

Temperature, Thermal Energy, and Heat

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.

	Energy Measured	Units
Temp.	Average kinetic energy of particles	
Thermal energy		
Heat		

Lab
zone

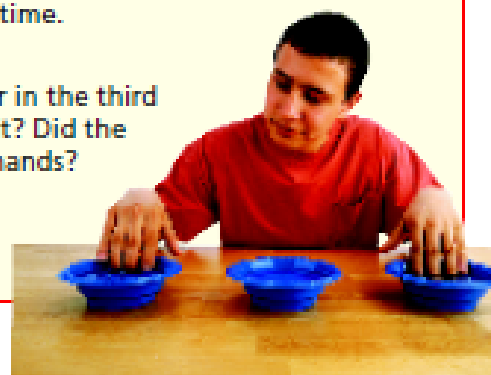
Discover Activity

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.

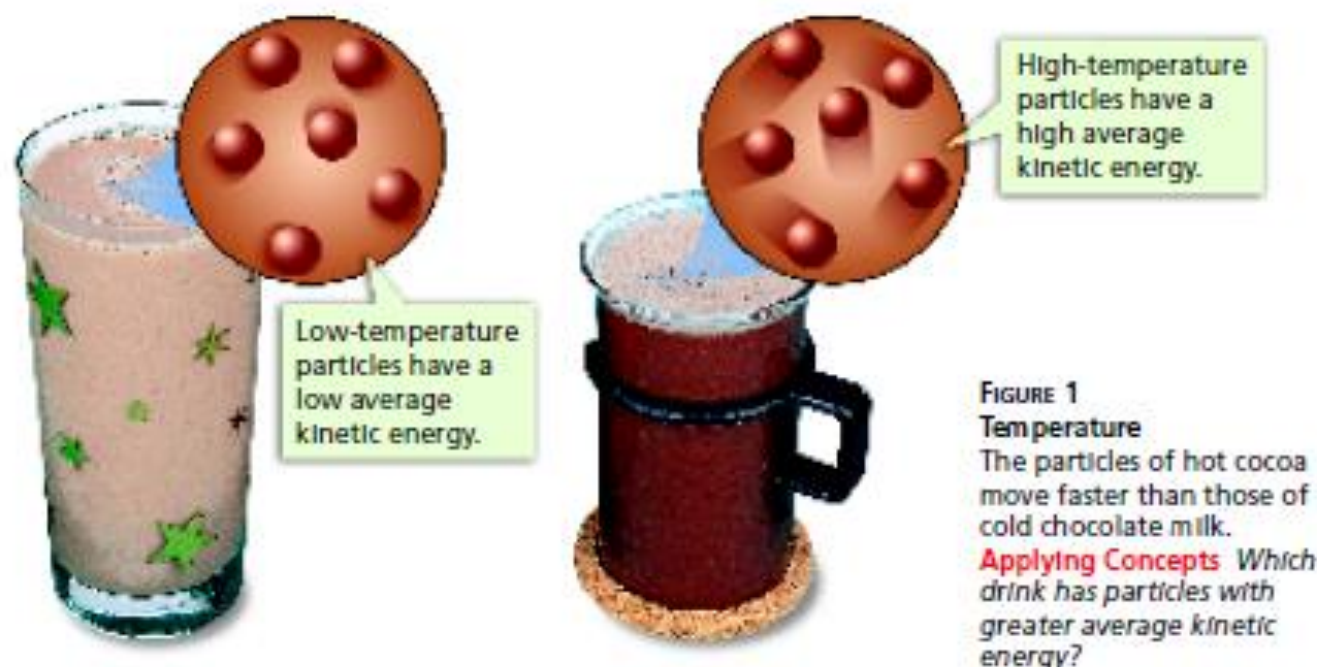


The radio weather report says that today's high temperature will be 25 degrees. What should you wear? Do you need a coat to keep warm, or only shorts and a T-shirt? What you decide depends on what "25 degrees" means.

Temperature

You don't need a science book to tell you that the word *hot* means higher temperatures or the word *cold* means lower temperatures. When scientists think about high and low temperatures, however, they do not think about "hot" and "cold." Instead, they think about particles of matter in motion.

Recall that all matter is made up of tiny particles. These particles are always moving even if the matter they make up is stationary. Recall that the energy of motion is called kinetic energy. So all particles of matter have kinetic energy. The faster particles move, the more kinetic energy they have. **Temperature** is a measure of the average kinetic energy of the individual particles in matter.



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.

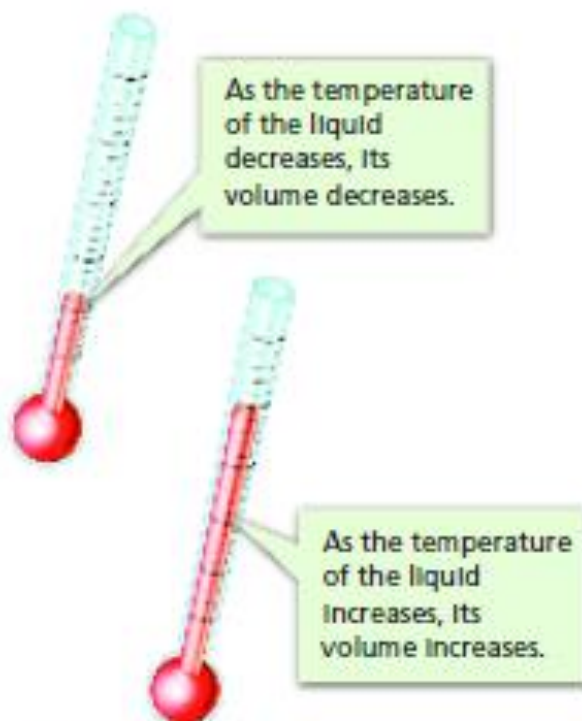


FIGURE 2
How a Thermometer Works
 Temperature changes cause the level of the liquid inside a thermometer to rise and fall.



Reading Checkpoint

What happens to the liquid particles inside a thermometer when it is heated?

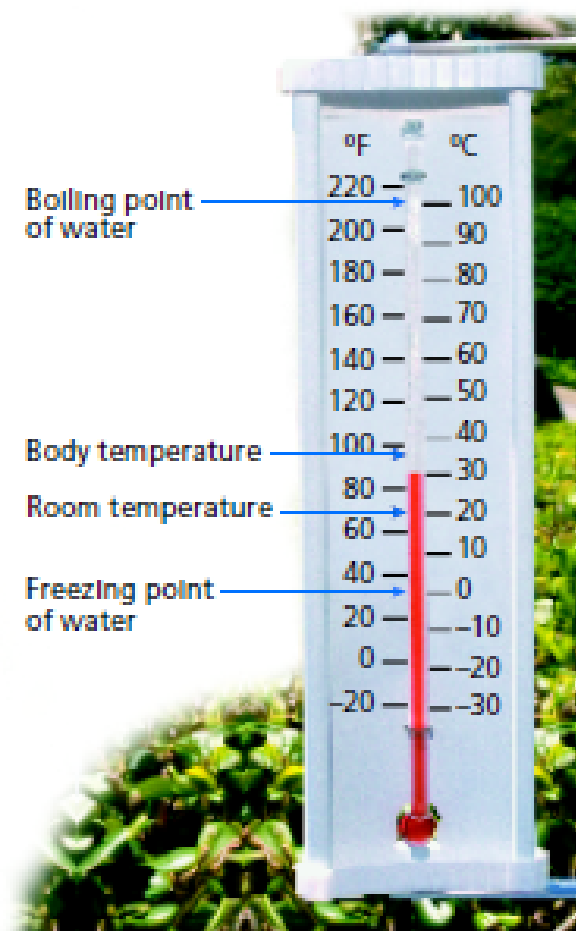


FIGURE 3

Temperature Scales

Many thermometers have both Celsius and Fahrenheit temperature scales.

Interpreting Photographs What is the boiling point of water on the Celsius scale? On the Fahrenheit scale?

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 ($^{\circ}\text{F}$). 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 ($^{\circ}\text{C}$), 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 and about heat. You may be used to thinking 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.

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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 work also involves the transfer of energy. Since work and heat are both energy transfers, they are both measured in the same unit—joules.



Reading Checkpoint

Why does an ice cube melt in your hand?

FIGURE 4

Heat Your hand transfers thermal energy to the ice cube. Even though your hand is cold, this transfer is called heat. Your hand feels cold because it is losing thermal energy.



Heat is transferred from the hand to the ice cubes.

Math

Skills

Converting Units

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

$$^{\circ}\text{C} = \frac{5}{9}(^{\circ}\text{F} - 32)$$

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

$$^{\circ}\text{C} = \frac{5}{9}(68 - 32)$$

$$^{\circ}\text{C} = \frac{5}{9} \times 36$$

$$^{\circ}\text{C} = 20$$

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?

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.



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 $J/(kg \cdot K)$.

Math

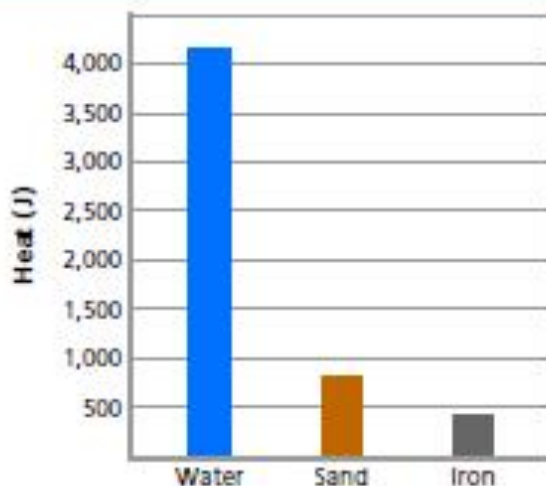
Analyzing Data

Specific Heat

The specific heat of three different materials was measured. These data are shown in the graph.

1. **Reading Graphs** What three materials are compared in the graph?
2. **Interpreting Data** About how much heat is required to raise 1 kg of water by 1 K?
3. **Drawing Conclusions** According to the graph, which material requires more heat to raise its temperature by 1 K, iron or sand?

Heat Needed to Raise 1 Kg by 1 K



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?

$$\begin{aligned}\text{Change in energy} &= 5 \text{ kg} \times 4,180 \text{ J/(kg}\cdot\text{K)} \times 10 \text{ K} \\ &= 209,000 \text{ J}\end{aligned}$$

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



Reading Checkpoint

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

Specific Heat of Common Materials	
Material	Specific Heat (J/(kg·K))
Aluminum	903
Copper	385
Glass	837
Ice	2,060
Iron	450
Sand	800
Silver	235
Water	4,180

FIGURE 6

This table lists the specific heats of several common materials.

Interpreting Tables How much more energy is required to raise the temperature of 1 kg of iron by 1 K than to raise the temperature of 1 kg of copper by 1 K?

Section 1 Assessment

- Target Reading Skill Comparing and Contrasting** Use the information in your table to help you answer Questions 1 and 2 below.

Reviewing Key Concepts

- Identifying** What is temperature?
 - Describing** How do thermometers measure temperature?
 - Comparing and Contrasting** How are the three temperature scales alike? How are they different?
- Defining** What is heat?
 - Explaining** What is the relationship between thermal energy and temperature? Between thermal energy and heat?
 - 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?

- Reviewing** Why do some materials get hot more quickly than others?
 - 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.)

Math

Practice

- Converting Units** Convert 5.0°F to degrees Celsius.
- Converting Units** The surface temperature on the planet Venus can reach 860°F. Convert this temperature to degrees Celsius.