off.

Reteach L1

Have students locate the boldface sentences in the section, and restate each in their own words.

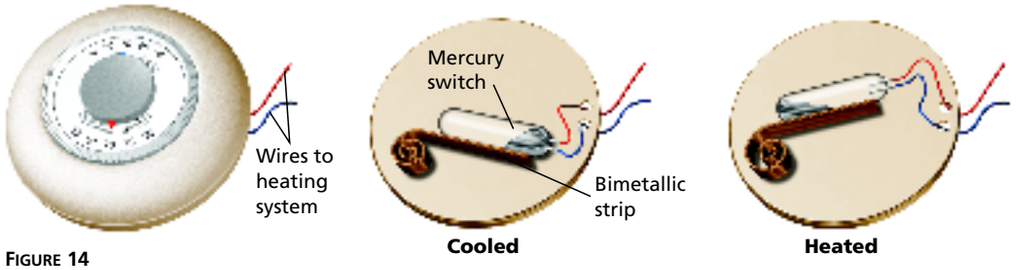

FIGURE 14
Thermostat
A bimetallic strip controls many thermostats. When it cools, the strip curls up and lowers the switch, allowing mercury to flow over the wires. When the strip warms up, it uncurls and raises the switch.

Thermal Expansion

Have you ever loosened a tight jar lid by holding it under a stream of hot water? This works because the metal lid expands a little. Do you know why? **As the thermal energy of matter increases, its particles spread out and the substance expands.** With a few exceptions, this is true for all matter, even when the matter is not changing state. The expanding of matter when it is heated is known as **thermal expansion.**

When matter is cooled, thermal energy is released. The motion of the particles slows down and the particles move closer together. In nearly all cases, as matter is cooled, it contracts, or decreases in volume.

Heat-regulating devices called thermostats use thermal expansion to work. Many thermostats contain bimetallic strips, which are strips of two different metals joined together. Different metals expand at different rates. When the bimetallic strip is heated, one side expands more than the other. This causes the strip to uncurl. The movement of the strip operates a switch, which can turn a heating system on or off.

Section 3 Assessment

Target Reading Skill **Building Vocabulary** Use your sentences to help answer the questions.

Reviewing Key Concepts

1. **a.** **Identifying** Name three states of matter.
   b. **Comparing and Contrasting** How are the three states of matter different from each other? How are they the same?
2. **a.** **Reviewing** What causes a change in state?
   b. **Describing** Why does the temperature of matter remain the same while the matter changes state?
   c. **Relating Cause and Effect** What causes a solid to melt?
3. **a.** **Defining** How can a liquid expand without changing state?
   b. **Applying Concepts** Why should you poke holes in a potato before baking it?
   c. **Interpreting Diagrams** How does a thermostat make use of thermal expansion?

Lab zone At-Home Activity

Frosty Balloons Blow up two balloons so that they are the same size. Have a family member use a measuring tape to measure the circumference of the balloons. Place one of the balloons in the freezer for 15 to 20 minutes. Then measure both balloons again. Explain how changes in thermal energy cause the change in size.

Performance Assessment L2

Drawing Have students make labeled diagrams that show the change of state of a container of water that starts cold and is heated until it boils and vaporizes.

All in One Teaching Resources

- Section Summary: *Thermal Energy and Heat*
- Review and Reinforcement: *Thermal Energy and Heat*
- Enrich: *Thermal Energy and Heat*

Lab zone At-Home Activity

Frosty Balloons L1 Suggest that students mark the location of the measuring tape on the balloon, so they can measure the same part of the balloon each time. Do not use Mylar™ balloons. Students should note that placing the balloon in the freezer causes the particles of the gas in the balloon to lose thermal energy. This causes the gas to contract, so that the balloon's circumference becomes smaller.