Temperature, Thermal Energy, and Heat

Objectives
After this lesson, students will be able to
M.6.1.1 Name the three common temperature scales.
M.6.1.2 Describe how thermal energy is related to temperature and heat.
M.6.1.3 Explain the significance of a high specific heat.

Target Reading Skill
Comparing and Contrasting Explain that comparing and contrasting information shows how ideas, facts, and events are similar and different. The results of the comparison can increase students' understanding.

Answers
Temperature—Average kinetic energy of particles, Fahrenheit or Celsius degrees, kelvins
Thermal energy—Total energy of all particles in an object, Joule
Heat—Energy transferred, Joule

Preteach
Build Background Knowledge
Temperature Measures Kinetic Energy
Have students use newspapers to locate the daily high and low temperatures for the past week. Invite students to describe the hottest and coldest temperatures they have experienced. Ask: When the temperature of a substance is 25°C, what is that a measure of? (Sample answer: How hot or cold something is) List the answers and use them as a basis for assessing misconceptions about temperature.

Reading Preview
Key Concepts
• What are the three common temperature scales?
• How is thermal energy related to temperature and heat?
• What does having a high specific heat mean?

Key Terms
• temperature
• Fahrenheit scale
• Celsius scale
• Kelvin scale
• absolute zero
• heat
• specific heat

Target Reading Skill
Comparing and Contrasting
As you read, compare and contrast temperature, thermal energy, and heat by completing a table like the one below:

<table>
<thead>
<tr>
<th>Energy Measured</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp.</td>
<td>Average kinetic energy of particles</td>
</tr>
<tr>
<td>Thermal energy</td>
<td>Heat</td>
</tr>
</tbody>
</table>

Expected Outcome
The water in the third bowl will feel warm to the hand that was in the cold water and cold to the hand that was in the warm water.

Think It Over
The water in the third bowl (room temperature water) felt warm to the hand that was in the cold water and cold to the hand that was in warm water. The sense of temperature by the body is relative.

Skills Focus
Observing

Materials
3 large bowls, warm tap water, cold tap water, room temperature water, markers, paper

Time
10 minutes

Tips
Keep paper towels on hand to clean up any water spills. CAUTION: Students should not use water with a temperature greater than 45°C.

How Cold Is the Water?
1. Fill a plastic bowl with cold water, another with warm water, and a third with water at room temperature. Label each bowl and line them up.
2. Place your right hand in the cold water and your left hand in the warm water.
3. After about a minute, place both your hands in the third bowl at the same time.

Think It Over
Observing How did the water in the third bowl feel when you touched it? Did the water feel the same on both hands? If not, explain why.

• specific heat
• heat
• absolute zero
• Kelvin scale
• Fahrenheit scale
• temperature

Key Terms
In Figure 1, the hot cocoa has a higher temperature than the cold chocolate milk. The cocoa’s particles are moving faster, so they have greater average kinetic energy. If the milk is heated, its particles will move faster, so their kinetic energy will increase. The temperature of the milk will rise.

Measuring Temperature To measure the temperature of the heated milk, you would probably use a thermometer like the one shown in Figure 2. A thermometer usually consists of a liquid such as mercury or alcohol sealed inside a narrow glass tube. When the tube is heated, the particles of the liquid speed up and spread out so the particles take up more space, or volume. You see the level of the liquid move up the tube. The reverse happens when the tube is cooled. The particles of the liquid slow down and move closer, taking up less volume. You see the level of the liquid move down in the tube.

A thermometer has numbers and units, or a scale, on it. When you read the scale on a thermometer, you read the temperature of the surrounding matter. Thermometers can have different scales. The temperature reading you see depends on the thermometer’s scale.

Instruct
Temperature
Teach Key Concepts

Describing and Measuring Temperature

Focus Tell students that in science the term temperature refers to the average kinetic energy of the tiny particles that make up matter.

Teach Ask: If the kinetic energy of the particles in an object increases, what happens to the temperature of the object? (The temperature increases.) If the kinetic energy of the particles in an object decreases, what happens to the temperature of the object? (The temperature decreases.) Tell students that temperature is measured using a thermometer. The higher the level of the liquid in the thermometer, the higher the temperature.

Apply Ask: What temperature scale are you most familiar with? (Sample answer: Fahrenheit) Why? (Sample answer: It is used in weather forecasts and recipes.)

Learning modality: logical/mathematical

Independent Practice

Temperature, Thermal Energy, and Heat

• Guided Reading and Study Worksheet: Temperature, Thermal Energy, and Heat

Subject: Reading, Science

Lesson: Temperature, Thermal Energy, and Heat

Monitor Progress

Writing Have students write a paragraph comparing the water particles in a pot of boiling water to those in an ice cube tray in the freezer.

Answers

Figure 1 The hot cocoa has particles with greater average kinetic energy. The liquid particles speed up and spread out, so the liquid takes up more volume.
**Thermal Energy and Heat**

**Teach Key Concepts**

**Differentiating Between Temperature, Thermal Energy, and Heat**

**Focus** Tell students that the terms temperature, thermal energy, and heat are related, but not identical, in meaning.

**Teach** Write the following sentences on the board:

(Thermal energy) is the total energy of all the particles in an object. (Temperature) is the measure of the average kinetic energy of the particles in an object. The transfer of thermal energy is called (heat). Ask for volunteers to supply the answer for each blank.

**Apply** Ask: Can two objects have the same temperature but different amounts of thermal energy? Explain.

**Help Students Read**

**SQ3R** Refer to the Content Refresher in this chapter, which provides guidelines for using the SQ3R strategy.

Have students survey the section, noting the headings. Students should generate one written question for each heading, for example: How are thermal energy and heat related? Then have students read the section and look for answers to their questions. When students have completed reading they should recite, or state aloud, their questions and answers. As a review, have students write the answers to their questions. learning modality: verbal

**Go Online** Teaching Resources

- Transparency M55
- Links on temperature and heat

**Temperature Scales** The three common scales for measuring temperature are the Fahrenheit, Celsius, and Kelvin scales. Each of these scales is divided into regular intervals.

The temperature scale you are probably most familiar with is the Fahrenheit scale. In the United States, the Fahrenheit scale is the most common temperature scale. The scale is divided into degrees Fahrenheit (°F). On this scale, the freezing point of water is 32°F and the boiling point is 212°F.

In nearly all other countries, however, the most common temperature scale is the Celsius scale. The Celsius scale is divided into degrees Celsius (°C), which are larger units than degrees Fahrenheit. On the Celsius scale, the freezing point of water is 0°C and the boiling point is 100°C.

The temperature scale commonly used in physical science is the Kelvin scale. Units on the Kelvin scale, called kelvins (K), are the same size as degrees on the Celsius scale. So, an increase of 1 K equals an increase of 1°C. The freezing point of water on the Kelvin scale is 273 K, and the boiling point is 373 K. The number 273 is special. Scientists have concluded from experiments that −273°C is the lowest temperature possible. No more thermal energy can be removed from matter at −273°C. Zero on the Kelvin scale represents −273°C and is called absolute zero.

**Thermal Energy and Heat**

Different objects at the same temperature can have different energies. To understand this, you need to know about thermal energy as heat, but they are not the same thing. Temperature, thermal energy, and heat are closely related, but they are all different.

**Thermal Energy** Recall from Chapter 5 that the total energy of all of the particles in an object is called thermal energy, or sometimes internal energy. The thermal energy of an object depends on the number of particles in the object, the temperature of the object, and the arrangement of the object’s particles. You will learn about how the arrangement of particles affects thermal energy in Section 3.
The more particles an object has at a given temperature, the more thermal energy it has. For example, a 1-liter pot of hot cocoa at 75°C has more thermal energy than a 0.2-liter mug of hot cocoa at 75°C because the pot contains more cocoa particles. On the other hand, the higher the temperature of an object is, the more thermal energy the object has. So, if two 1-liter pots of hot cocoa have different temperatures, the pot with the higher temperature has more thermal energy. In Section 3, you will learn about how thermal energies differ for solids, liquids, and gases.

**Heat**  Thermal energy that is transferred from matter at a higher temperature to matter at a lower temperature is called heat. The scientific definition of heat is different from its everyday use. In a conversation, you might say that an object contains heat. However, objects contain thermal energy, not heat. Only when thermal energy is transferred is it called heat. Heat is thermal energy moving from a warmer object to a cooler object. For example, when you hold an ice cube in your hand, as shown in Figure 4, the ice cube melts because thermal energy is transferred from your hand to the ice cube.

Recall from Chapter 5 that the average kinetic energy of the particles in a substance determines the temperature of the container. The more total energy of all the particles means the container has a higher temperature. This is why you can touch a hot stove and not a cold one.

### Practice Problem
While at the beach, you measure the ocean temperature as 77°F. The temperature of your classroom is 68°F.

**Answer** The ocean temperature is higher than the classroom temperature古典.

**Math Skills**

**Converting Units**

To convert a Fahrenheit temperature to a Celsius temperature, use the following formula:

\[ °C = \frac{5}{9}(°F - 32) \]

For example, if the temperature in your classroom is 68°F, what is the temperature in degrees Celsius?

- \[ °C = \frac{5}{9}(68 - 32) \]
- \[ °C = \frac{5}{9} \times 36 \]
- \[ °C = 20 \]

The temperature of your classroom is 20°C.

**Practice Problem** While at the beach, you measure the ocean temperature as 77°F. What is the temperature of the ocean in degrees Celsius?

### Address Misconceptions

**What Is Heat?**

Some of these misconceptions are fostered by the everyday uses of the word that differ from the scientific usage. Write the word heat on the board. Ask: In science, what does the term heat refer to? (The transfer of thermal energy) Can an object contain heat? (No)

**Learning modality: verbal**

### Skills Check

Have students calculate the temperature in degrees Celsius if the outdoor thermometer on a summer day reads 95°F.

**Answers**

- 35°C

An ice cube melts in your hand because thermal energy is transferred from your hand to the ice cube.
## Specific Heat

### Teach Key Concepts

#### Specific Heat and Temperature Change

**Focus** Remind students that a material’s specific heat is how much energy is required to raise the temperature of 1 kilogram of the material by 1 kelvin.

**Teach** Tell students that different materials have different specific heats. Direct students’ attention to Figure 6. Ask: Which material listed in the table has the lowest specific heat? (Silver) If 1 kilogram of each of the listed materials absorbed the same amount of energy, how would the temperature change of the silver compare with the temperature change of the other materials? (Silver would have a greater temperature change than any other listed material.)

**Apply** Ask: Why do foods that contain lots of water stay hot longer than those that don’t contain much water? (Water changes temperature more slowly than many other substances, so foods containing lots of water stay warm longer than those that don’t contain much water.)

**Answers**

1. water, sand, and iron
2. About 4,200 J would be required.
3. sand

### Math: Analyzing Data

#### Math Skill
Making and interpreting graphs

**Focus** Tell students that a bar graph is used to show information about separate but related items.

**Teach** Call students’ attention to the graph. Explain that the lower the specific heat, the smaller the amount of heat required to raise the temperature of the material. A higher bar on the graph represents a greater specific heat. Of the materials shown, water has the highest specific heat. Ask: Which material shown has the lowest specific heat? (Sand)

**Answers**

1. water, sand, and iron
2. About 4,200 J would be required.
3. sand

### Specific Heat

Imagine running across hot sand toward the ocean. You run to the water’s edge, but you don’t go any farther—the water is too cold. How can the sand be so hot and the water so cold? After all, the sun heats both of them. The answer is that water requires more heat to raise its temperature than sand does.

When an object is heated, its temperature rises. But the temperature does not rise at the same rate for all objects. The amount of heat required to raise the temperature of an object depends on the object’s chemical makeup. To change the temperature of different objects by the same amount, different amounts of heat are required.

Scientists have defined a quantity to measure the relationship between heat and temperature change. The amount of energy required to raise the temperature of 1 kilogram of a material by 1 kelvin is called its specific heat. The unit of measure for specific heat is joules per kilogram-kelvin, or J/(kg·K).

### FIGURE 5 Specific Heat of Sand and Water

The specific heat of water is greater than the specific heat of sand. On a sunny day the water feels cooler than the sand.

### Heat Needed to Raise 1 Kg by 1 K

<table>
<thead>
<tr>
<th>Material</th>
<th>Heat Needed (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>4,000</td>
</tr>
<tr>
<td>Sand</td>
<td>3,500</td>
</tr>
<tr>
<td>Iron</td>
<td>3,000</td>
</tr>
</tbody>
</table>

### Differentiated Instruction

**Gifted and Talented**

Making a Game: Have students create a board game that can be used to review the material in this section. Possible game topics include definitions of key terms, calculations of specific heat, and questions based on the key concepts. When the games are complete, have students share their games with the class.

**Learning modality:** logical/mathematical

**Less Proficient Readers**

Reviewing Key Terms: Have students listen to this section of the chapter on Student Edition on Audio CD. After they have completed listening, ask them to write the key terms from the section on index cards. Then pair students and have one display an index card, and the other define the term aloud. Students can take turns displaying cards and defining terms.

**Learning modality:** verbal
Look at the specific heats of the materials listed in Figure 6. Notice that the specific heat of water is quite high. One kilogram of water requires 4,180 joules of energy to raise its temperature 1 kelvin.

A material with a high specific heat can absorb a great deal of thermal energy without a great change in temperature. On the other hand, a material with a low specific heat would have a large temperature change after absorbing the same amount of thermal energy.

The energy gained or lost by a material is related to its mass, change in temperature, and specific heat. You can calculate thermal energy changes with the following formula.

\[ \text{Change in energy} = \text{Mass} \times \text{Specific heat} \times \text{Change in temperature} \]

How much heat is required to raise the temperature of 5 kilograms of water by 10 kelvins?

\[ \text{Change in energy} = 5 \text{ kg} \times 4,180 \text{ J/(kg}\cdot\text{K}) \times 10 \text{ K} = 209,000 \text{ J} \]

You need to transfer 209,000 joules to the water to increase its temperature by 10 kelvins.

What formula allows you to determine an object's change in thermal energy?

**Reviewing Key Concepts**

**1. a. Identifying** What is temperature?

**b. Describing** How do thermometers measure temperature?

**c. Comparing and Contrasting** How are the three temperature scales alike? How are they different?

**2. a. Defining** What is heat?

**b. Explaining** What is the relationship between thermal energy and temperature? Between thermal energy and heat?

**c. Relating Cause and Effect** What happens to the motion of an object's particles as their thermal energy increases? What happens to the temperature of the object?

**Changing the Third Variable:**

- **Calculation:**
  - **Defining**
  - **Calculating**
  - **Comparing and Contrasting**
  - **Converting Units**
  - **Defining**
  - **Calculating**
  - **Defining**
  - **Calculating**

**Answers**

- **Section 1 Assessment**
  - **Changing the Third Variable:**
    - **1. a. Temperature is a measure of the average kinetic energy of the individual particles in matter.**
      - **b. Sample answer:** When a thermometer is heated, the liquid level rises because particles of the liquid speed up and spread out. When the thermometer is cooled, the liquid level falls because particles of the liquid slow down and move closer together.
      - **c. Each of the three temperature scales is divided into degrees. Celsius degrees are the same size as Kelvin degrees, and both are larger than Fahrenheit degrees.**
      - **The three scales give different readings for all temperatures, including absolute zero, the freezing point of water, and the boiling point of water.**

- **Math Skills**
  - **Converting units**
    - **Answers**
      - **4.**
        - °C = 5/9 °F + 32;
        - °C = 5/9 (5.0 – 32);
        - °C = –15
        - °F = 9/5 °C + 32;
        - °F = 9/5 (560 – 32);
        - °C = about 460

- **Textbook Practice**
  - **3. a. Reviewing** Why do some materials get hot more quickly than others?
    - **b. Calculating** You stir your hot cocoa with a silver spoon that has a mass of 0.032 kg. The spoon's temperature increases from 20 K to 60 K. What is the change in the spoon's thermal energy? (Hint: Use the table in Figure 6 to find the specific heat of silver.)

- **Specific Heat of Common Materials**
  - **Material**
  - **Specific Heat (J/(kg\cdot\text{K})**
    - Aluminum 903
    - Copper 385
    - Glass 837
    - Ice 2,060
    - Iron 450
    - Sand 800
    - Silver 235
    - Water 4,180

**Monitor Progress**

- **Figure 6**
  - It requires 65 joules more energy to raise 1 kg of iron by 1 K than to raise 1 kg of copper by the same amount.

- **Change in energy = Mass \times \text{Specific heat} \times \text{Change in temperature**}

**Assess**

**Reviewing Key Concepts**

1. **a.** Temperature is a measure of the average kinetic energy of the individual particles in matter.  
   **b.** Sample answer: When a thermometer is heated, the liquid level rises because particles of the liquid speed up and spread out. When the thermometer is cooled, the liquid level falls because particles of the liquid slow down and move closer together.  
   **c.** Each of the three temperature scales is divided into degrees. Celsius degrees are the same size as Kelvin degrees, and both are larger than Fahrenheit degrees. The three scales give different readings for all temperatures, including absolute zero, the freezing point of water, and the boiling point of water.

2. **a.** Heat is thermal energy moving from a warmer object to a cooler object.  
   **b.** Temperature is one of the factors that determine an object’s thermal energy. The others are the number of particles and the arrangement of the particles. Heat is the flow of thermal energy between objects.  
   **c.** When the motion of an object’s particles increase, its temperature rises. All else equal, this will result in an increase in the object’s thermal energy.

3. **a.** Materials with smaller specific heats need less heat to change temperature by a given amount.  
   **b.** 3.00 J (0.032 kg \times 235 J/(kg\cdot\text{K}) \times 40 \text{ K})

**Reteach**

Have students review the figures in the section. Then ask volunteers to state the main idea of each figure. Review the caption questions and answers aloud with students.

**Performance Assessment**

**Skills Check:** Have students determine the energy gained by 16 kilograms of copper when its temperature increases by 15 kelvins. (57,750 J)
Evaluate the Design
Making Models
Inferring
Measuring

Appendix A.

Water. Review the safety guidelines in
thermometers, glass soda bottles, and hot

Caution students to be careful using

Safety
tubing, index cards, plastic bottles
One-hole rubber stoppers, glass flask, plastic

Alternative Materials
common hot water bath and ice bath.

Gather required materials. Soften the clay
to make it easier to work with. Set up a
common hot water bath and ice bath.

Prepare for Inquiry

Skills Objective
After this lab, students will be able to
• evaluate the design of a thermometer
• troubleshoot a technical design
• redesign and improve their thermometer
based on the results of their testing

Prep Time 30 minutes
Class Time 40 minutes
Advance Planning

Guide Inquiry

Introduce the Procedure
Prepare and display a sample of the
thermometer for Part 1. Have students
review the procedure and ask any questions
they may have. Review the concept of
thermal expansion.

Troubleshooting the Experiment
Be certain students obtain an airtight seal
with the clay. Fill the bottle and straw when
adding water to the straw in Step 3.

Expected Outcome
When the thermometer was placed in cold
water, the water in the straw decreased.
When the thermometer was placed in the
hot water, the water in the straw increased.

Lab Worksheet: Build Your Own
Thermometer

Build Your Own Thermometer

Problem
Can you build a thermometer out of simple
materials?

Design Skills

evaluating the design, measuring,

making models

Materials

• bowl of hot water • bowl of ice water
• water of unknown temperature
• tap water • 500-mL beaker
• clear glass juice or soda bottle, 20–25 cm
• clear plastic tubing, 18–20 cm • food coloring
• plastic dropper • cooking oil
• modeling clay
• metric ruler
• fine-point marker

Procedure

1. You can use simple materials to build a
model of an alcohol thermometer. First, mix
food coloring into a beaker of tap water.
Then fill a glass bottle with the colored
water.

2. Place a straw in the bottle. Use modelling
clay to position the straw so that it extends at
least 10 cm above the bottle mouth. Do not
let the straw touch the bottom. The clay
should completely seal off the bottle mouth.
Make sure there is no air in the bottle.

3. Using a dropper, add colored water into the
straw to a level 5 cm above the bottle. Place
a drop of cooking oil in the straw to prevent
evaporation.

4. Place your thermometer into a bowl of hot
water. When the colored water reaches its
highest level, place a mark on the straw.

Analyze and Conclude

1. Sample answer: The thermometer is a
reasonable model of a real thermometer. It is
like a real thermometer in that it has a scale
that can be used to measure temperatures.
The actual scale intervals are different than
in a real thermometer. Water expands when
it is heated, like alcohol, but not to the same
extent.

2. When the thermometer is placed in hot
water, thermal energy is transferred to the
particles in the thermometer and these
particles speed up and spread out (their
kinetic energy increases). The opposite
occurs when the thermometer is placed in
ice water.

3. The thermometer measures temperatures
between 0°C and 100°C.

4. Possible answers may include using a
different liquid, using a finer scale, changing
the thickness of the column of liquid, or
changing the size of the reservoir of liquid.