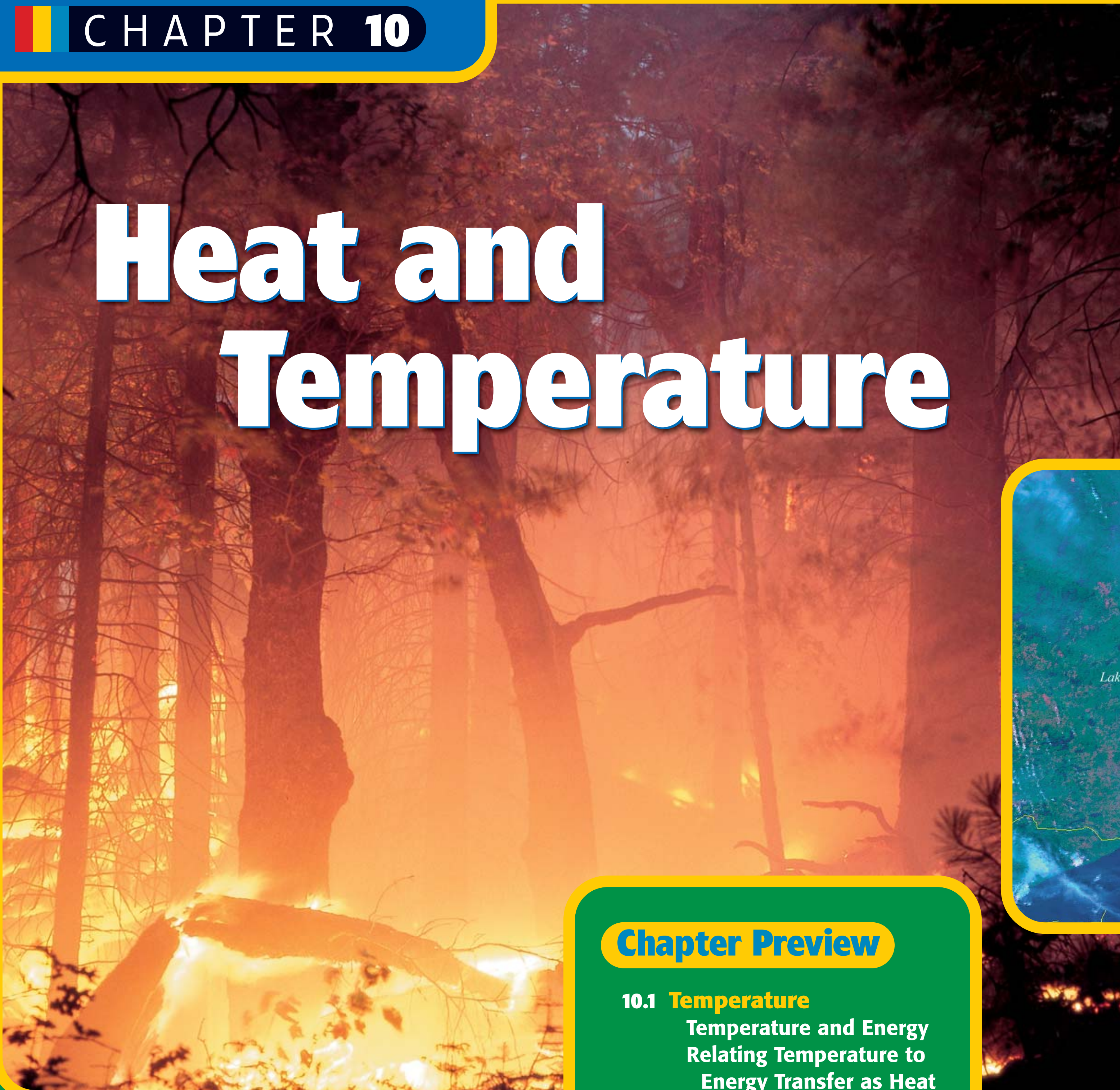
CHAPTER 10

Heat and Temperature



Chapter Preview

INTEGRATING TECHNOLOGY and Society

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Unlike visible light, infrared radiation from the fire passes through the smoke, making an otherwise invisible fire easy to see and locate. In infrared images, the high-temperature fire is brighter than its cooler surroundings.

Focus ACTIVITY

Background The fire started at night. By the time firefighters arrived the next morning, the forest was filled with thick smoke. The firefighters knew the fire was still raging in the forest, but they had to see through the smoke to find the fire's exact location.

Fortunately, firefighters have instruments that detect infrared radiation. Infrared radiation is a form of light that is invisible to the eye and is given off by hot objects, such as burning wood. Infrared radiation passes through the smoke and is picked up by infrared detectors. The images formed by these instruments are then converted into pictures that we can see. From these pictures, the fire's exact location can be determined, and the firefighters can keep the fire from spreading.

Activity 1 Use a prism to separate a beam of sunlight into its component colors, and project these onto a sheet of paper. Use a thermometer to record the temperature of the air in the room, and then place the thermometer bulb in each colored band for 3 minutes. Record the final temperature of each colored band. Place the thermometer on the dark side of the red band, where infrared radiation is found, for 3 minutes. How do the final temperature readings differ? Do your results suggest why infrared radiation is associated with hot objects?

Activity 2 Obtain several cups that are about the same size but are made of different materials (glass, metal, ceramic, plastic foam). Fill one cup with hot tap water, and measure the time it takes for the outside of the cup to feel hot (at a temperature of about 35°C). Repeat this for each cup. List the materials, with the one that warms fastest listed first. Note any differences such as cup thickness, cup volume, or changes in the temperature of your hand.

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10.1

Temperature

KEY TERMS

temperature
thermometer
absolute zero
heat

OBJECTIVES

- Define *temperature* in terms of the average kinetic energy of atoms or molecules.
- Convert temperature readings between the Fahrenheit, Celsius, and Kelvin scales.
- Recognize heat as a form of energy transfer.

temperature a measure of the average kinetic energy of all the particles within an object

People use **temperature** readings, such as those shown in **Figure 10-1,** to make a wide variety of decisions every day. You check the temperature of the outdoor air to decide what to wear. The temperature of a roasting turkey is monitored to see if it is properly cooked. A nurse monitors the condition of a patient by checking the patient's body temperature. But what exactly is it that you, the cook, and the nurse are measuring? What does the temperature indicate?

Temperature and Energy

When you touch the hood of an automobile, you sense how hot or cold it is. In everyday life, we associate this sensation of hot or cold with the temperature of an object. However, this sensation serves only as a rough indicator of temperature. The Quick Activity on the next page illustrates this point.

Figure 10-1
Many decisions are made based on temperature.

Quick ACTIVITY

Sensing Hot and Cold

For this exercise you will need three bowls.

1. Put an equal amount of water in all three bowls. In the first bowl, put some cold tap water. Put some hot tap water in the second bowl. Then, mix equal amounts of hot and cold tap water in the third bowl.
2. Place one hand in the hot water and the other hand in the cold water. Leave them there for 15 s.
3. Place both hands in the third bowl, which contains the mixture of hot and cold water. How does the water temperature feel to each hand? Explain.

In Chapter 2, you learned that all particles in a substance are constantly moving. Like all moving objects, each particle has kinetic energy. If we average the kinetic energy of all the particles in an object, it turns out that this average kinetic energy is related to the temperature of the object. In fact, the temperature is proportional to the average kinetic energy.

In other words, as the average kinetic energy of an object increases, its temperature will increase. Compared to a cool car hood, the particles in a hot hood move faster because they have more kinetic energy. But how do we measure the temperature of an object? It is impossible to find the kinetic energy of every particle in an object and calculate its average. Actually, nature provides a very simple way to measure temperature directly.

Common thermometers rely on expansion

Icicles forming on trees, flowers wilting in the sun, and the red glow of a stove-top burner are all indicators of certain temperature ranges. You feel these temperatures as hot or cold. How you sense hot and cold depends not only on an object's temperature but also on other factors, such as the temperature of your skin.

To measure temperature accurately, we rely on a simple physical property of substances: most objects expand when their temperature increases. Ordinary **thermometers** are based on this principle and use liquid substances like mercury or colored alcohol that expand as their temperature increases and contract as their temperature falls. The expansion and contraction is the result of energy exchange between the thermometer and its surroundings.

For example, the thermometer shown in **Figure 10-2** can measure the temperature of air on a sunny day. As the temperature rises, the particles in the liquid inside the thermometer gain kinetic energy and move faster. With this increased motion, the particles in the liquid move farther apart causing it to expand and rise up the narrow tube.

thermometer a device that measures temperature

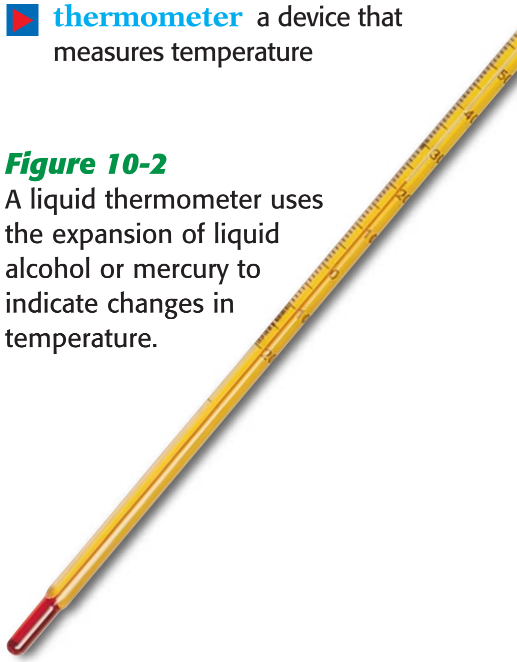

Figure 10-2
A liquid thermometer uses the expansion of liquid alcohol or mercury to indicate changes in temperature.

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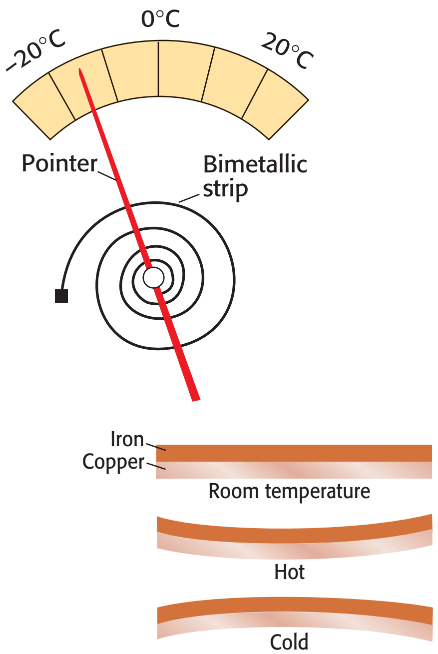


Figure 10-3
A refrigerator thermometer uses the bending of a strip made from two metals to indicate the correct temperature.

Liquid thermometers can measure only temperatures within a certain range. This is because below a certain temperature, the liquid used in the thermometer freezes. Also, above a certain temperature the liquid boils. Therefore, different types of thermometers are designed to measure extreme temperatures.

The thermometer used in a refrigerator is based on the expansion of metal, as shown in **Figure 10-3.** The thermometer contains a coil made from two different metal strips pressed together. Both strips expand and contract at different rates as the temperature changes. As the temperature falls, the coil unwinds moving the pointer to the correct temperature. A digital thermometer, shown in **Figure 10-4,** is designed to measure temperature by noting the change in current. Changes in temperature also cause electric current to change in a circuit.

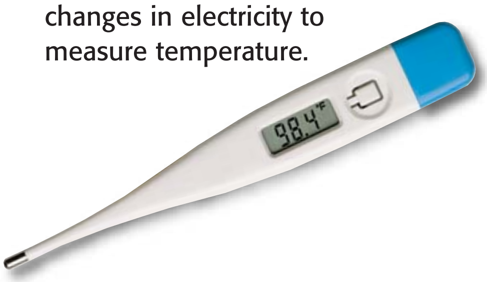
Fahrenheit and Celsius are common scales used for measuring temperatures

The temperature scale that is probably most familiar to you from weather reports and cookbooks is the Fahrenheit scale. The units on the Fahrenheit scale are called degrees Fahrenheit, or °F. On the Fahrenheit scale, water freezes at 32°F and boils at 212°F.

Most countries other than the United States use the Celsius (or centigrade) scale. This scale is widely used in science. The Celsius scale gives a value of zero to the freezing point of water and a value of 100 to the boiling point of water at standard atmospheric pressure. The difference between these two points is divided into 100 equal parts, called degrees Celsius, or °C.

A degree Celsius is nearly twice as large as a degree Fahrenheit. Also, the temperature at which water freezes differs for the two scales by 32 degrees. To convert from one scale to the other, use one of the following formulas.

Figure 10-4
A digital thermometer uses changes in electricity to measure temperature.



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Celsius-Fahrenheit Conversion Equation

$$\textit{Fahrenheit temperature} = \left(\frac{9}{5} \times \textit{Celsius temperature}\right) + 32.0$$

$$T_F = \frac{9}{5}t + 32.0$$

Fahrenheit-Celsius Conversion Equation

$$\textit{Celsius temperature} = \frac{5}{9}(\textit{Fahrenheit temperature} - 32.0)$$

$$t = \frac{5}{9}(T_F - 32.0)$$

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The Kelvin scale is based on absolute zero

You have probably heard of negative temperatures, such as those reported on extremely cold winter days in the northern United States and Canada. Remember that temperature is a measure of the average kinetic energy of the particles in an object. Even far below 0°C these particles are moving and therefore have some kinetic energy. But how low can the temperature fall? Physically, the lowest possible temperature is –273.13°C. This temperature is referred to as **absolute zero.** At absolute zero the energy of an object is minimal, that is, the energy of the object cannot be any lower.

Absolute zero is the basis for another temperature scale called the Kelvin scale. On this scale, 0 kelvin, or 0 K, is absolute zero. Since the lowest possible temperature is assigned a zero value, there are no negative temperature values on the Kelvin scale. The Kelvin scale is used in many fields of science, especially those involving low temperatures. The three temperature scales are compared in **Figure 10-5.**

In magnitude, a unit of kelvin is equal to a degree on the Celsius scale. Therefore, the temperature of any object in kelvins can be found by simply adding 273 to the object's temperature in degrees Celsius. The equation for this conversion is given below.

Temperature Values on Different Scales

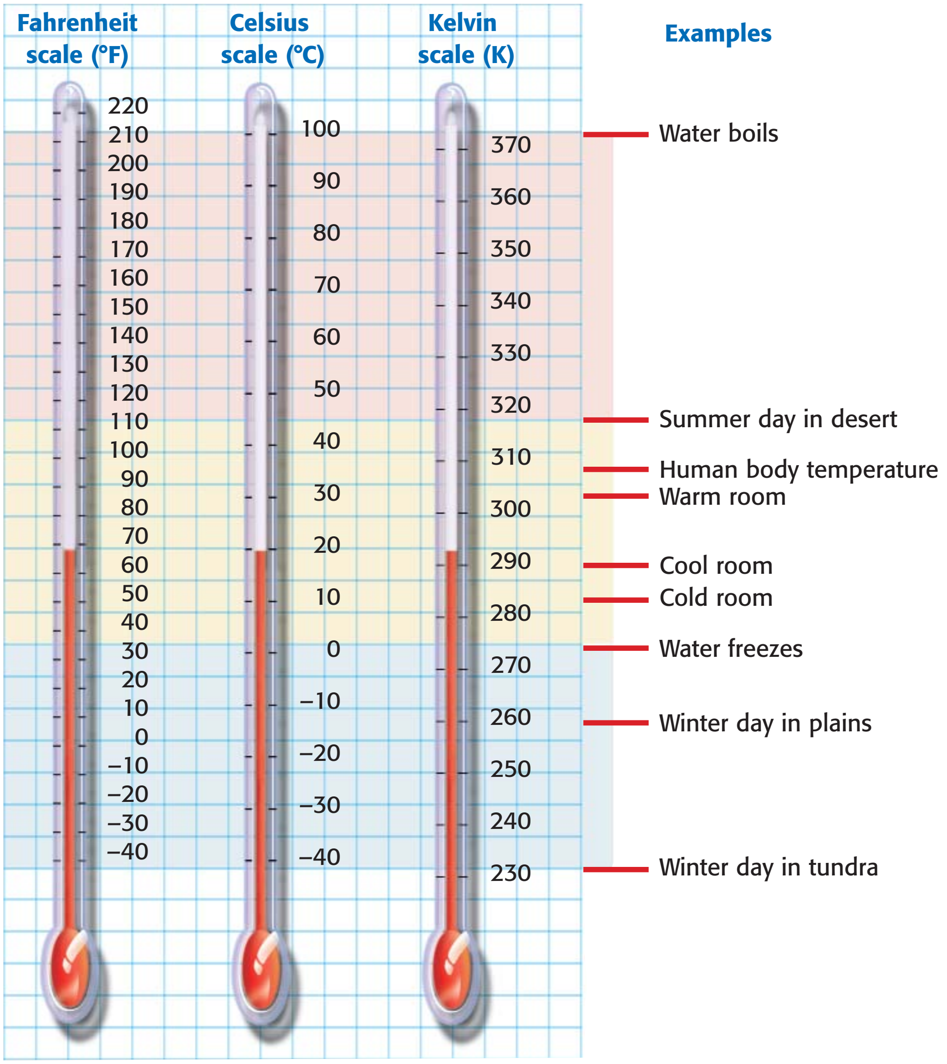

Figure 10-5
Temperatures on the Celsius scale can be converted to both Fahrenheit and Kelvin scales. Note that all Kelvin temperatures are positive.

absolute zero the temperature at which an object's energy is minimal

Celsius-Kelvin Conversion Equation

$$\textit{Kelvin temperature} = \textit{Celsius temperature} + 273$$

$$T = t + 273$$

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INTEGRATING

SPACE SCIENCE

From cold deep space to hot stars, astronomers measure a wide range of temperatures of objects in the universe. All objects produce different types of electromagnetic waves depending on their temperature. By identifying the distribution of wavelengths an object radiates, astronomers can estimate the object's temperature.

Light (an electromagnetic wave) received from the sun indicates that the temperature of its surface is 6000 K. If you think that is hot, try the center of the sun, where the temperature increases to 15 000 000 K!

PHYSICAL SCIENCE INTERACTIVE TUTOR

***Disc One, Module 7:* Heat**
Use the Interactive Tutor to learn more about this topic.

Math Skills

Temperature Scale Conversion The highest atmospheric temperature ever recorded on Earth was 57.8°C. Express this temperature both in degrees Fahrenheit and in kelvins.

1 List the given and unknown values.

Given: $t = 57.8°C$

Unknown: $T_F = ?°F$, $T = ?K$

2 Write down the equations for temperature conversions from pages 326 and 327.

$$T_F = \frac{9}{5}t + 32.0$$

$$T = t + 273$$

3 Insert the known values into the equations, and solve.

$$T_F = \left(\frac{9}{5} \times 57.8\right) + 32.0 = 104 + 32.0 = 136°F$$

$$T = 57.8 + 273 = 331 \text{ K}$$

Practice

Temperature Scale Conversion

1. Convert the following temperatures to both degrees Fahrenheit and kelvins.

a. the boiling point of liquid hydrogen (–252.87°C)

b. the temperature of a winter day at the North Pole (–40.0°C)

c. the melting point of gold (1064°C)

2. For each of the four temperatures given in the table below, make the necessary conversions to complete the table.

Example	Temp. (°C)	Temp. (°F)	Temp. (K)
Air in a typical living room	21	?	?
Metal in a running car engine	?	?	388
Liquid nitrogen	–200.	?	?
Air on a summer day in the desert	?	110.	?

3. Use **Figure 10-5** to determine which of the following is a likely temperature for ice cubes in a freezer.

a. –20°C
b. –4°F
c. 253 K
d. all of the above

4. Use **Figure 10-5** to determine which of the following is the nearest value for normal human body temperature.

a. 50°C
b. 75°F
c. 310 K
d. all of the above

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Relating Temperature to Energy Transfer as Heat

When you grab a piece of ice, it feels very cold. When you step into a hot bath, the water feels very hot. Clasping your hands together usually produces neither sensation. These three cases can be explained by comparing the temperatures of the two objects making contact with each other.

The feeling associated with temperature difference results from energy transfer

Imagine that you are holding a piece of ice. The temperature of ice is lower than your hand; therefore, the molecules in the ice move very slowly compared with the molecules in your hand. As the molecules on the surface of your hand collide with those on the surface of the ice, energy is transferred to the ice. As a result, the molecules in the ice speed up and their kinetic energy increases. This causes the ice to melt.

Inquiry Lab

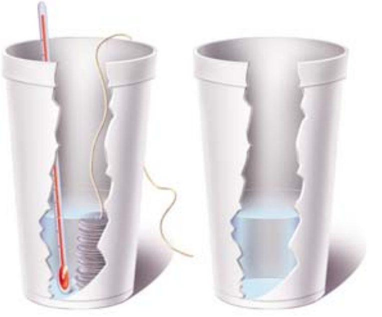
How do temperature and energy relate?

Materials

- ✔ glass beaker
- ✔ tongs
- ✔ 2 pieces of string, 20 cm each
- ✔ thermometer
- ✔ clock
- ✔ electric hot plate
- ✔ graduated cylinder
- ✔ 40 identical small metal washers
- ✔ 2 plastic-foam cups

Procedure

1. Tie 10 washers on one piece of string and 30 washers on another piece of string.
2. Fill the beaker two-thirds full with water, lower the washers in, and set the beaker on the hot plate.
3. Heat the water to boiling.
4. While the water heats, put exactly 50 mL of cool water in each plastic-foam cup.
5. Use a thermometer to measure and record the initial temperature of water in each cup.
6. When the water in the beaker has boiled for about 3 minutes, use tongs to remove the group of 30 washers. Gently shake any water off the washers back into the beaker, and quickly place the washers into one of the plastic-foam cups.
7. Observe the change in temperature of the cup's water. Record the highest temperature reached.



8. Repeat steps 6 and 7 by placing the 10 washers in the other plastic-foam cup.

Analysis

1. Which cup had the higher final temperature?
2. Both cups had the same starting temperature. Both sets of washers started at 100°C. Why did one cup reach a higher final temperature?

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heat the transfer of energy from the particles of one object to those of another object due to a temperature difference between the two objects

INTEGRATING

HEALTH

Food supplies the human body with the energy it needs. A person on a typical diet takes in and expends about 2400 Calories (about 10^7J) per day, or about 100 J/s. Much of this energy is eventually transferred away by heat, which is why a full classroom feels hotter toward the end of class.

In a similar manner, a hot-water bottle transfers energy from the hot water to your skin. However, when both your hands are at the same temperature, neither hand feels warm or cold because there is no energy transfer.

The transfer of energy between the particles of two objects due to a temperature difference between the two objects is called **heat.** This transfer of energy always takes place from a substance at a higher temperature to a substance at a lower temperature.

Because temperature is an indicator of the particles' average kinetic energy, you can use it to predict which way energy will be transferred. The warmer object, such as the hot-water bottle, will transfer energy to the cooler object, such as your skin. When energy is transferred as heat from the hot water to your skin, the temperature of the water falls while the temperature of your skin rises.

When both your skin and the hot-water bottle approach the same temperature, less energy is transferred from the bottle to your skin. To continue the transfer of energy, the temperature of the hot water must be kept at a higher temperature than your skin. The greater the difference in the temperatures of the two objects, the more energy that will transfer as heat.

SECTION 10.1 REVIEW

SUMMARY

- Temperature is a measure of the average kinetic energy of an object's particles.
- A thermometer is a device that measures temperature.
- On the Celsius temperature scale, water freezes at 0° and boils at 100°.
- A kelvin is the same size as a degree Celsius. The lowest temperature possible—absolute zero—is 0 K.
- At absolute zero the particles of an object have no kinetic energy to transfer.
- Heat is the transfer of energy between objects with different temperatures.

CHECK YOUR UNDERSTANDING

1. **Define** *absolute zero* in terms of particles and their kinetic energy.
2. **Predict** which molecules will move faster on average: water molecules in a cup of hot soup or water molecules in a glass of iced lemonade.
3. **Explain** how your precautions would differ if you were preparing to enter a chamber at 100 K as opposed to one at 100°C.
4. **Predict** whether a greater amount of energy will be transferred as heat between 1 kg of water at 10°C and a freezer at –15°C or between 1 kg of water at 60°C and an oven at 65°C.
5. **Critical Thinking** Determine which of the following has a higher temperature and which contains a larger amount of total kinetic energy: a cup of boiling water or Lake Michigan.

Math Skills

6. Convert the temperature of the air in an air-conditioned room, 20.0°C, to equivalent values on the Fahrenheit and Kelvin temperature scales.
7. Convert the coldest outdoor temperature ever recorded, –128.6°F, to equivalent Celsius and Kelvin temperatures.

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10.2

Energy Transfer

OBJECTIVES

- Investigate and demonstrate how energy is transferred by conduction, convection, and radiation.
- Identify and distinguish between conductors and insulators.
- Solve problems involving specific heat.

KEY TERMS

conduction
convection
convection current
radiation
conductor
insulator
specific heat

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 are all examples of energy transfers from one object to another.

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Methods of Energy Transfer

The energy transfer as heat from a hot object can occur in three ways. Roasting marshmallows around a campfire, as shown in **Figure 10-6,** provides an opportunity to experience each of these three ways.

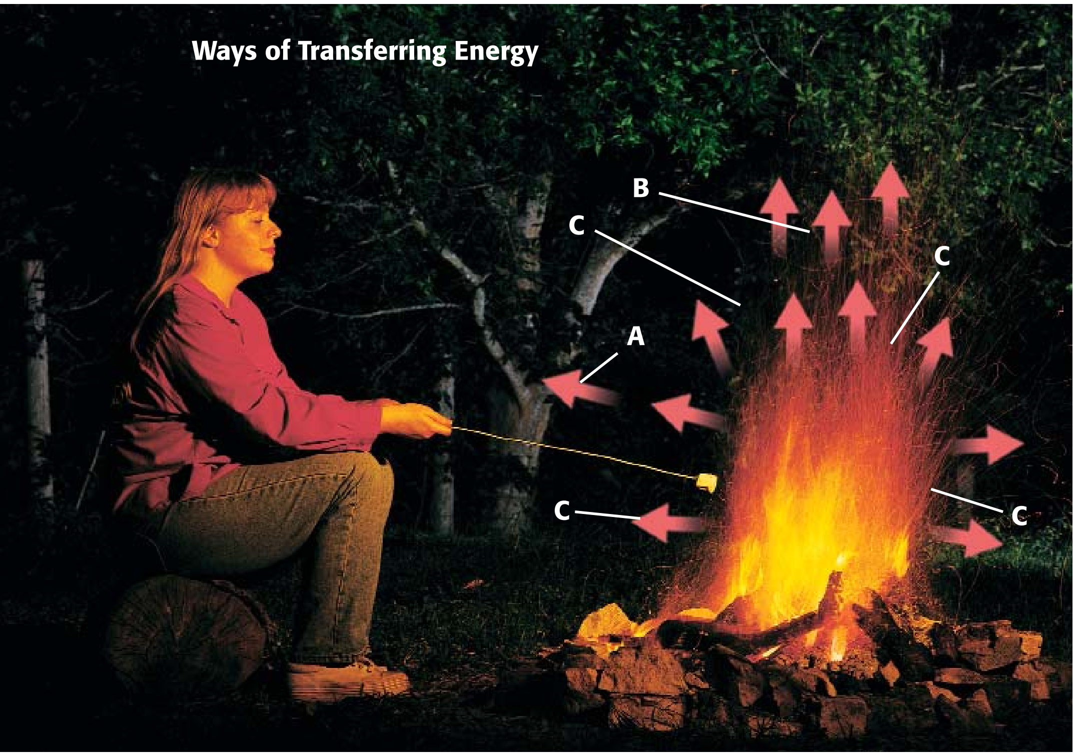

Figure 10-6

A Conduction transfers energy as heat along the wire and into the hand.

B Embers swirl upward in the convection currents that are created as warmed air above the fire rises.

C Electromagnetic waves emitted by the hot campfire transfer energy by radiation.

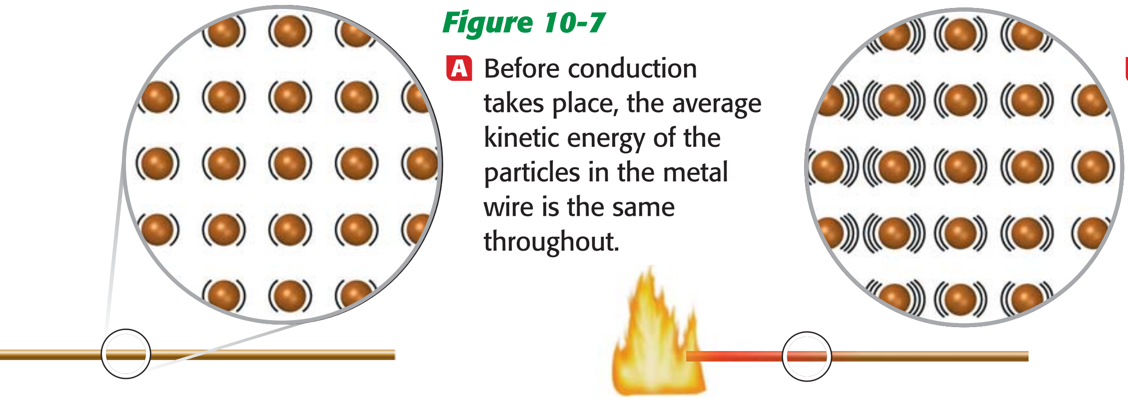

Figure 10-7

A Before conduction takes place, the average kinetic energy of the particles in the metal wire is the same throughout.

B During conduction, the rapidly moving particles in the wire transfer some of their energy to slowly moving particles nearby.

conduction the transfer of energy as heat between particles as they collide within a substance or between two objects in contact

convection the transfer of energy by the movement of fluids with different temperatures

Conduction involves objects in direct contact

Imagine 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 in the campfire flame. Soon you will notice that the end of the wire you are holding is getting warmer. This is an example of energy transfer by **conduction.**

Conduction is one of the methods of energy transfer. Conduction takes place when two objects that are in contact are at unequal temperatures. It also takes place between particles within an object. In the case of the wire in the campfire, the rapidly moving air molecules close to the flame collide with the atoms at the end of the wire. The energy transferred to the atoms in the wire causes them to vibrate rapidly. As shown in **Figure 10-7,** these rapidly vibrating atoms collide with slowly vibrating atoms, transferring energy as heat all along the wire. The energy is then transferred to you as the wire's atoms collide with the molecules in your skin, creating a hot sensation in your hand.

Convection results from the movement of warm fluids

While roasting your marshmallow, you may notice that tiny glowing embers from the fire rise and begin to swirl, as shown in **Figure 10-6.** They are following the movement of air away from the fire. The air close to the fire becomes hot and expands so that there is more space between the air particles. As a result, the air becomes less dense and moves upward, carrying its extra energy with it, as shown in **Figure 10-8.** The rising warm air is replaced by cooler, denser air. The cooler air then becomes hot by the fire until it also expands and rises. Eventually, the rising hot air cools, contracts, becomes denser, and sinks. This is an example of energy transfer by **convection.**

Convection involves the movement of the heated substance itself. This is possible only if the substance is a fluid—either a liquid or a gas—because particles within solids are not as free to move.

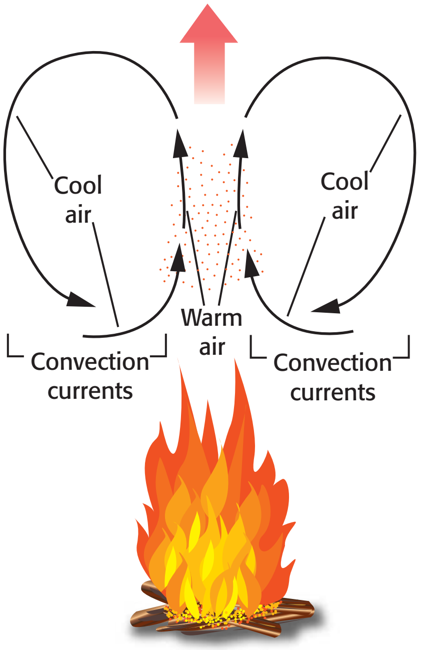

Figure 10-8
During convection, energy is carried away by a heated gas or liquid that expands and rises above cooler, denser gas or liquid.

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The cycle of a heated fluid that rises and then cools and falls is called a **convection current.** The glowing embers rising from the campfire are caught up in the convection currents created in the air surrounding the fire. The proper heating and cooling of a building requires the use of 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. Eventually, the temperature of all the air in the room is increased by convection currents.

convection current the flow of a fluid due to heated expansion followed by cooling and contraction

Quick ACTIVITY

Convection

Light a candle. Carefully observe the motion of the tiny soot particles in smoke. They move because of convection currents.

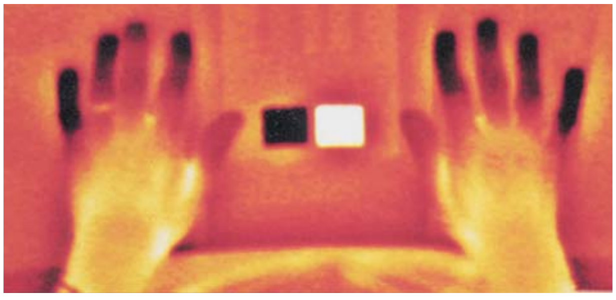
Radiation does not require physical contact between objects

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 energy transfer as heat from the fire in this case is in the form of *electromagnetic waves,* which include infrared radiation, visible light, and ultraviolet rays. The transfer of energy by electromagnetic waves is called **radiation.** You will learn more about electromagnetic radiation in Chapters 11 and 12.

When you stand near a fire, your skin absorbs the energy radiated by the fire. As the molecules in your skin absorb this energy, the average kinetic energy of these molecules—and thus the temperature of your skin—increases. A hot object radiates more energy than a cool object or cool surroundings, as shown in **Figure 10-9.**

radiation the transfer of energy by electromagnetic waves

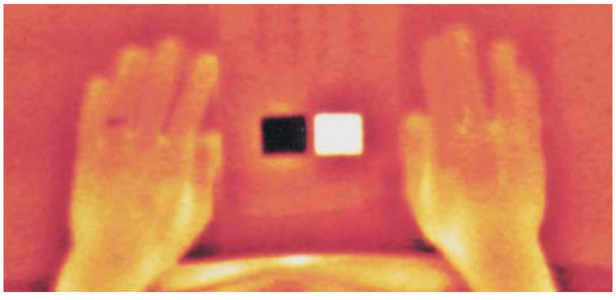
Radiation differs from conduction and convection in that it does not involve the movement of matter. Radiation is therefore the only method of energy transfer that can take place in a vacuum, such as outer space. Much of the energy we receive from the sun is transferred by radiation.



Changes in Radiated Energy

Figure 10-9

A Before surgery, as seen in the infrared photo, the fingers are cooler than the rest of the hand. This results from poor blood flow in this patient's fingers.



B After surgery, the blood flow has been restored, so the temperature of the fingers, and the amount of energy they radiate, increases.

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Inquiry Lab

What color absorbs more radiation?

Materials
- ✔ empty soup can, painted black inside and out, label removed
- ✔ empty soup can, label removed
- ✔ 2 thermometers
- ✔ clock
- ✔ graduated cylinder
- ✔ bright lamp or sunlight

Procedure

1. Prepare a data table with three columns and at least seven rows. Label the first column "Time," the second column "Temperature of painted can (°C)," and the third column "Temperature of unpainted can (°C)."
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 the lamp at the cans, or place them in sunlight.
4. Record the temperature of the water in each can every 3 minutes for at least 15 minutes.

Analysis

1. Prepare a graph. Label the *x*-axis "Time" and the *y*-axis "Temperature". Plot your data for each can of water.
2. Which color absorbed more radiation?
3. Which variables in the lab were controlled (unchanged throughout the experiment)? For each of the following variables, explain your answer.
   a. starting temperature of water in cans
   b. volume of water in cans
   c. distance of cans from light
   d. size of cans
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.

Conductors and Insulators

When you are cooking, the energy transfer as heat from the stove to the food must occur effectively. However, it is important that the handle does not get uncomfortably hot.

Energy is transferred as heat quickly in conductors

To increase the temperature of a substance using conduction, we must use materials through which energy can be quickly transferred as heat. Cooking pans are made of metal because energy is passed easily and quickly between the particles in most metals. Any material through which energy can be easily transferred as heat is called a **conductor.**

conductor a material through which energy can be easily transferred as heat

Part of what determines how well a substance conducts is whether it is a gas, liquid, or solid. Gases are extremely poor conductors because their particles are far apart, and the particle collisions necessary to transfer energy rarely occur. The particles in liquids are more closely packed. However, while liquids conduct better than gases, they are not very effective conductors.

Some solids, like rubber and wood, conduct energy about as well as liquids. However, metals such as copper and silver conduct energy transfer as heat very well. Some solids are better conductors than other solids. Metals, in general, are better conductors than non-metals.

Figure 10-10
The skillet conducts energy from the stove element to the food. The wooden spoon and handle insulate the hands from the energy of the skillet.

Insulators slow the transfer of energy as heat

Because energy costs money, we try to avoid wasting it. This waste is most often due to unwanted energy transfer. To reduce or stop unwanted energy transfer, we use materials that are poor conductors. A material of this type is called an **insulator.**

insulator a material that is a poor energy conductor

Examples of conductors and insulators are shown in **Figure 10-10.** The skillet is made of iron, a good conductor, so that energy is transferred effectively as heat to the food. Wood is an insulator, so the energy from the hot skillet won't reach your hand through the wooden spoon or the wooden handle.

Quick ACTIVITY

Conductors and Insulators

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.

1. Place the ice cubes in the bowl. Position the utensils in the bowl so that an equal length of each utensil lies under the ice.
2. Check the utensils' temperature by briefly touching each utensil at the same distance from the ice every 20 s. Which utensil becomes colder first? What variables might affect your results?

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Figure 10-11
The spoon's temperature increases rapidly because of the spoon's low specific heat.

Specific Heat

You have probably noticed that a metal spoon, like the one shown in **Figure 10-11,** becomes hot when it is placed in a cup of hot liquid. You have also probably 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 they are good conductors or good insulators. But what makes a substance a good or poor conductor depends in part on how much energy a substance requires to change its temperature by a certain degree.

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

Not all substances behave the same when they absorb energy by heat. For example, a metal spoon left in a metal pot becomes hot seconds after the pot is placed on a hot stovetop burner. This is because a few joules of energy are enough to raise the spoon's temperature substantially. However, if an amount of water with the same mass as the spoon is placed in the same pot, that same amount of energy will produce a much smaller temperature change in the water.

For all substances, the amount of energy that must be transferred to the substance in order to raise the temperature of 1 kg of the substance by 1 K is a characteristic physical property. This property is known as **specific heat** and is denoted by c.

specific heat the amount of energy transferred as heat that will raise the temperature of 1 kg of a substance by 1 K.

Some values for specific heat are given in **Table 10-1.** These values are in units of J/kg•K, meaning each is the amount of energy in J needed to raise the temperature of 1 kg of the substance by exactly 1 K.

Table 10-1 **Specific Heats at 25°C**

Substance	c (J/kg•K)	Substance	c (J/kg•K)
Water (liquid)	4186	Copper	385
Steam	1870	Gold	129
Ammonia (gas)	2060	Iron	449
Ethanol (liquid)	2440	Mercury	140
Aluminum	897	Lead	129
Carbon (graphite)	709	Silver	234

Back

On a hot summer day, the temperature of the water in a swimming pool remains much lower than the air temperature and the temperature of the concrete around the pool. This is due to water's relatively high specific heat as well as the large mass of water in the pool. Similarly, at night, the concrete and the air cool off quickly, while the water changes temperature only slightly.

Specific heat can be used in calculations

Because specific heat is a ratio, it can be used to predict the effects of larger temperature changes for masses other than 1 kg. For example, if it takes 4186 J to raise the temperature of 1 kg of water by 1 K, twice as much energy, 8372 J, will be required to raise the temperature of 2 kg of water by 1 K. Three times that amount, 25 120 J, will be required to raise the temperature of the 2 kg of water by 3 K. This relationship is summed up in the equation below.

Specific Heat Equation

$$energy = (specific\ heat) \times (mass) \times (temperature\ change)$$

$$energy = cm\Delta t$$

Specific heat can change slightly with changing pressure and volume. *However, problems and questions in this chapter will assume that specific heat does not change.*

Math Skills

Specific Heat How much energy must be transferred as heat to the 420 kg of water in a bathtub in order to raise the water's temperature from 25°C to 37°C?

1 List the given and unknown values.

Given: $\Delta t = 37°C - 25°C = 12°C = 12\ K$

$m = 420\ kg$

$c = 4186\ J/kg{\bullet}K$

Unknown: $energy = ?\ J$

2 Write down the specific heat equation from this page.

$energy = cm\Delta t$

3 Substitute the specific heat, mass, and temperature change values, and solve.

$$energy = \left(\frac{4186\ J}{kg{\bullet}K}\right) \times (420\ kg) \times (12\ K)$$

$$energy = 21\ 000\ 000\ J = 2.1 \times 10^4\ kJ$$

INTEGRATING

EARTH SCIENCE

Sea breezes result from both convection currents in the coastal air and differences in the specific heats of water and sand or soil. During the day, the temperature of the land increases more than the temperature of the ocean water, which has a larger specific heat. As a result, the temperature of the air over land increases more than the temperature of air over the ocean. This causes the warm air over the land to rise and the cool ocean air to move inland to replace the rising warm air. At night, the temperature of the dry land drops below that of the ocean, and the direction of the breezes is reversed.

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Practice HINT

- To rearrange the equation to isolate temperature change, divide both sides of the equation by *mc*.

$$\frac{energy}{mc} = \left(\frac{\cancel{mc}}{\cancel{mc}}\right)\Delta t$$

$$\Delta t = \frac{energy}{mc}$$

- Use this version of the equation for Practice Problem 4.
- For Practice Problems 5 and 6, you will need to isolate *m* and *c*.

Practice

Specific Heat

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 so that the temperature of the water will drop from 35°C to 5°C?
3. 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?
4. An aluminum baking sheet with a mass of 225 g absorbs 2.4×10^4 J from an oven. If its temperature was initially 25°C, what will its new temperature be?
5. What mass of water is required to absorb 4.7×10^5 J of energy from a car engine while the temperature increases from 298 K to 355 K?
6. A vanadium bolt gives up 1124 J of energy as its temperature drops 25 K. If the bolt's mass is 93 g, what is its specific heat?

SECTION 10.2 REVIEW

SUMMARY

- Conduction is the transfer of energy as heat between particles as they collide within a substance or between objects in contact.
- Convection currents are the movement of gases and liquids as they become heated, expand, and rise, then cool, contract, and fall.
- Radiation is the transfer of energy by electromagnetic waves.
- Conductors are materials through which energy is easily transferred as heat.
- Insulators are materials that conduct energy poorly.
- Specific heat is the energy required to heat 1 kg of a substance by 1 K.

CHECK YOUR UNDERSTANDING

1. **Describe** how energy is transferred by conduction, convection, and radiation.
2. **Rank** the following in order from the best conductor to the best insulator:
   a. iron
   b. air
   c. water
   d. gold
3. **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.

WRITING SKILL

4. **Explain** why there are temperature differences on the moon's surface, even though there is no atmosphere present.
5. **Critical Thinking** Explain why cookies baked near the turned-up edges of a cookie sheet receive more energy than those baked near the center.

Math Skills

6. When a shiny chunk of metal with a mass of 1.32 kg absorbs 3250 J of energy, the temperature of the metal increases from 273 K to 292 K. Is this metal likely to be silver, lead, or aluminum?
7. A 0.400 kg sample of glass requires 3190 J for its temperature to increase from 273 K to 308 K. What is the specific heat for this type of glass?

10.3

INTEGRATING TECHNOLOGY and Society

Using Heat

OBJECTIVES

- Describe the mechanisms of different heating and cooling systems, and discuss their advantages and drawbacks.
- Compare different heating and cooling systems in terms of how they decrease the amount of usable energy.

KEY TERMS

heating system
cooling system
refrigerant

Heating a house in the winter, cooling an office building in the summer, or preserving food throughout the year is possible because of machines that transfer energy as heat from one place to another. An example of one of these machines, an air conditioner, is shown in **Figure 10-12.** An air conditioner does work to remove energy as heat from the warm air inside a room and then transfers the energy to the warmer air outside the room. An air conditioner can do this because of two principles about energy that you have already studied.

The first principle, from Chapter 9, is that the total energy used in any process—whether that energy is transferred as a result of work, heat, or both—is conserved. This principle of conservation of energy is called the first law of thermodynamics.

The second principle, from this chapter, is that the energy transferred as heat always moves from an object at a high temperature to an object at a low temperature.

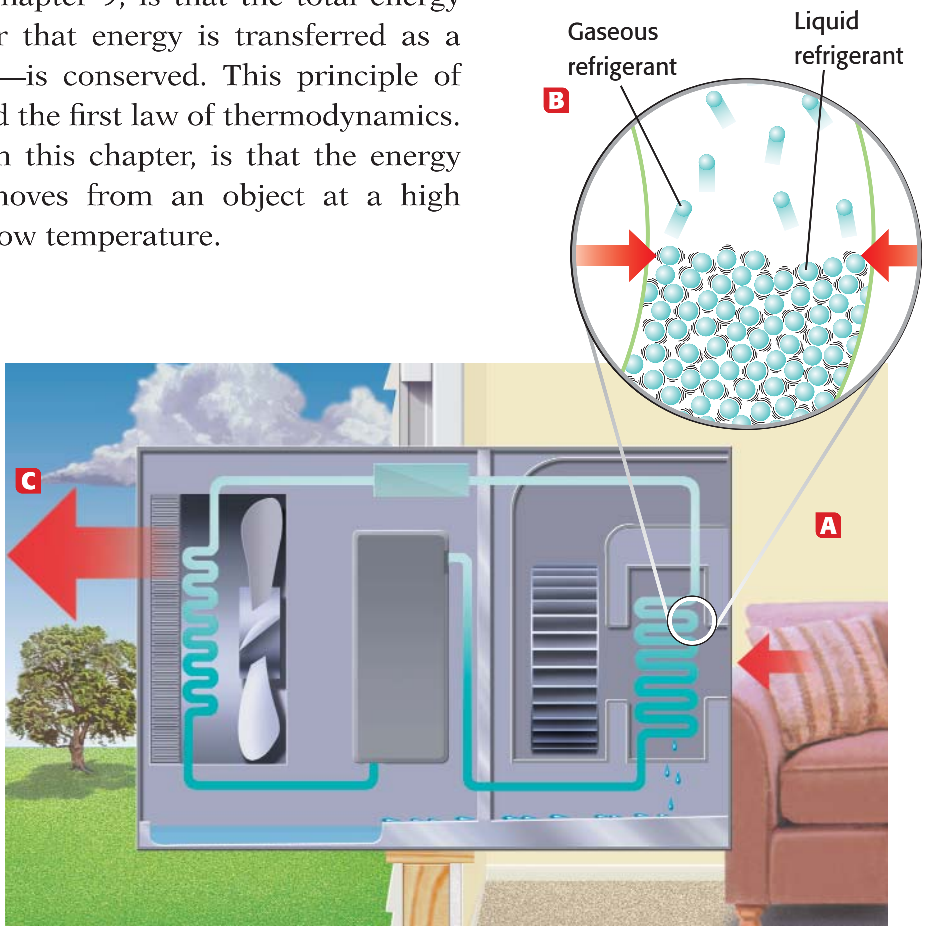

Figure 10-12

A A substance that easily evaporates and condenses is used in air conditioners to transfer energy from a room to the air outside.

B When the liquid evaporates, it absorbs energy from the surrounding air, thereby cooling it.

C Outside, the air conditioner causes the gas to condense, releasing energy.

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Connection to SOCIAL STUDIES

In 1769, a Scottish engineer named James Watt patented a new design that made steam engines more efficient. During the next 50 years, the improved steam engines were used to power trains and ships. Previously, transportation had depended on the work done by horses or the wind.

Watt's new steam engines were used in machines and factories of the industrial revolution. In 1784, Watt used steam coils to heat his office. This was the first practical use of steam for heating.

Making the Connection

1. Old steam-powered riverboats are popular tourist attractions in many cities. Make a list of at least three other instances in which the energy in steam is used for practical purposes.
2. What devices in older buildings function like the steam coils Watt used for heating his office?

Heating Systems

People generally feel and work their best when the temperature of the air around them is in the range of 21°C–25°C (70°F–77°F). To raise the indoor temperature on colder days, energy must be transferred into a room's air by a **heating system.** Most heating systems use a source of energy to raise the temperature of a substance such as air or water.

heating system any device or process that transfers energy to a substance to raise the temperature of the substance

Work can be done to increase temperature

When you rub your hands together, they become warmer. The energy you transfer to your hands by work is transferred to the molecules of your hands, and their temperature increases. Processes that involve energy transfer by work are called mechanical processes.

Another example of a mechanical heating process is a device used in the past by certain American Indian tribes to start fires. The device consists of a bow with a loop in the bowstring that holds a pointed stick. The sharp end of the stick is placed in a small indentation in a stone. A small pile of wood shavings is then put around the place where the stick and stone make contact. A person then does work to move the bow back and forth. This energy is transferred to the stick, which turns rapidly. The friction between the stick and stone causes the temperature to rise until the shavings are set on fire.

The energy from food is transferred as heat to blood moving throughout the human body

You may not think of yourself as a heating system. But unless you are sick, your body maintains a temperature of about 37°C (98.6°F), whether you are in a place that is cool or hot. Maintaining this temperature in cool air requires your body to function like a heating system.

If you are surrounded by cold air, energy will be transferred as heat from your skin to the air, and the temperature of your skin will drop. To compensate, stored nutrients are broken down by your body to provide energy, and this energy is transferred as heat to your blood. The warm blood circulates through your body, transferring energy as heat to your skin and increasing your skin's temperature. In this way your body can maintain a constant temperature.

internetconnect

SCILINKS NSTA

TOPIC: Heating and cooling systems
GO TO: www.scilinks.org
KEYWORD: HK1104

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Heated water or air transfers energy as heat in central heating systems

Most modern homes and large buildings have a central heating system. As is the case with your body, when the building is surrounded by cold air, energy is transferred as heat from the building to the outside air. The temperature of the building begins to drop.

A central heating system has a furnace that burns coal, fuel oil, or natural gas. The energy released in the furnace is transferred as heat to water, steam, or air, as shown in **Figure 10-13.** The steam, hot water, or hot air is then moved to each room through pipes or ducts. Because the temperature of the pipe is higher than that of the air, energy is transferred as heat to the air in the room.

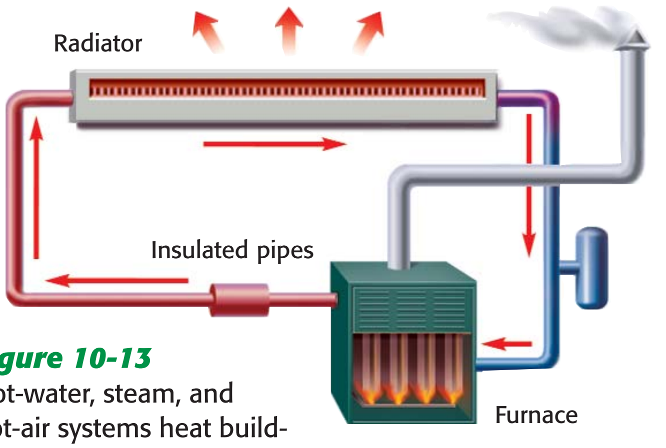

Figure 10-13
Hot-water, steam, and hot-air systems heat buildings by circulating heated fluids to each room.

Solar heating systems also use warmed air or water

Cold-blooded animals, such as lizards and turtles, increase their body temperature by using external sources, such as the sun. You may have seen these animals sitting motionless on rocks on sunny days, as shown in **Figure 10-14.** During such behavior, called basking, energy is absorbed by the reptile's skin through conduction from the warmer air and rocks, and by radiation from sunlight. This absorbed energy is then transferred as heat to the reptile's blood. As the blood circulates, it transfers this energy to all parts of the reptile's body.

Figure 10-14
Reptiles bask in the sun to raise their body temperature.

Solar heating systems, such as the one illustrated in **Figure 10-15,** use an approach similar to that of a basking reptile. A solar collector uses panels to gather energy radiated from the sun. This energy is used to heat water. The hot water is then moved throughout the house by the same methods other hot-water systems use.

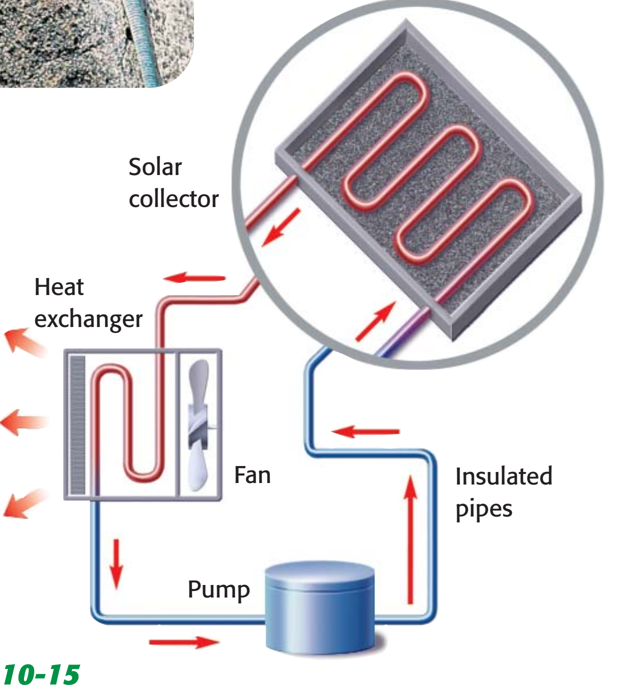

Figure 10-15
An active solar heating system moves water heated by sunlight through pipes and a heat exchanger.

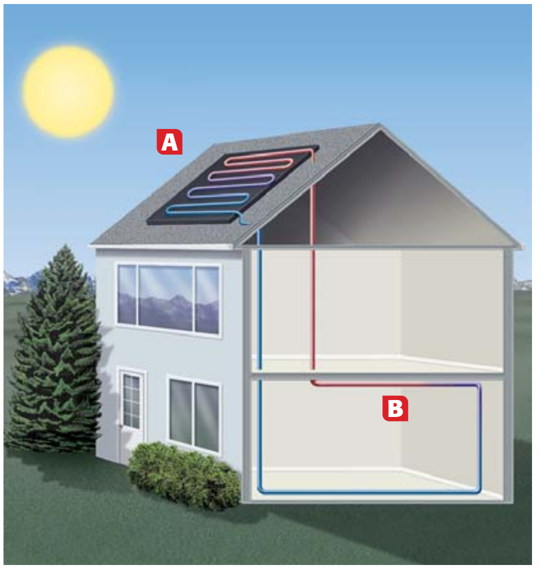

Figure 10-16
(A) In a passive solar heating system, energy from sunlight is absorbed in a rooftop panel. (B) Pipes carry the hot fluid that exchanges energy as heat with the air in each room.

The warm water can also be pumped through a device called a heat exchanger, which transfers energy from the water to a mass of air by conduction and radiation. The warmed air is then blown through ducts as with other warm-air heating systems.

Both of these types of solar heating systems are called active solar heating systems. They require extra energy from another source, such as electricity, in order to move the heated water or air around.

Passive solar heating systems, as shown in **Figure 10-16,** require no extra energy to move the hot fluids through the pipe. In this type of system, energy transfer is accomplished by radiation and convection currents created in heated water or air. In warm, sunny climates, passive solar heating systems are easy to construct and maintain and are clean and inexpensive to operate.

Usable energy decreases in all energy transfers

When energy can be easily transformed and transferred to accomplish a task, such as heating a room, we say that the energy is in a usable form. After this transfer, the same amount of energy is present, according to the law of conservation of energy. Yet less of it is in a form that can be used.

The energy used to increase the temperature of the water in a hot-water tank should ideally stay in the hot water. However, it is impossible to keep some energy from being transferred as heat to parts of the hot-water tank and its surroundings. The amount of usable energy decreases even in the most efficient heating systems.

Due to conduction and radiation, some energy is lost to the tank's surroundings, such as the air and nearby walls. Cold water in the pipes that feed into the water heater also draw energy from some of the hot water in the tank. When energy from electricity is used to heat water in the hot-water heater, some of the energy is used to increase the temperature of the electrical wire, the metal cover of the water heater, and the air around the water heater. All of these portions of the total energy put into the hot-water heater can no longer be used to heat the water, and therefore are no longer in a usable form. In general, the amount of usable energy always decreases whenever energy is transferred or transformed.

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Figure 10-17
Insulating materials, such as fiberglass and cellulose, are used in most buildings to reduce the transfer of energy as heat.

Table 10-2
***R*-Values for Some Common Building Materials**

Substance	*R*-value
Drywall, 1.3 cm (0.50 in.)	0.45
Wood shingles, (overlapping)	0.87
Flat glass, 0.318 cm (0.125 in.)	0.89
Hardwood siding, 2.54 cm (1.00 in.)	0.91
Vertical air space, 8.9 cm (3.5 in.)	1.01
Insulating glass, 0.64 cm (0.25 in.)	1.54
Cellulose fiber, 2.54 cm (1.00 in.)	3.70
Brick, 10.2 cm (4.00 in.)	4.00
Fiberglass batting, 8.9 cm (3.5 in.)	10.90

Insulation minimizes undesirable energy transfers

During winter, some of the energy from the warm air inside a building is lost to the cold outside air. Similarly, during the summer, energy from warm air outside seeps into an air-conditioned building, raising the temperature of the cool inside air. Good insulation can reduce, but not entirely eliminate, the unwanted transfer of energy to and from the building's surroundings. As shown in **Figure 10-17,** insulation material is placed in the walls and attics of homes and other buildings to reduce the unwanted transfer of energy as heat.

A standard rating system has been developed to measure the effectiveness of insulation materials. This rating, called the *R-value,* is determined by the type of material used and the material's thickness. *R*-values for several common building and insulating materials of a given thickness are listed in **Table 10-2.** The greater the *R*-value, the greater the material's ability to decrease unwanted energy transfers.

Cooling Systems

If you quickly let the air out of a compressed-air tank like the one used by scuba divers, the air from the tank and the tank's nozzle feel slightly cooler than they did before the air was released. This is because the molecules in the air lose some of their kinetic energy as the air's pressure and volume change and the temperature of the air decreases. This process is a simple example of a **cooling system.** In all cooling systems, energy is transferred as heat from one substance to another, leaving the first substance with less energy and thus a lower temperature.

cooling system a device that transfers energy as heat out of an object to lower its temperature

Cooling systems often use evaporation to transfer energy from their surroundings

In the case of a refrigerator, the temperature of the air and food inside is lowered. But because the first law of thermodynamics requires energy to be conserved, the energy inside the refrigerator must be transferred to the air outside the refrigerator. If you place your hand near the rear or base of a refrigerator, you will feel warm air being discharged. Much of the energy in this air was removed from inside the refrigerator.

Hidden in the back wall of a refrigerator is a set of coiled pipes through which a substance called a **refrigerant** flows, as shown in **Figure 10-18.** During each operating cycle of the refrigerator, the refrigerant evaporates into a gas and then condenses back into a liquid.

Recall from Chapter 2 and the beginning of this section that evaporation produces a cooling effect. Changes of state always involve the transfer of relatively large amounts of energy. In liquids that are good refrigerants, such as Freon®, evaporation occurs at a much lower temperature than that of the air inside the refrigerator. When the liquid refrigerant is in a set of pipes near the inside of the refrigerator, energy is transferred by heat from the air to the refrigerant. This exchange causes the air and food to cool.

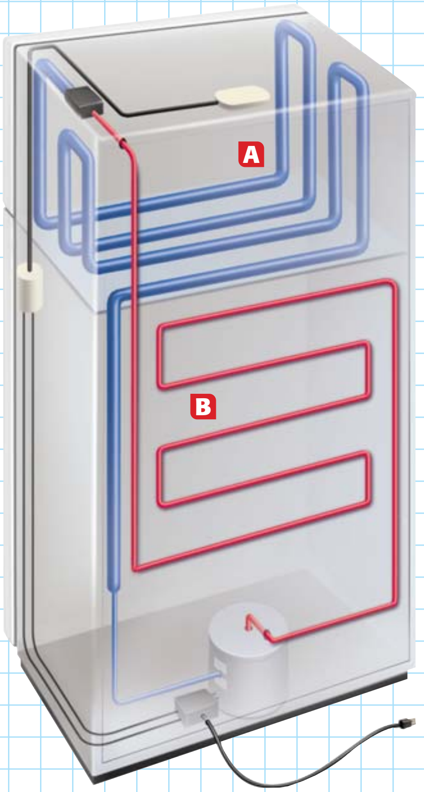
refrigerant a substance used in cooling systems that transfers large amounts of energy as it changes state

INTEGRATING

BIOLOGY

In hot regions, the ears of many mammals serve as cooling systems. Larger ears provide more area for energy to be transferred from blood to the surrounding air, helping the animals to maintain their body temperature. Rabbits and foxes that live in the desert have much longer ears than rabbits and foxes that live in temperate or arctic climates.

Figure 10-18



A Liquid refrigerant flowing through the pipes inside a refrigerator cools the compartment by evaporation.

B Energy is removed by the outside coils as the warmed refrigerant vapor cools and condenses back into a liquid.

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Condensation transfers energy to the surroundings

The refrigerant has become a gas by absorbing energy. This gas moves to the section of coils outside the refrigerator, where electrical energy is used to power a compressor. Pressure is used to condense the refrigerant back into a liquid. Because condensation involves transferring energy from the vapor as heat, the temperature of the air outside the refrigerator increases. This explains why the outside coils stay warm.

Air-conditioning systems in homes and buildings use the same process refrigerators use. As air near the evaporation coils is cooled, a fan blows this air through ducts into the rooms and hallways. Convection currents in the room then allow the cool air to circulate as displaced warmer air flows into return ducts.

Heat pumps can transfer energy to or from rooms

Heat pumps use the evaporation and condensation of a refrigerant to provide heating in the winter and cooling in the summer. A heat pump is a refrigeration unit in which the cooling cycle can be reversed.

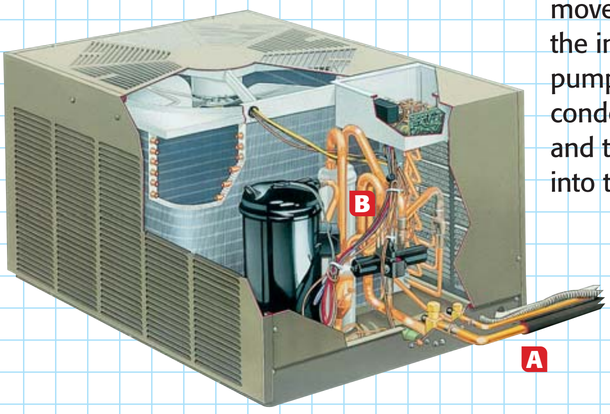
As shown in **Figure 10-19A,** the liquid refrigerant travels through the outdoor coils during the winter and absorbs enough energy from the outside air to evaporate. Work is done on the gas by a compressor, increasing the refrigerant's energy. Then the refrigerant moves through the coils inside the house, as shown in **Figure 10-19B.** The hot gas transfers energy as heat to the air inside the house. This process warms the air while cooling the refrigerant gas enough for it to condense back into a liquid.

In the summer, the refrigerant is pumped in the opposite direction, so that the heat pump functions like a refrigerator or an air conditioner. The liquid refrigerant absorbs energy from the air inside the house as it evaporates. The hot refrigerant gas is then moved to the coils which are outside the house. The refrigerant then condenses, transferring energy as heat to the outside air.

Figure 10-19

A Liquid refrigerant evaporates in the outdoor coils as energy is transferred from the air.

B The hot refrigerant gas moves through the coils into the indoor portion of the pump, where the refrigerant condenses back into a liquid and transfers energy as heat into the room.



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REAL WORLD APPLICATIONS

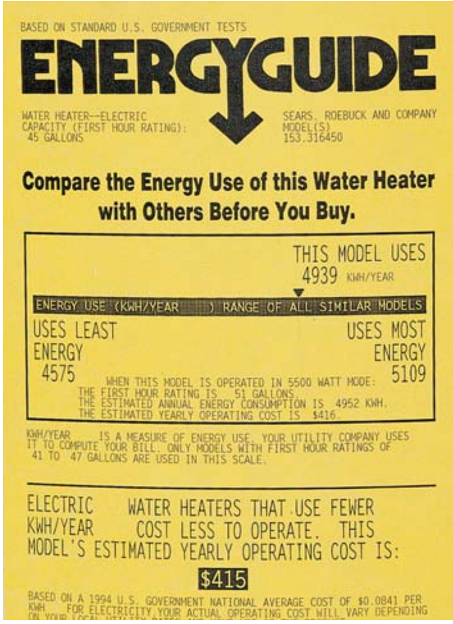
Buying Appliances Most major appliances, including those that involve the transfer of energy as heat, are required by law to have an *Energyguide* label attached to them.

The label indicates the average amount of energy used by the appliance in a year. It also gives the average cost of using the appliance based on a national average of cost per energy unit.

The *Energyguide* label provides consumers a way to compare various brands and models of appliances.

Applying Information

1. Use the *Energyguide* label shown to find how much energy the appliance uses each hour.
2. What is the daily operating cost of the appliance?



SECTION 10.3 REVIEW

SUMMARY

- Heating and cooling systems regulate temperature by transferring energy.
- Usable energy decreases during any process in which energy is transferred.
- The total amount of energy, both usable and unusable, is constant in any process.
- In heating systems, energy is transferred to a fluid, which then transfers its energy to the air in rooms.
- Heating systems use fuel-burning furnaces or sunlight for heating.
- Refrigerators and air conditioners use the evaporation of a refrigerant for cooling.

CHECK YOUR UNDERSTANDING

1. **Explain** how evaporation is a cooling process.
2. **List** one type of home heating system, and describe how it transfers energy to warm the air inside the rooms.
3. **Describe** how energy changes from a usable form to a less usable form in a building's heating system.
4. **Compare** the advantages and disadvantages of using a solar heating system in your geographical area.
5. **Critical Thinking** Water has a high specific heat, meaning it takes a good deal of energy to raise its temperature. For this reason, the cost of heating water is a large part of a monthly household energy bill. Describe two ways the people in your household could change their routines, without sacrificing results, in order to save money by using less hot water.
6. **Create** a spreadsheet to calculate the rate of energy transfer for each of the substances listed in **Table 10-2.** This rate can be determined using the following equation.

$$\textit{rate of energy transfer} = \frac{(\textit{area}) \times (\textit{temp. diff.})}{(\textit{R-value})}$$

COMPUTER SKILL

Assume an area of 1.0 m^2 and a temperature difference of 20.0°C.

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CHAPTER 10 REVIEW

Chapter Highlights

Before you begin, review the summaries of the key ideas of each section, found on pages 330, 338, and 346. The key vocabulary terms are listed on pages 324, 331, and 339.

UNDERSTANDING CONCEPTS

1. Temperature is proportional to the average kinetic energy of particles in an object. Thus an increase in temperature results in a(n) ________.

a. increase in mass
b. decrease in average kinetic energy
c. increase in average kinetic energy
d. decrease in mass

2. As measured on the Celsius scale, the temperature at which ice melts is __________.

a. –273°C **c.** 32°C
b. 0°C **d.** 100°C

3. As measured on the Fahrenheit scale, the temperature at which water boils is __________.

a. 32°F **c.** 100°F
b. 212°F **d.** 451°F

4. The temperature at which the particles of a substance have no more kinetic energy to transfer is __________.

a. –273 K **c.** 0°C
b. 0 K **d.** 273 K

5. Which kind of energy transfer can occur in empty space?

a. convection **c.** conduction
b. contraction **d.** radiation

6. Campfires transfer energy as heat to their surroundings by methods of __________.

a. convection and conduction
b. convection and radiation
c. conduction and radiation
d. convection, conduction, and radiation

7. The amount of energy required to raise the temperature of 1 kg of a substance by 1 K is determined by its __________.

a. *R*-value
b. usable energy
c. specific heat
d. convection current

8. The amount of usable energy decreases when __________.

a. systems are used only for heating
b. systems are used only for cooling
c. systems are used for heating or cooling
d. the heating or cooling system is poorly designed

9. A refrigerant in a cooling system cools the surrounding air __________.

a. as it evaporates
b. as it condenses
c. both as it evaporates and as it condenses
d. when it neither evaporates nor condenses

10. Solar heating systems are classified as __________.

a. positive and negative
b. active and passive
c. AC and DC
d. active and indirect

Using Vocabulary

11. Why is it incorrect to say that an object contains *heat*?

12. Use the concepts of average particle kinetic energy, *temperature,* and *absolute zero* to predict whether an object at 0°C or an object at 0 K will transfer more energy as heat to its surroundings.

13. How would a *thermometer* that measures temperatures using the Kelvin scale differ from one that measures temperatures using the Celsius scale?

14. Explain how water can transfer energy by *conduction* and by *convection.*

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CHAPTER 10 REVIEW

15. Explain how *convection currents* form up-drafts near tall mountain ranges along deserts, as shown in the figure below.

16. Use the differences between a *conductor* and an *insulator* and the concept of *specific heat* to explain whether you would rather drink a hot beverage from a metal cup or from a china cup.

17. If you wear dark clothing on a sunny day, the clothing will become hot after a while. Use the concept of *radiation* to explain this.

18. Explain why ammonia, which has a boiling point of –33.4°C, is sometimes used as a *refrigerant* in a *cooling system*. Why would ammonia be less effective in a *heating system*?

BUILDING MATH SKILLS

19. Temperature Scale Conversion A piece of dry ice, solid CO_2, has a temperature of –100.°C. What is its temperature in kelvins and in degrees Fahrenheit?

20. Temperature Scale Conversion The temperature in deep space is thought to be around 3 K. What is 3 K in degrees Celsius? in degrees Fahrenheit?

21. Specific Heat How much energy is needed to raise the temperature of a silver necklace chain with a mass of 22.5 g from room temperature, 25°C, to body temperature, 37°C? (**Hint:** Refer to **Table 10-1** on p. 336)

22. Specific Heat How much energy would be absorbed by 550 g of copper when it is heated from 24°C to 45°C? (**Hint:** Refer to **Table 10-1** on p. 336.)

THINKING CRITICALLY

23. Interpreting Graphics Graph the Celsius-Fahrenheit conversion equation, plotting Celsius temperature along the *x*-axis and Fahrenheit temperature on the *y*-axis. Use an *x*-axis range from –100°C to 100°C, then use the graph to find the following values:

a. the Fahrenheit temperature equal to 77°C

b. the Fahrenheit temperature equal to –40°C

c. the Celsius temperature equal to 23°F

d. the Celsius temperature equal to –17°F

24. Applying Knowledge If two objects that have the same temperature come into contact with each other, what can you say about the amount of energy that will be transferred between them as heat?

25. Applying Knowledge If two objects that have different temperatures come into contact with each other, what can you say about their temperatures after several minutes of contact?

26. Creative Thinking Why does a metal doorknob feel cooler to your hand than a carpet feels to your bare feet?

27. Creative Thinking Why do the metal shades of desk lamps have small holes at the top?

28. Creative Thinking Why does the temperature of hot chocolate decrease faster if you place a metal spoon in the liquid?

29. Creative Thinking If you bite into a piece of hot apple pie, the pie filling might burn your mouth while the crust, at the same temperature, will not. Explain why.

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30. Applying Technology Glass can conduct some energy. Double-pane windows consist of two plates of glass separated by a small layer of insulating air. Explain why a double-pane window prevents more energy from escaping your house than a single-pane window.

31. Understanding Systems Explain why window unit air conditioners always have the back part of the air conditioner hanging outside. Why is it that the entire air-conditioner cannot be in the room?

32. Making Decisions If the only factor considered were specific heat, which would make a better coolant for automobile engines: water or ethanol? Explain your answer.

DEVELOPING LIFE/WORK SKILLS

33. Allocating Resources In one southern state the projected yearly costs for heating a home were $463 using a heat pump, $508 using a natural-gas furnace, and $1220 using electric radiators. Contact your local utility company to determine the projected costs for the three different systems in your area. Make a table comparing the costs of the three systems.

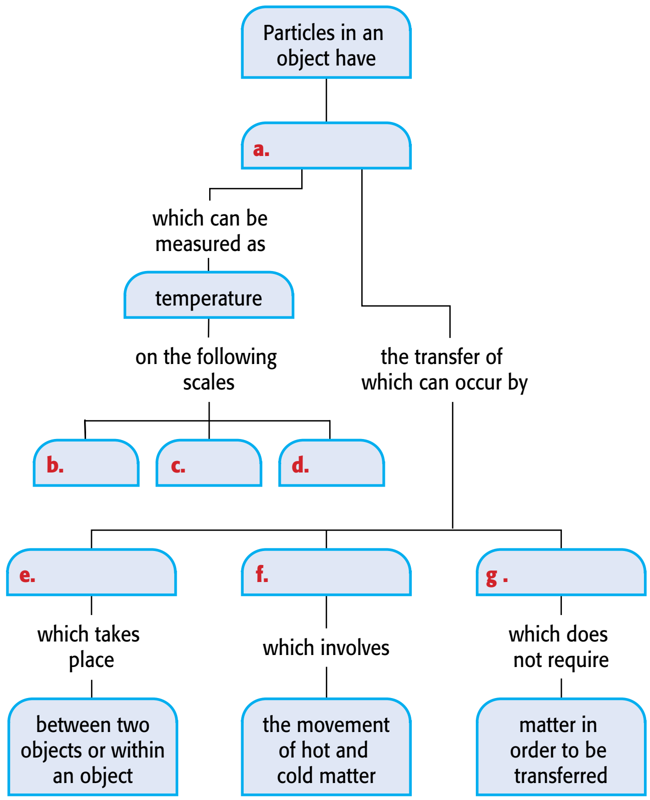
34. Working Cooperatively Read the following statements, and discuss with a group of classmates which statement is correct. Explain your answer.

a. Energy is lost when water is boiled.

b. The energy used to boil water is still present, but it is no longer in a usable form unless you use work or heat to make it usable.

INTEGRATING CONCEPTS

35. Concept Mapping Copy the unfinished concept map below onto a sheet of paper. Complete the map by writing the correct word or phrase in the lettered boxes.



36. Connection to Social Studies WRITING SKILL

Research the work of Benjamin Thompson, also known as Count Rumford. What was the prevailing theory of heat during Thompson's time? What observations led to Thompson's theory?

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Design Your Own Lab

Investigating Conduction of Heat

Introduction

How can you determine whether the thickness of a metal wire affects its ability to conduct energy as heat?

Objectives

- ***Develop*** a plan to measure how quickly energy is transferred as heat through a metal wire.
- ***Compare*** the speed of heat conduction in metal wires of different thicknesses.

Materials

3 metal wires of different thicknesses, each about 30 cm long
clothespin
candle
lighter or matches
candle holder
metric ruler
stopwatch

Safety Needs

goggles
apron

▶ Demonstrating Conduction in Wires

1. Obtain three wires of different thicknesses. Clip a clothespin on one end of one of the wires. Lay the wire and attached clothespin on the lab table.
2. Light the candle and place it in the holder. **SAFETY CAUTION** Tie back long hair and confine loose clothing. Never reach across an open flame. Always use the clothespin to hold the wire as you heat it and move it to avoid burning yourself. Remember that the wires will be hot for some time after they are removed from the flame.
3. Hold the lighted candle in its holder above the middle of the wire, and tilt the candle slightly so that some of the melted wax drips onto the middle of the wire.
4. Wait a couple of minutes for the wire and dripped wax to cool completely. The dripped wax will harden and form a small ball. Using the clothespin to hold the wire, place the other end of the wire in the candle's flame. When the ball of wax melts, remove the wire from the flame, and place it on the lab table. Think about what caused the wax on the wire to melt.

▶ Designing Your Experiment

5. With your lab partner(s), decide how you will use the materials available in the lab to compare the speed of conduction in three wires of different thicknesses. Form a hypothesis about whether a thick wire will conduct energy more quickly or more slowly than a thin wire.
6. In your lab report, list each step you will perform in your experiment.
7. Have your teacher approve your plan before you carry out your experiment.

Performing Your Experiment

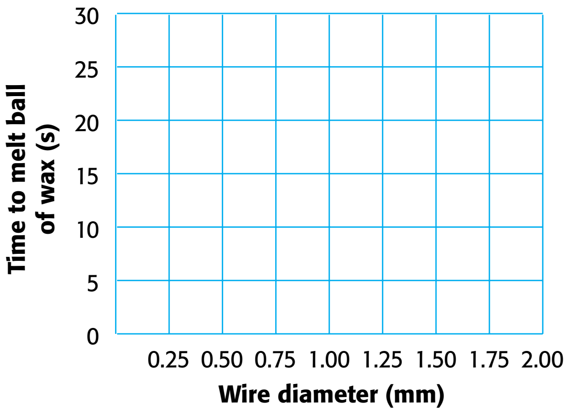
8. After your teacher approves your plan, you can carry out your experiment.
9. Prepare a data table in your lab report that is similar to the one shown below.
10. Record in your table how many seconds it takes for the ball of wax on each wire to melt. Perform three trials for each wire, allowing the wires to cool to room temperature between trials.

Conductivity Data

	Wire diameter (mm)	Time to melt wax (s)			
		Trial 1	Trial 2	Trial 3	Average time
Wire 1					
Wire 2					
Wire 3					

Analyzing Your Results

1. Find the diameter of each wire you tested. If the diameter is listed in inches, convert it to millimeters by multiplying by 25.4. If the diameter is listed in mils, convert it to millimeters by multiplying by 0.0254. In your data table, record the diameter of each wire in millimeters.
2. Calculate the average time required to melt the ball of wax for each wire. Record your answers in your data table.
3. Plot your data in your lab report in the form of a graph like the one shown. On your graph, draw the line or smooth curve that fits the points best.
4. **Reaching Conclusions** Based on your graph, does a thick wire or a thin wire conduct energy more quickly?
5. When roasting a large cut of meat, some cooks insert a metal skewer into the meat to make the inside cook more quickly. If you were roasting meat, would you insert a thick skewer or a thin skewer? Why?



Defending Your Conclusions

6. Suppose someone tells you that your conclusion is valid only for the particular metal you tested. How could you show that your conclusion is valid for other metals as well?