SECTION 2

# What Is Heat?

**It's time for your annual physical. The doctor comes in and begins her exam by placing a metal stethoscope on your back. You jump a little and say, "Whoa! That's cold!"**

What is it about the stethoscope that made it feel cold? The answer has to do with how energy moves between the metal and your skin. In this section, you'll learn about this kind of energy transfer.

## Transferred Thermal Energy

You might think of the word *heat* as having to do with things that feel hot. But heat also has to do with things that feel cold—such as the stethoscope. In fact, heat is what causes objects to feel hot or cold or to get hot or cold under the right conditions. You probably use the word *heat* every day to mean different things. However, in this chapter, you will use only one specific meaning for *heat*. **Heat** is the energy transferred between objects that are at different temperatures.

Why do some things feel hot, while others feel cold? When two objects at different temperatures come into contact, energy is always transferred from the object that has the higher temperature to the object that has the lower temperature. Look at **Figure 1.** The doctor's stethoscope touches your back. Energy is transferred from your back to the stethoscope because your back has a higher temperature (about 37°C) than the stethoscope (probably room temperature, about 20°C) has. This energy is transferred quickly, so the stethoscope feels cold to you.

### What You Will Learn

- Define *heat* as thermal energy transferred between objects at different temperatures.
- Compare conduction, convection, and radiation.
- Use specific heat capacity to calculate heat.

### Vocabulary

heat
thermal energy
thermal conduction
thermal conductor
thermal insulator
convection
radiation
specific heat

### READING STRATEGY

**Paired Summarizing** Read this section silently. In pairs, take turns summarizing the material. Stop to discuss ideas that seem confusing.

**heat** the energy transferred between objects that are at different temperatures

**Figure 1** *The metal stethoscope feels cold because of heat!*

## Heat and Thermal Energy

If heat is transferred energy, what form of energy is being transferred? The answer is thermal energy. **Thermal energy** is the total kinetic energy of the particles that make up a substance. Thermal energy, which is measured in joules (J), depends partly on temperature. Something at a high temperature has more thermal energy than it would have at a lower temperature. Thermal energy also depends on how much of a substance there is. Look at **Figure 2.** The more particles there are in a substance at a given temperature, the greater the thermal energy of the substance is.

**Figure 2** *Although both soups are at the same temperature, there is more soup in the pan. So, the soup in the pan has more thermal energy than the soup in the bowl.*

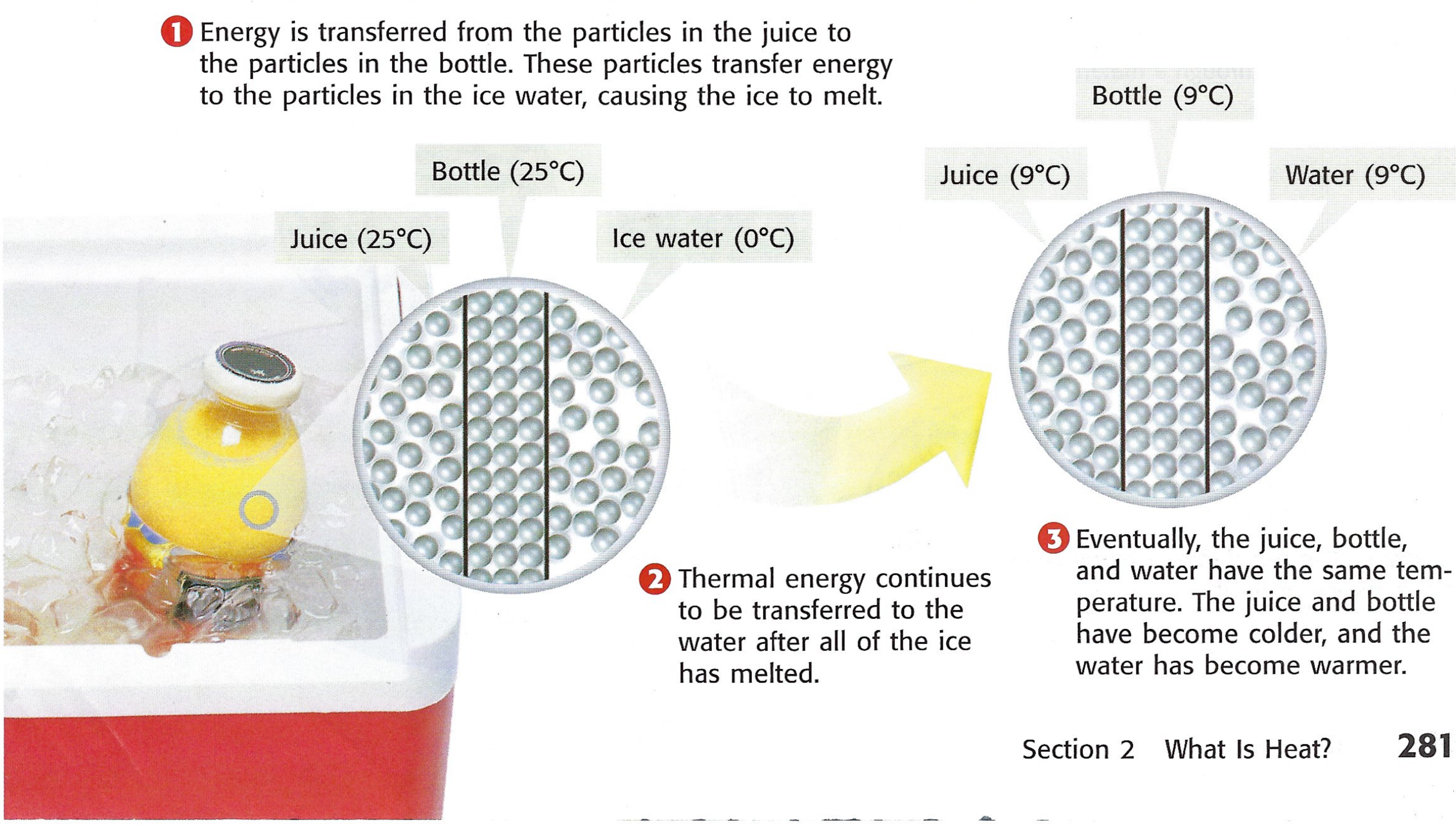
## Reaching the Same Temperature

Look at **Figure 3.** When objects that have different temperatures come into contact, energy will always be transferred. Energy will pass from the warmer object to the cooler object until both have the same temperature. When objects that are touching each other have the same temperature, there is no net change in the thermal energy of either one. Although one object may have more thermal energy than the other object, both objects will be at the same temperature.

**thermal energy** the kinetic energy of a substance's atoms

**Reading Check** **What will happen if two objects at different temperatures come into contact?** (*See the Appendix for answers to Reading Checks.*)

**Figure 3** **Transfer of Thermal Energy**



## Conduction, Convection, and Radiation

You already know several examples of energy transfer. You know that stoves transfer energy to soup in a pot. You adjust the temperature of your bath water by adding cold or hot water to the tub. And the sun warms your skin. In the next few pages, you'll learn about three ways to transfer thermal energy: *conduction, convection,* and *radiation.*

### Conduction

Imagine that you have put a cold metal spoon in a bowl of hot soup, as shown in **Figure 4.** Soon, the handle of the spoon warms up—even though it is not in the soup! The entire spoon gets warm because of conduction. **Thermal conduction** is the transfer of thermal energy from one substance to another through direct contact. Conduction can also occur within a substance, such as the spoon in **Figure 4.**

How does conduction work? When objects touch each other, their particles collide. Thermal energy is transferred from the higher-temperature substance to the lower-temperature substance. Remember that particles of substances at different temperatures have different average kinetic energies. So, when particles collide, particles with higher kinetic energy transfer energy to those with lower kinetic energy. This transfer makes some particles slow down and other particles speed up until all particles have the same average kinetic energy. As a result, the substances have the same temperature.

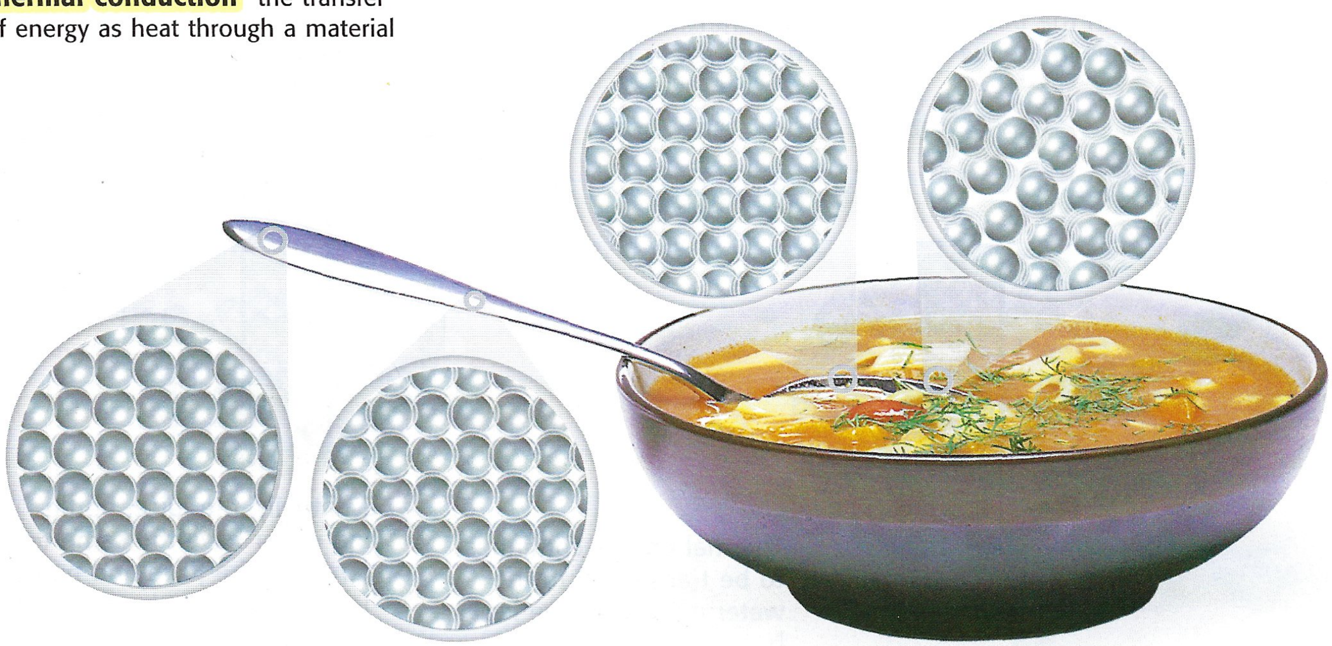
**Quick Lab**

**Heat Exchange**

1. Fill a **film canister** with **hot water.** Insert the **thermometer apparatus** prepared by your teacher. Record the temperature.
2. Fill a **250 mL beaker** two-thirds full with **cool water.** Insert **another thermometer** into the cool water, and record its temperature.
3. Place the canister in the cool water. Record the temperature measured by each thermometer every 30 s.
4. When the thermometers read nearly the same temperature, stop and graph your data. Plot temperature (*y*-axis) versus time (*x*-axis).
5. Describe what happens to the rate of energy transfer as the two temperatures get closer.

**thermal conduction** the transfer of energy as heat through a material

**Figure 4** *The end of this spoon will warm up because conduction, the transfer of energy through direct contact, occurs all the way up the handle.*



## Conductors and Insulators

Substances that conduct thermal energy very well are called **thermal conductors.** For example, the metal in a doctor's stethoscope is a conductor. Energy is transferred rapidly from your warm skin to the cool stethoscope. That's why the stethoscope feels cold. Substances that do not conduct thermal energy very well are called **thermal insulators.** For example, a doctor's wooden tongue depressor is an insulator. It is at the same temperature as the stethoscope. But the tongue depressor doesn't feel cold. The reason is that thermal energy is transferred very slowly from your tongue to the wood. Some typical conductors and insulators are shown in **Table 1** at right.

**Table 1 Conductors and Insulators**

| Conductors | Insulators |
|---|---|
| Curling iron | Flannel shirt |
| Cookie sheet | Oven mitt |
| Iron skillet | Plastic spatula |
| Copper pipe | Fiberglass insulation |
| Stove coil | Ceramic bowl |

**Reading Check** **How can two objects that are the same temperature feel as if they are at different temperatures?**

## Convection

A second way thermal energy is transferred is **convection,** the transfer of thermal energy by the movement of a liquid or a gas. Look at **Figure 5.** When you boil water in a pot, the water moves in roughly circular patterns because of convection. The water at the bottom of a pot on a stove burner gets hot because it is touching the pot (conduction). As it heats, the water becomes less dense because its higher-energy particles spread apart. The warmer water rises through the denser, cooler water above it. At the surface, the warm water begins to cool. The particles move closer together, making the water denser. The cooler water then sinks back to the bottom. It is heated again, and the cycle begins again. This circular motion of liquids or gases due to density differences that result from temperature differences is called a *convection current*.

**thermal conductor** a material through which energy can be transferred as heat

**thermal insulator** a material that reduces or prevents the transfer of heat

**convection** the transfer of thermal energy by the circulation or movement of a liquid or gas

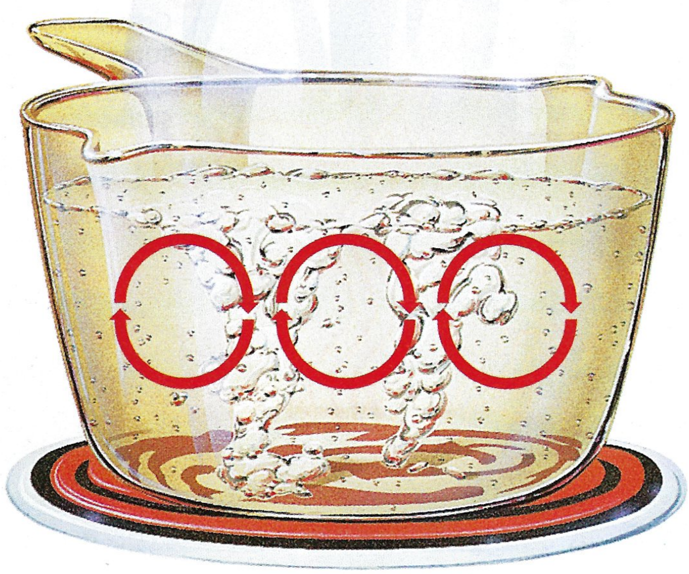


**Figure 5** *The repeated rising and sinking of water during boiling are due to convection.*

**radiation** the transfer of energy as electromagnetic waves

## Radiation

A third way thermal energy is transferred is **radiation,** the transfer of energy by electromagnetic waves, such as visible light and infrared waves. Unlike conduction and convection, radiation can involve either an energy transfer between particles of matter or an energy transfer across empty space.

All objects, including the heater in **Figure 6,** radiate electromagnetic waves. The sun emits visible light, which you can see, and waves of other frequencies, such as infrared and ultraviolet waves, which you cannot see. When your body absorbs infrared waves, you feel warmer.

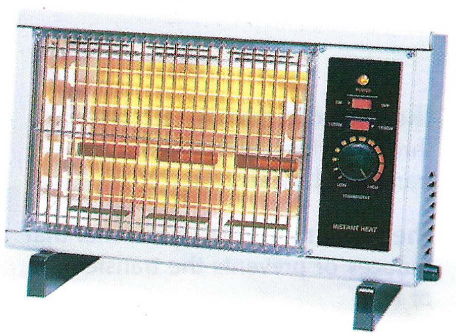


**Figure 6** *The coils of this portable heater warm a room partly by radiating visible light and infrared waves.*

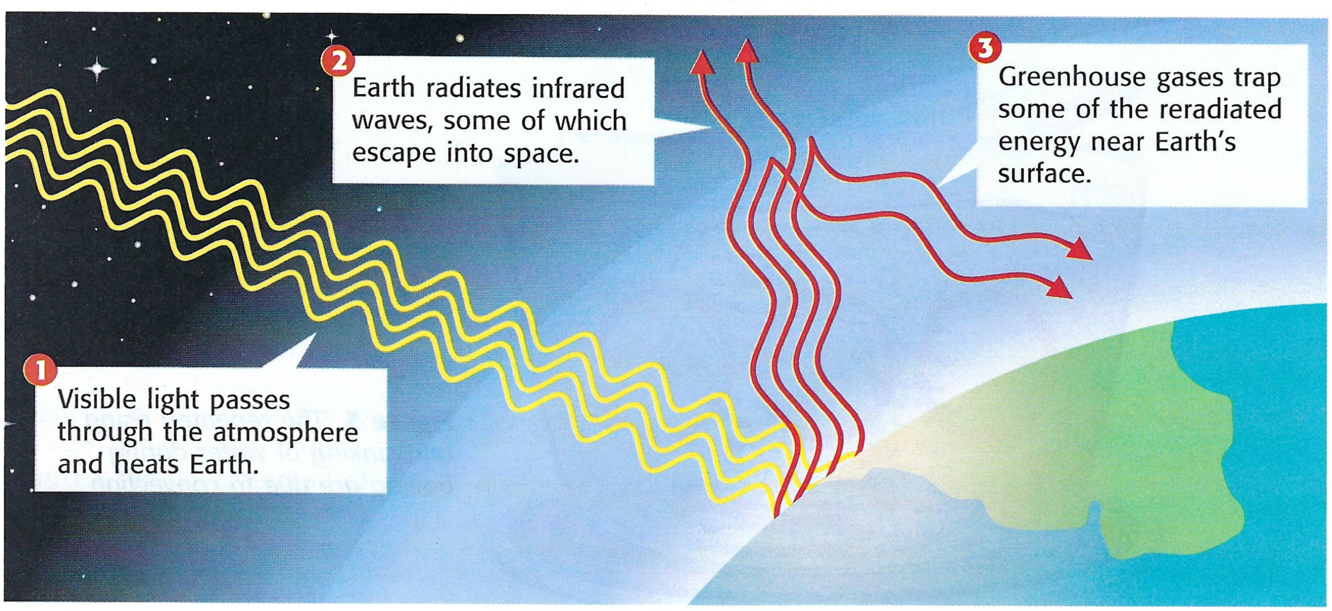
## Radiation and the Greenhouse Effect

Earth's atmosphere acts like the windows of a greenhouse. It allows the sun's visible light to pass through it. A greenhouse also traps heat energy, keeping the inside warm. The atmosphere traps some energy, too. This process, called the *greenhouse effect,* is illustrated in **Figure 7.** If our atmosphere did not trap the sun's energy in this way, most of the sun's energy that reached Earth would be radiated immediately back into space. Earth would be a cold, lifeless planet.

The atmosphere traps the sun's energy because of *greenhouse gases,* such as water vapor, carbon dioxide, and methane, which trap energy especially well. Some scientists are concerned that high levels of greenhouse gases in the atmosphere may trap too much energy and make Earth too warm.

**Reading Check** **What is the greenhouse effect?**

**Figure 7** **The Greenhouse Effect**



## Heat and Temperature Change

Have you ever fastened your seat belt on a hot summer day? If so, you may have noticed that the metal buckle felt hotter than the cloth belt did. Why?

### Thermal Conductivity

Different substances have different thermal conductivities. *Thermal conductivity* is the rate at which a substance conducts thermal energy. The metal buckle of a seat belt, such as the one shown in **Figure 8,** has a higher thermal conductivity than the cloth belt has. Because of its higher thermal conductivity, the metal transfers energy more rapidly to your hand when you touch it than the cloth does. So, even if the cloth and metal are at the same temperature, the metal feels hotter.

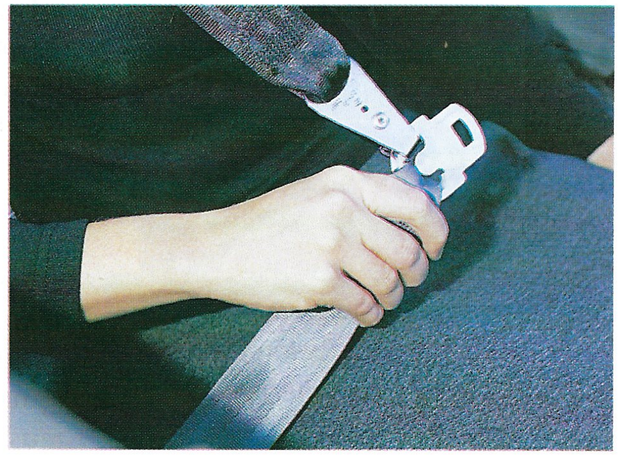


**Figure 8** *The cloth part of a seat belt does not feel as hot as the metal part.*

### Specific Heat

Another difference between the metal and the cloth is how easily each changes temperature when it absorbs or loses energy. When equal amounts of energy are transferred to or from equal masses of different substances, the change in temperature for each substance will differ. **Specific heat** is the amount of energy needed to change the temperature of 1 kg of a substance by 1°C.

**specific heat** the quantity of heat required to raise a unit mass of homogeneous material 1 K or 1°C in a specified way given constant pressure and volume

Look at **Table 2.** The specific heat of the cloth of a seat belt is more than twice that of the metal buckle. So, for equal masses of metal and cloth, the same thermal energy will increase the temperature of the metal twice as much as the cloth. The higher the specific heat of something is, the more energy it takes to increase its temperature. **Table 2** shows that most metals have very low specific heats. On the other hand, the specific heat of water is very high. This is why swimming-pool water usually feels cool, even on a hot day. The same energy heats up the air more than it heats up the water.

**Table 2 Specific Heat of Some Common Substances**

| Substance | Specific heat (J/kg•°C) | Substance | Specific heat (J/kg•°C) |
|---|---|---|---|
| Lead | 128 | Glass | 837 |
| Gold | 129 | Aluminum | 899 |
| Copper | 387 | Cloth of seat belt | 1,340 |
| Iron | 448 | Ice | 2,090 |
| Metal of seat belt | 500 | Water | 4,184 |

**CONNECTION TO Social Studies**

**WRITING SKILL** **Living near Coastlines** Water has a higher specific heat than land does. Because of water's high specific heat, the ocean has a moderating effect on the weather of coastal areas. The mild weather of coastal areas is one reason they tend to be heavily populated. Find out what the weather is like in various coastal areas in the world. Research the various reasons why coastal areas tend to be heavily populated, and write a brief report in your **science journal.**

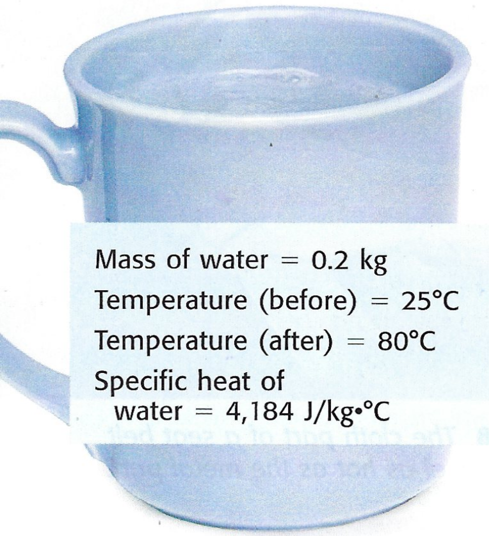



**Figure 9** *Information used to calculate heat, the amount of energy transferred to the water, is shown above.*

## Heat, Temperature, and Amount

Unlike temperature, energy transferred between objects can not be measured directly. Instead, it must be calculated. When calculating energy transferred between objects, you can use the definition of *heat* as the amount of energy that is transferred between two objects that are at different temperatures. Heat can then be expressed in joules (J).

How much energy is needed to heat a cup of water to make tea? To answer this question, you have to consider the water's mass, its change in temperature, and its specific heat. These are all listed in **Figure 9.** In general, if you know an object's mass, its change in temperature, and its specific heat, you can use the equation below to calculate heat.

$$heat\ (J) = specific\ heat\ (J/kg \bullet {}^\circ C) \times mass\ (kg) \times change\ in\ temperature\ ({}^\circ C)$$

## Calculating Heat

Using the equation above, you can calculate the heat transferred to the water. Because the water's temperature increases, the value of heat is positive. You can also use this equation to calculate the heat transferred from an object when it cools down. The value for heat would then be negative because the temperature decreases.

**Reading Check** **What are the three pieces of information needed to calculate heat?**

## Math Focus

**Calculating Heat** Calculate the heat transferred to a mass of 0.2 kg of water to change the temperature of the water from 25°C to 80°C. (The specific heat of water is 4,184 J/kg•°C.)

**Step 1:** Write the equation for calculating heat.

$$heat = specific\ heat \times mass \times change\ in\ temperature$$

**Step 2:** Replace the specific heat, mass, and temperature change with the values given in the problem, and solve.

$$heat = 4{,}184\ J/kg \bullet {}^\circ C \times 0.2\ kg \times (80^\circ C - 25^\circ C)$$

$$heat = 46{,}024\ J$$

**Now It's Your Turn**

1. Imagine that you heat 2.0 kg of water to make pasta. The temperature of the water before you heat it is 40°C, and the temperature after is 100°C. How much heat was transferred to the water?

## SECTION Review

### Summary

- Heat is energy transferred between objects that are at different temperatures.
- Thermal energy is the total kinetic energy of the particles that make up a substance.
- Thermal energy will always be transferred from higher to lower temperature.
- Transfer of thermal energy ends when two objects that are in contact are at the same temperature.
- Conduction, convection, and radiation are three ways thermal energy is transferred.
- Specific heat is the amount of energy needed to change the temperature of 1 kg of a substance by 1°C.
- Energy transferred by heat cannot be measured directly. It must be calculated using specific heat, mass, and change in temperature.
- Energy transferred by heat is expressed in joules (J) and is calculated as follows: *heat* (J) = *specific heat* (J/kg•°C) × *mass* (kg) × *change in temperature* (°C).

### Using Key Terms

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

1. *thermal conductor* and *thermal insulator*
2. *convection* and *radiation*

### Understanding Key Ideas

3. Two objects at different temperatures are in contact. Which of the following happens to their thermal energy?
   a. Their thermal energies remain the same.
   b. Thermal energy passes from the cooler object to the warmer object.
   c. Thermal energy passes from the warmer object to the cooler object.
   d. Thermal energy passes back and forth equally between the two objects.
4. What is heat?

### Math Skills

5. The specific heat of lead is 128 J/kg•°C. How much heat is needed to raise the temperature of a 0.015 kg sample of lead by 10°C?

### Critical Thinking

6. **Making Inferences** Two objects have the same total thermal energy. They are different sizes. Are they at the same temperature? Explain.
7. **Applying Concepts** Why do many metal cooking utensils have wooden handles?

### Interpreting Graphics

8. Look at the photo below. It shows examples of heat transfer by conduction, convection, and radiation. Indicate which type of heat transfer is happening next to each letter.