4.2

KEY CONCEPT

Energy flows from warmer to cooler objects.

BEFORE, you learned

- All matter is made of moving particles
- Temperature is the measurement of average kinetic energy of particles in an object
- Temperature can be measured

NOW, you will learn

- How heat is different from temperature
- How heat is measured
- Why some substances change temperature more easily than others

VOCABULARY

heat p. 110
thermal energy p. 111
calorie p. 112
joule p. 112
specific heat p. 113

THINK ABOUT

Why does water warm up so slowly?

If you have ever seen food being fried in oil or butter, you know that the metal frying pan heats up very quickly, as does the oil or butter used to coat the pan's surface. However, if you put the same amount of water as you put oil in the same pan, the water warms up more slowly. Why does water behave so differently from the metal, oil, or butter?

NOTE-TAKING STRATEGY
The mind map organizer would be a good choice for taking notes on heat.

Heat is different from temperature.

Heat and temperature are very closely related. As a result, people often confuse the concepts of heat and temperature. However, they are not the same. Temperature is a measurement of the average kinetic energy of particles in an object. **Heat** is a flow of energy from an object at a higher temperature to an object at a lower temperature.

If you add energy as heat to a pot of water, the water's temperature starts to increase. The added energy increases the average kinetic energy of the water molecules. Once the water starts to boil, however, adding energy no longer changes the temperature of the water. Instead, the heat goes into changing the physical state of the water from liquid to gas rather than increasing the kinetic energy of the water molecules. This fact is one demonstration that heat and temperature are not the same thing.

CHECK YOUR READING What is heat?

Heat and Thermal Energy

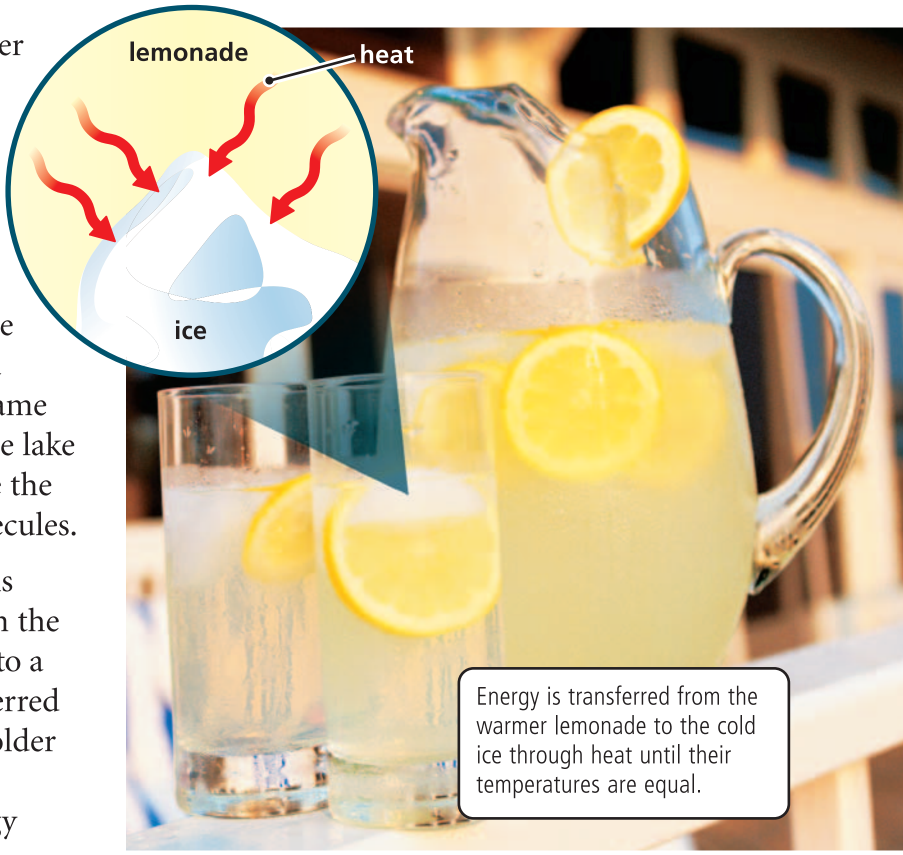
RESOURCE CENTER
CLASSZONE.COM
Learn more about thermal energy.

Suppose you place an ice cube in a bowl on a table. At first, the bowl and the ice cube have different temperatures. However, the ice cube melts, and the water that comes from the ice will eventually have the same temperature as the bowl. This temperature will be lower than the original temperature of the bowl but higher than the original temperature of the ice cube. The water and the bowl end up at the same temperature because the particles in the ice cube and the particles in the bowl continually bump into each other and energy is transferred from the bowl to the ice.

Heat is always the transfer of energy from an object at a higher temperature to an object at a lower temperature. So energy flows from the particles in the warmer bowl to the particles in the cold ice and, later, the cooler water. If energy flowed in the opposite direction—from cooler to warmer—the ice would get colder and the bowl would get hotter, and you know that never happens.

CHECK YOUR READING In which direction does heat always transfer energy?

When energy flows from a warmer object to a cooler object, the thermal energy of both of the objects changes. **Thermal energy** is the total random kinetic energy of particles in an object. Note that temperature and thermal energy are different from each other. Temperature is an average and thermal energy is a total. A glass of water can have the same temperature as Lake Superior, but the lake has far more thermal energy because the lake contains many more water molecules.



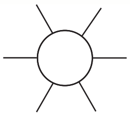
Energy is transferred from the warmer lemonade to the cold ice through heat until their temperatures are equal.

Another example of how energy is transferred through heat is shown on the right. Soon after you put ice cubes into a pitcher of lemonade, energy is transferred from the warmer lemonade to the colder ice. The lemonade's thermal energy decreases and the ice's thermal energy increases. Because the particles in the lemonade have transferred some of their energy to the particles in the ice, the average kinetic energy of the particles in the lemonade decreases. As a result, the temperature of the lemonade decreases.

CHECK YOUR READING How are heat and thermal energy related to each other?

Measuring Heat

> **VOCABULARY**
> Remember to make description wheel diagrams for *calorie, joule,* and other vocabulary terms.



The most common units of heat measurement are the calorie and the joule (jool). One **calorie** is the amount of energy needed to raise the temperature of 1 gram of water by 1°C. The **joule** (J) is the standard scientific unit in which energy is measured. One calorie is equal to 4.18 joules.

You probably think of calories in terms of food. However, in nutrition, one Calorie—written with a capital C—is actually one kilocalorie, or 1000 calories. This means that one Calorie in food contains enough energy to raise the temperature of 1 kilogram of water by 1°C. So, each Calorie in food contains 1000 calories of energy.

How do we know how many Calories are in a food, such as a piece of chocolate cake? The cake is burned inside an instrument called a calorimeter. The amount of energy released from the cake through heat is the number of Calories transferred from the cake to the calorimeter. The energy transferred to the calorimeter is equal to the amount of energy originally in the cake. A thermometer inside the calorimeter measures the increase in temperature from the burning cake, which is used to calculate how much energy is released.

CHECK YOUR READING How is heat measured?

INVESTIGATE Heat Transfer

Which substances change temperature faster?

PROCEDURE

1. Using the graduated cylinder and the balance, separately measure 20 g of room-temperature water, 20 g of pennies, and 20 g of aluminum foil. Pour the water into a beaker until it is needed.
2. Using the graduated cylinder, pour 50 mL of hot water into each of the cups. Record the water temperature in each cup.
3. Pour the room-temperature water into one cup. Place the pennies in the second cup and the foil in the third. After 5 minutes, record the temperature of the water in each of the cups.

WHAT DO YOU THINK?

- How did the temperature changes in the three cups compare?
- What might account for the differences you observed?

CHALLENGE Why might items such as pots and pans be made of materials like copper, stainless steel, or iron?

SKILL FOCUS
Measuring

MATERIALS
- graduated cylinder
- balance
- room-temperature water
- pennies
- aluminum foil
- hot tap water
- 100 mL beaker
- 3 plastic cups
- thermometer
- stopwatch

TIME
30 minutes

Some substances change temperature more easily than others.

Have you ever seen an apple pie taken right out of the oven? If you put a piece of pie on a plate to cool, you can touch the pie crust in a few minutes and it will feel only slightly warm. But if you try to take a bite, the hot pie filling will burn your mouth. The pie crust cools much more quickly than the filling, which is mostly water.

Specific Heat

The amount of energy required to raise the temperature of 1 gram of a substance by 1°C is the **specific heat** of that substance. Every substance has its own specific heat value. So, each substance absorbs a different amount of energy in order to show the same increase in temperature.

If you look back at the definition of a calorie, you will see that it is defined in terms of water—one calorie raises the temperature of 1 gram of water by 1°C. So, water has a specific heat of exactly 1.00 calorie per gram per °C. Because one calorie is equal to 4.18 J, it takes 4.18 J to raise the temperature of one gram of water by 1°C. In joules, water's specific heat is 4.18 J per gram per °C. If you look at the specific heat graph shown below, you will see that 4.18 is an unusually large value. For example, one gram of iron has to absorb only 0.45 joules for its temperature to increase by 1°C.

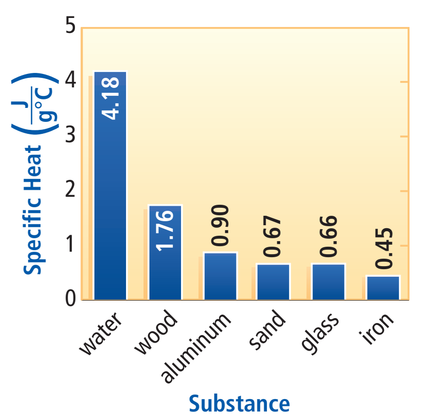
READING TIP

Joules per gram per °C is shown as $\frac{J}{g°C}$.

A substance with a high specific heat value, like water, not only has to absorb a large quantity of energy for its temperature to increase, but it also must release a large quantity of energy for its temperature to decrease. This is why the apple pie filling can still be hot while the pie crust is cool. The liquid filling takes longer to cool. The high specific heat of water is also one reason it is used as a coolant in car radiators. The water can absorb a great deal of energy and protect the engine from getting too hot.

CHECK YOUR READING How is specific heat related to a change in temperature?

Specific Heat of Substances



APPLY More energy is needed to warm water than many other substances. What materials in this photograph might be warmer than the water?

Specific Heat and Mass

Recall that thermal energy is the total kinetic energy of all particles in an object. So, thermal energy depends on the object's mass. Suppose you have a cup of water at a temperature of 90°C (194°F) and a bathtub full of water at a temperature of 40°C (104°F). Which mass of water has more thermal energy? There are many more water molecules in the bathtub, so the water in the tub has more thermal energy.

Specific Heat, Mass, and Weather

The temperature of a large body of water influences the temperature of nearby land. The green shading shows how far this effect extends.

The water in the cup has the same specific heat as the water in the tub. However, the cup of water will cool more quickly than the water in the bathtub. The tub of water has to release more thermal energy to its surroundings, through heat, to show a decrease in temperature because it has so much more mass.

This idea is particularly relevant to very large masses. For example, Lake Michigan holds 4.92 quadrillion liters (1.30 quadrillion gallons) of water. Because of the high specific heat of water and the mass of water in the lake, the temperature of Lake Michigan changes very slowly.

The temperature of the lake affects the temperatures on its shores. During spring and early summer, the lake warms slowly, which helps keep the nearby land cooler. During the winter, the lake cools slowly, which helps keep the nearby land warmer. Temperatures within about 15 miles of the lake can differ by as much as 6°C (about 10°F) from areas farther away from the lake.

As you will read in the next section, the way in which a large body of water can influence temperatures on land depends on how energy is transferred through heat.

CHECK YOUR READING How does an object's thermal energy depend on its mass?

4.2 Review

KEY CONCEPTS

1. How is temperature related to heat?
2. How do the units that are used to measure heat differ from the units that are used to measure temperature?
3. Describe specific heat in your own words.

CRITICAL THINKING

4. **Compare and Contrast** How are a calorie and a joule similar? How are they different?
5. **Synthesize** Describe the relationships among kinetic energy, temperature, heat, and thermal energy.

CHALLENGE

6. **Infer** Suppose you are spending a hot summer day by a pool. Why might the water in the pool cool the air near the pool?