SECTION 2

# Energy Transfer

**Key Ideas**

- How does energy transfer happen?
- What do conductors and insulators do?
- What makes something a good conductor of heat?

**Key Terms**

**thermal conduction**
**convection**
**convection current**
**radiation**
**specific heat**

**Why It Matters**

Energy transfer is a crucial factor that governs global wind patterns, which mariners use to navigate safely.

While water is being heated for your morning shower, your breakfast food is cooking. In the freezer, water in ice trays becomes solid after the freezer cools the water to 0 °C. Outside, the morning dew evaporates soon after light from the rising sun strikes it. These examples are ways that energy transfers from one object to another.

## Methods of Energy Transfer

**Heat energy can be transferred in three ways: conduction, convection, and radiation.** Roasting marshmallows around a campfire, as **Figure 1** shows, provides an opportunity to experience each of these three ways.

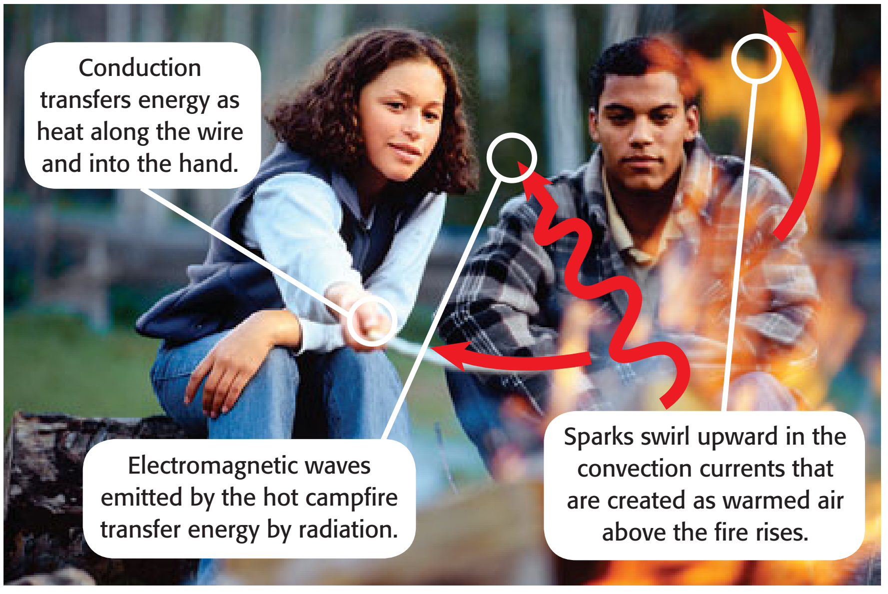
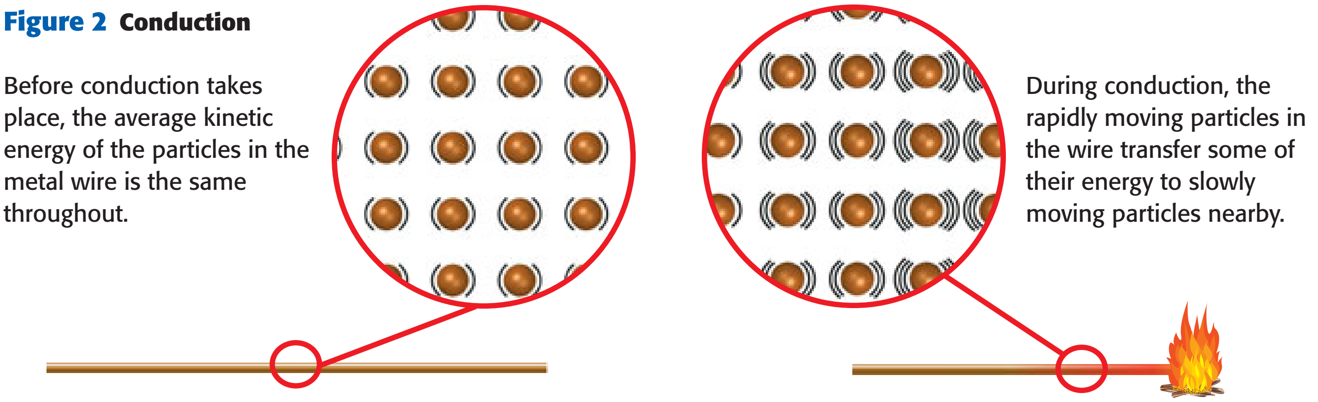



**Figure 1** **Ways of Transferring Energy**

**Figure 2** **Conduction**




## Conduction occurs between objects in direct contact.

Imagine that you place a marshmallow on one end of a wire made from a metal coat hanger. Then, you hold the other end of the wire while letting the marshmallow cook over the campfire flame. Soon, the end of the wire that you are holding gets warmer. This transfer of energy as heat through the wire is an example of **thermal conduction.**

Conduction takes place when objects that are in direct contact are at unequal temperatures. It also takes place between particles within an object. The energy transferred from the fire to the atoms in the wire causes the atoms to vibrate rapidly. As **Figure 2** shows, when these rapidly vibrating atoms collide with slowly vibrating atoms, energy is transferred as heat all along the wire and to your hand.

**thermal conduction** (THUHR muhl kuhn DUHK shuhn) the transfer of energy as heat through a material

**convection** (kuhn VEK shuhn) the movement of matter due to differences in density that are caused by temperature variations

**convection current** (kuhn VEK shuhn KUHR uhnt) any movement of matter that results from differences in density; may be vertical, circular, or cyclical

## Convection results from the movement of warm fluids.

While roasting your marshmallow, you may notice that sparks from the fire rise and begin to swirl. They are following the movement of air away from the fire. The air close to the fire becomes hot and expands, so the space between the air particles increases. As a result, the air becomes less dense and moves upward, carrying its extra energy with it, as **Figure 3** shows. The rising warm air is forced upward by cooler, denser air. The cooler air then expands and rises as it is heated by the fire. Eventually, the rising hot air cools, contracts, becomes denser, and sinks. Energy transfer resulting from the movement of warm fluids is **convection.**

Convection is possible only in fluids. Most fluids are liquids or gases. The cycle of a heated fluid that rises and then cools and falls is called a **convection current.** The heating and cooling of a room involves convection currents. Warm air expands and rises from vents near the floor. It cools and contracts near the ceiling and then sinks back to the floor. In this way, all of the air in the room gets heated.

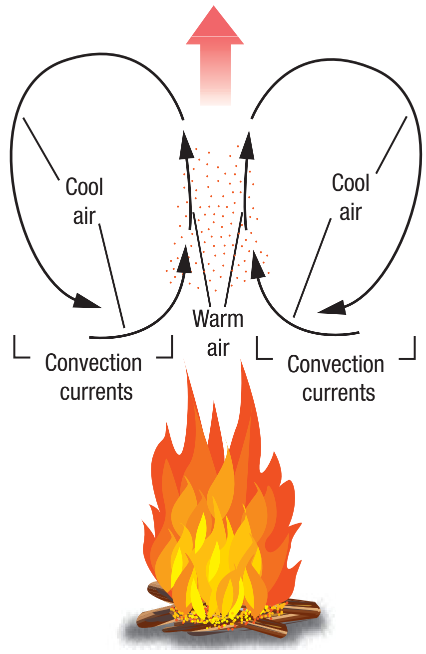



**Figure 3** During convection, energy is carried away by a heated fluid that expands and rises above cooler, denser fluids.

## InquiryLab Absorption of Radiated Heat

30 min

### Procedure

1. Obtain **two empty soup cans,** and remove the labels. Paint the inside and outside of one soup can with **black paint.**
2. Pour **50 mL of cool water** into each can.
3. Place a **thermometer** in each can, and record the temperature of the water in each can at the start. Leave the thermometers in the cans. Aim a bright **lamp** at the cans, or place them in sunlight.
4. Record the temperature of the water in each can every 3 min for at least 15 min.

### Analysis

1. Prepare a graph. Label the *x*-axis "Time" and the *y*-axis "Temperature." Plot your data for each can of water.
2. The water in which can absorbed more radiation?
3. Which variables in the lab were controlled (unchanged throughout the experiment)? How did the controlled variables help you obtain valid results?
4. Use your results to explain why panels used for solar heating are often painted black.
5. Based on your results, what color would you want your car to be in the winter? in the summer? Justify your answer.

**radiation** (RAY dee AY shuhn) the energy that is transferred as electromagnetic waves, such as visible light and infrared waves

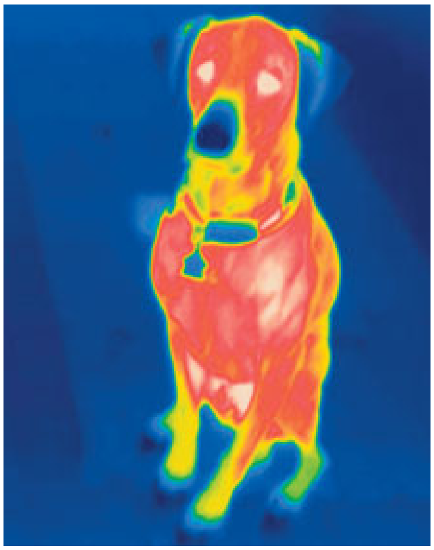


**Figure 4** Heat as infrared radiation is visible in this thermogram. The warmest parts of the dog are white, and the coolest parts are dark blue.

### Radiation does not require physical contact between objects.

As you stand close to a campfire, you can feel its warmth. This warmth can be felt even when you are not in the path of a convection current. The fire emits energy in the form of *electromagnetic waves,* which include infrared radiation, visible light, and ultraviolet rays. Energy that is transferred as electromagnetic waves is called **radiation.** When the molecules in your skin absorb this energy, the average kinetic energy of these molecules—and thus the temperature of your skin—increases.

All hot objects give off infrared radiation, which is electromagnetic waves at a frequency lower than that of visible light. The warmer an object is, the more infrared radiation it gives off. The image of the dog in **Figure 4** shows the areas of the dog that are warmer (white and red) and the areas that are cooler (black and blue).

Radiation differs from conduction and convection in that it does not involve the movement of matter across space. Only electromagnetic waves carry radiation. Radiation is therefore the only way that energy can be transferred through a vacuum, such as outer space. Much of the energy that we receive from the sun is transferred by radiation.

**Reading Check** **How does radiation differ from conduction and convection?**

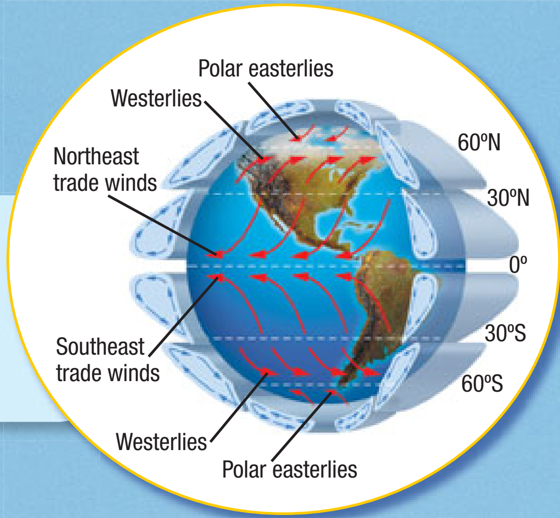
Why It **Matters**



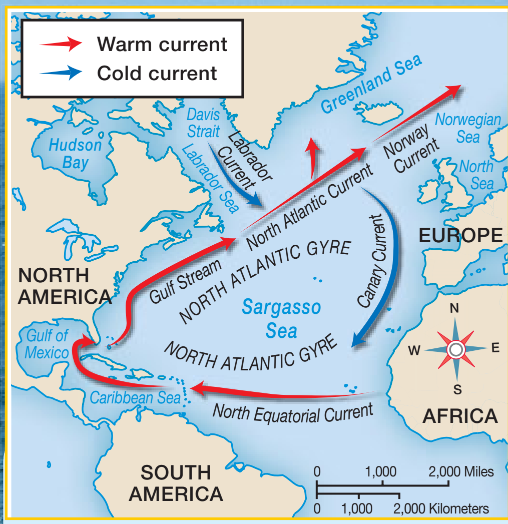
# Why Does the Wind Blow?

**As Earth rotates, the sun's rays heat up the part of Earth facing the sun. This differential heating causes convection, in which cooler air or water moves to replace warmer air or water. Convection affects global wind and ocean-current patterns. Mariners have known about and taken advantage of these patterns for centuries.**

Seagoing navigators can take advantage of prevailing winds and ocean currents in planning routes.




Convection currents over Earth's surface are partly responsible for the global wind patterns shown here.




Convection of ocean water causes ocean currents, such as the ones shown here in the Atlantic Ocean.

**YOUR TURN**

**UNDERSTANDING CONCEPTS**

1. How do convection patterns determine global wind and ocean-current patterns?

**CRITICAL THINKING**

2. How would Earth's convection patterns be different if the sun's radiation reached every part of Earth equally?

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**Figure 5** A well-insulated coat can keep in body heat even in cold temperatures.

**Academic Vocabulary**

**conduct** (kuhn DUHKT) to be able to carry

## Conductors and Insulators

When you are cooking, the pan must conduct energy to heat the food, but the handle must be insulated from the heat so that you can hold the handle. If you are using conduction to increase the temperature of a substance, you must use materials through which energy can be quickly transferred as heat. Cooking pans are usually made of metal because energy passes quickly between the particles in most metals. **A *conductor* is a material through which energy can be easily transferred as heat.**

Many people avoid wasting energy. Energy is most often wasted by its transfer through the roof or walls of a house. Using an insulator can reduce energy transfer. **An *insulator,* or insulation, is a material that transfers energy poorly.** Insulation in the attic or walls of a house helps keep energy from escaping. Insulation in warm clothing, such as that shown in **Figure 5,** keeps energy as heat from leaving the body.

### Heat energy is transferred through particle collisions.

Gases are very poor heat conductors because their particles are so far apart. Much less energy per volume can be transferred through a gas than through a solid or a liquid, whose particles are much closer together. Denser materials usually conduct energy better than less dense materials do. Metals tend to conduct energy very well, and plastics conduct energy poorly. For this reason, metal pots and pans often have plastic handles. Energy as heat moves through the plastic slower than it moves through the metal.

**Reading Check** **What makes a material a good conductor?**

## QuickLab Conductors and Insulators

10 min

### Procedure

1. For this activity, you will need **several flatware utensils.** Each one should be made of a different material, such as **stainless steel, aluminum,** and **plastic.** You will also need a **bowl** and **ice cubes.**
2. Place the ice cubes in the bowl. Place an equal length of each utensil under the ice.

### Analysis

1. After the utensils have been in the ice for 30 s, briefly touch each utensil at the same distance from the ice. Which utensil feels coldest? Which differences between the utensils might account for the different results? Explain.

## Specific Heat

You have probably noticed that a metal spoon, such as the one shown in **Figure 6,** becomes hot when placed in a cup of hot liquid. And you may have noticed that a spoon made of a different material, such as plastic, does not become hot as quickly. The difference between the final temperatures of the two spoons depends on whether the spoons are good conductors or good insulators. **What makes a substance a good or poor conductor depends in part on how much energy is required to change the temperature of the substance by a certain amount.**

**Figure 6** The spoon's temperature increases rapidly because of the spoon's low specific heat.

### Specific heat describes how much energy is required to raise an object's temperature.

Not all substances behave the same way when they absorb energy. For example, a metal spoon left in a metal pot becomes hot seconds after the pot is placed on a hot stovetop burner. The reason is that a small amount of energy is enough to raise the spoon's temperature by a lot. However, if you place a wooden spoon that has the same mass as the metal spoon in the same pot, that same amount of energy produces a much smaller temperature change in the wooden spoon.

For all substances, specific heat is a characteristic physical property, which is represented by *c*. In this book, the **specific heat** of any substance is the amount of energy required to raise the temperature of 1 kg of that substance by 1 K.

Some values for specific heat are given in **Figure 7.** These values are in units of joules per kilogram times kelvin (J/kg•K). Thus, each value is the amount of energy in joules needed to raise the temperature of 1 kg of the substance by exactly 1 K.

**Figure 7 Values of Specific Heat at 25 °C**

| Substance | *c* (J/kg•K) | Substance | *c* (J/kg•K) |
|---|---|---|---|
| Water (liquid) | 4,186 | Copper | 385 |
| Ethanol (liquid) | 2,440 | Iron | 449 |
| Ammonia (gas) | 2,060 | Silver | 234 |
| Steam | 1,870 | Mercury | 140 |
| Aluminum | 897 | Gold | 129 |
| Carbon (graphite) | 709 | Lead | 129 |

**READING TOOLBOX**

**Comparison Table**

To help you understand specific heat, make a comparison table. Compare the amount of heat it takes to raise the temperature of some of the substances listed on this page.

**specific heat** (spuh SIF ik HEET) the quantity of heat required to raise a unit mass of homogenous material 1 K or 1 °C in a specified way given constant pressure and volume

## Integrating **Earth Science**

**Specific Heat and Sea Breezes** Sea breezes result from convection currents in the coastal air and from differences in the specific heats of water and land. During the day, the temperature of the land increases more than that of the ocean water, which has a larger specific heat. Thus, the temperature of the air over land increases more than the temperature of air over the ocean. As a result, the warm air over the land rises, and the cool ocean air moves inland to replace the rising warm air. At night, the temperature of the land drops below that of the ocean, and the breezes reverse direction.

### Specific heat can be used to figure out how much energy it takes to raise an object's temperature.

Because specific heat is a ratio, it can be used to predict the effects of temperature changes for masses other than 1 kg. For example, if 4,186 J is required to raise the temperature of 1 kg of water by 1 K, twice as much energy, 8,372 J, will raise the temperature of 2 kg of water by 1 K. About 25,120 J will be required to raise the temperature of the 2 kg of water by 3 K. This relationship is described by the equation below.

**Specific heat equation**

energy = specific heat × mass × temperature change

$$\text{energy} = cm\Delta T$$

The specific heat of a substance can change slightly with changes in pressure and volume. However, the problems in this chapter will assume that specific heat does not change.

## Math Skills — Specific Heat

How much energy must be transferred as heat to 200 kg of water in a bathtub to raise the water's temperature from 25 °C to 37 °C?

**Identify**

List the given and unknown values.

**Given:**

$\Delta T = 37\ °C - 25\ °C = 12\ °C = 12\ K$

$\Delta T = 12\ K$

$m = 200\ kg$

$c = 4{,}186\ J/kg{\bullet}K$

**Unknown:**

$energy = ?\ J$

**Plan**

Write down the specific heat equation from this page.

$energy = cm\Delta T$

**Solve**

Substitute values of specific heat, mass, and temperature change, and solve.

$$energy = \left(\frac{4{,}186\ J}{\cancel{kg}{\bullet}\cancel{K}}\right) \times (200\ \cancel{kg}) \times (12\ \cancel{K})$$

$$energy = 10{,}000{,}000\ J = 1.0 \times 10^4\ kJ$$

### Practice

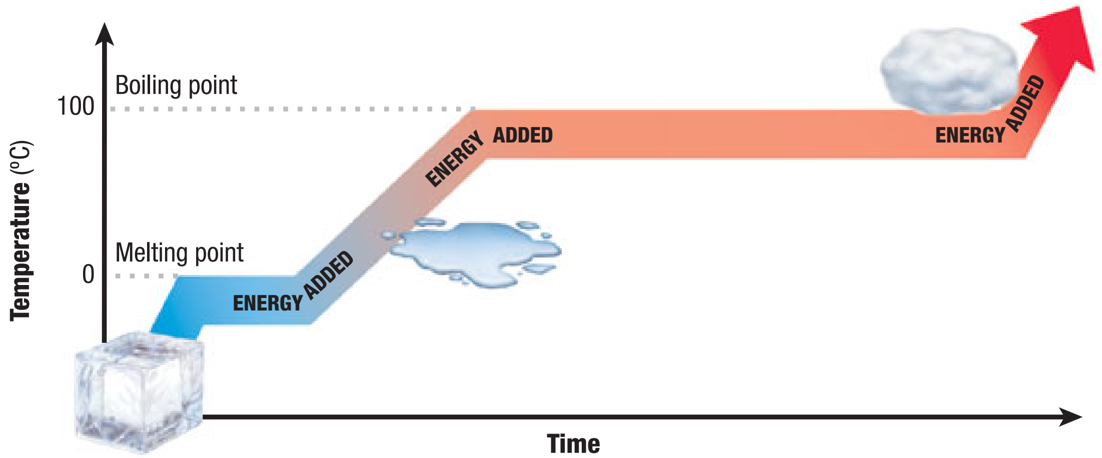
1. How much energy is needed to increase the temperature of 755 g of iron from 283 K to 403 K?
2. How much energy must a refrigerator absorb from 225 g of water to decrease the temperature of the water from 35 °C to 5 °C?

For more practice, visit **go.hrw.com** and enter keyword **HK8MP.**

### Heat raises an object's temperature or changes the object's state.

The graph in **Figure 8** represents what happens to water over a range of temperatures as energy is added. At 0 °C, the water is at first in the solid state (ice). A certain amount of energy per kilogram is required to melt the ice. While the ice is melting, the temperature does not change. The same is true when water is at 100 °C and is boiling. Energy is required to pull liquid molecules apart. While the water is boiling, energy added to the water is used in changing the water to a gas. While water is changing to a gas, the temperature does not change. For any substance, added energy either raises its temperature or changes its state, not both at the same time.

**Figure 8** Energy put into a substance either raises the substance's temperature or changes the substance's state. **As energy is added to water, what is happening during the times that temperature does not change?**




## Section 2 Review

**KEY IDEAS**

1. **Describe** how energy is transferred by conduction, convection, and radiation.
2. **Predict** whether the hottest part of a room will be near the ceiling, in the center, or near the floor, given that there is a hot-air vent near the floor. Explain your reasoning.
3. **Explain** why there are temperature differences on the moon's surface even though there is no atmosphere present.

**CRITICAL THINKING**

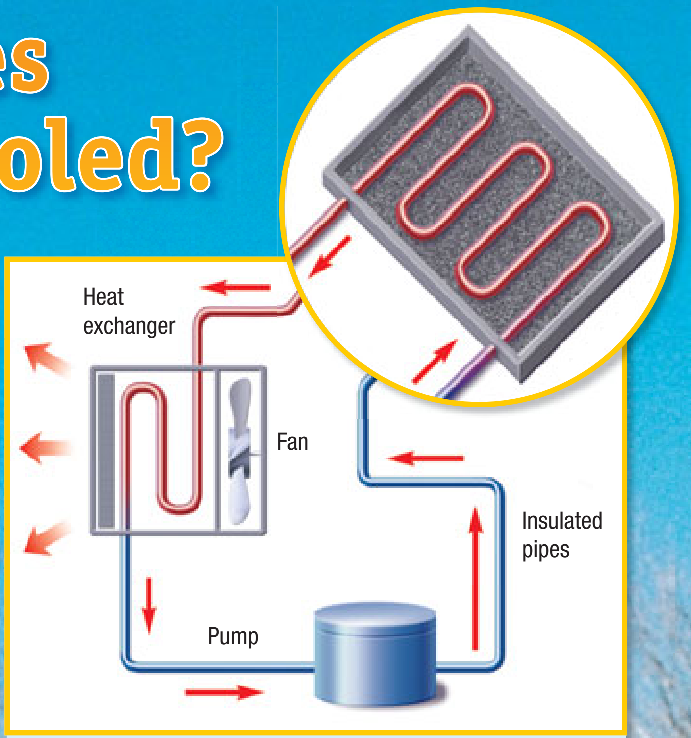
4. **Applying Concepts** Explain why cookies baked near the turned-up edges of a cookie sheet receive more energy than those baked near the center do.

**Math Skills**

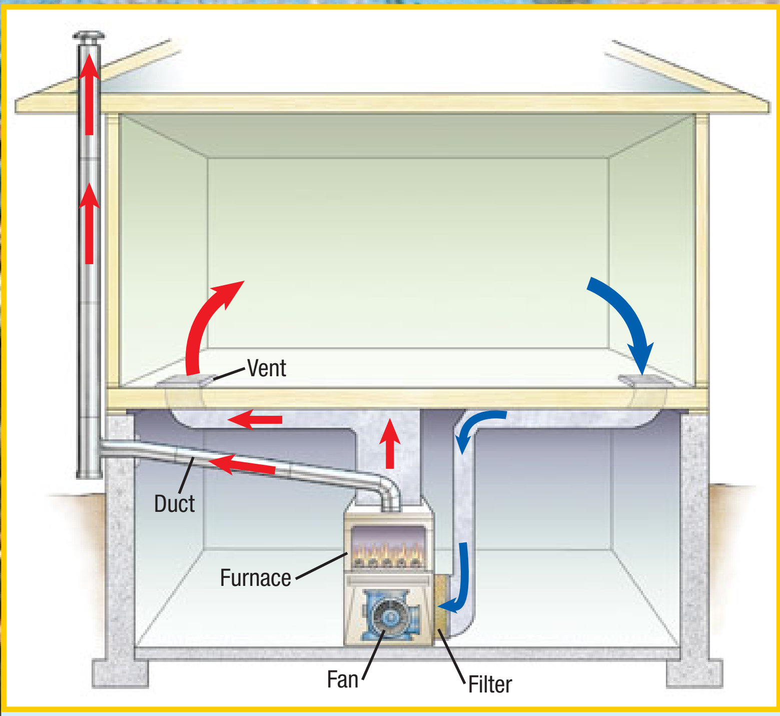
5. How much energy would be absorbed by 550 g of copper that is heated from 24 °C to 45 °C? (Hint: Refer to **Figure 7.**)
6. A 144 kg park bench made of iron sits in the sun, and its temperature increases from 25 °C to 35 °C. How many kilojoules of energy does the bench absorb? (Hint: Refer to **Figure 7.**)
7. Suppose that a car's radiator contains 2.0 kg of water. The water absorbs energy from the car engine. In the process, the water's temperature increases from 298 K to 355 K. How much energy did the water absorb?

# How Are Homes Heated and Cooled?

**People tend to be most comfortable when the temperature of the air around them is in the range of 21 °C to 25° C (70 °F to 77 °F). To raise the indoor temperature on colder days, one must use a heating system to transfer energy into a room's air. Most heating systems use a source of energy to raise the temperature of a substance such as air or water. In cooling systems, energy is transferred as heat from one substance to another, which leaves the first substance at a lower temperature. Cooled or heated air circulates throughout a home by convection currents. For the temperature of a home to be effectively regulated, heating and cooling units must be designed to make the best use of the flow of heat energy by convection.**



An active solar-heating system moves solar-heated water through pipes and a heat exchanger.



Hot-water, steam, and hot-air systems heat buildings by circulating heated fluids through each room.

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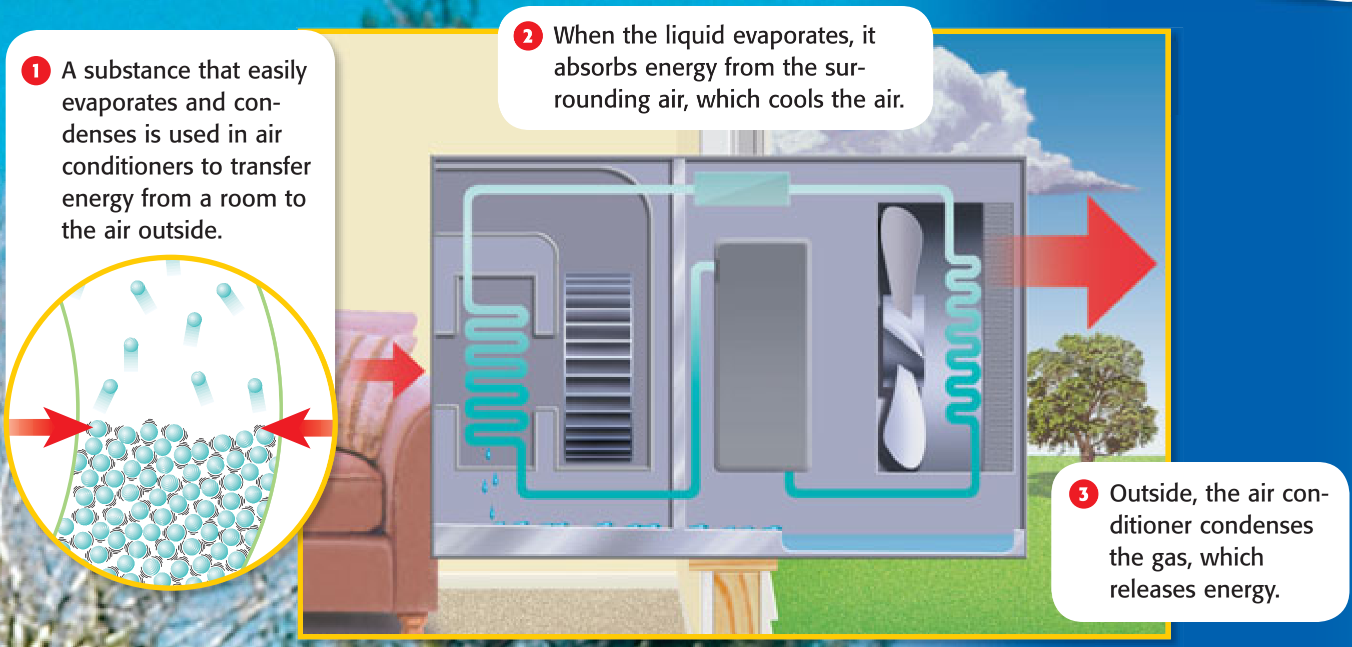
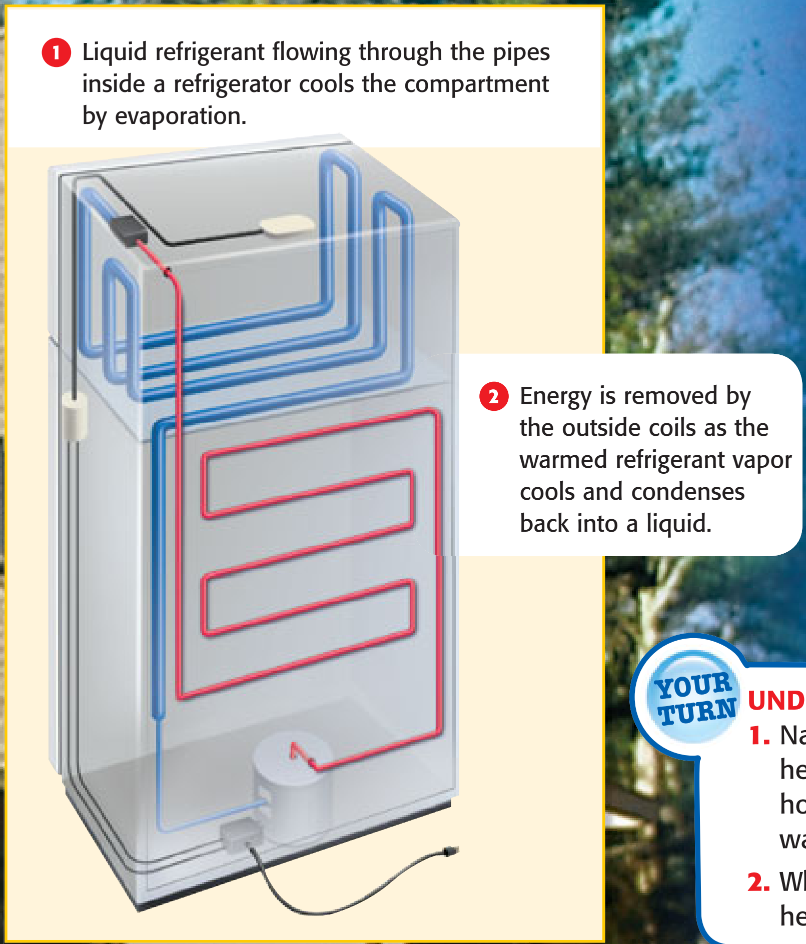
# REAL WORLD




YOUR TURN

## UNDERSTANDING CONCEPTS

1. Name one type of home heating system, and describe how it transfers energy to warm the air inside the rooms.
2. Why does an air conditioner heat up while it is operating?