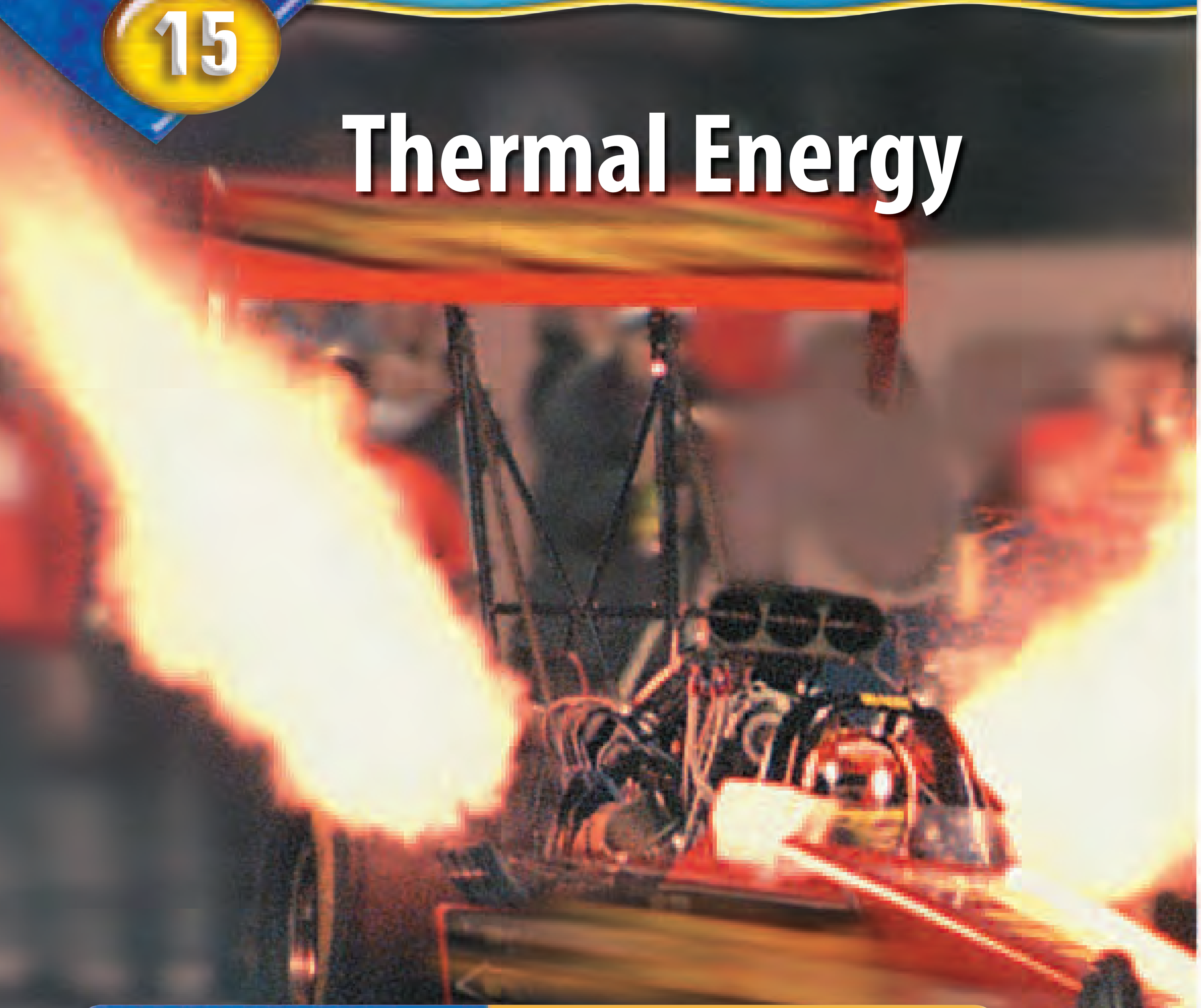
chapter 15

6-5.5 Illustrate the directional transfer of heat energy through convection, radiation, and conduction. **Also covers:** 6-1.1, 6-1.2, 6-1.5

Thermal Energy



chapter preview

sections

1 Temperature and Thermal Energy

2 Heat

Lab Heating Up and Cooling Down

3 Engines and Refrigerators

Lab Comparing Thermal Insulators

Virtual Lab How do the insulation properties of various materials compare?

Fastest to the Finish Line

In order to reach an extraordinary speed in a short distance, this dragster depends on more than an aerodynamic design. Its engine must transform the thermal energy produced by burning fuel to mechanical energy, which propels the dragster down the track.

Science Journal Describe five things that you do to make yourself feel warmer or cooler.

Peter Walton/Index Stock

Start-Up Activities

Launch LAB

Measuring Temperature

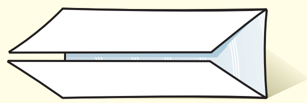
When you leave a glass of ice water on a kitchen table, the ice gradually melts and the temperature of the water increases. What is temperature, and why does the temperature of the ice water increase? In this lab you will explore one way of determining temperature.

1. Obtain three pans. Fill one pan with lukewarm water. Fill a second pan with cold water and crushed ice. Fill a third pan with very warm tap water. Label each pan.
2. Soak one of your hands in the warm water for one minute. Remove your hand from the warm water and put it in the lukewarm water. Does the lukewarm water feel cool or warm?
3. Now soak your hand in the cold water for one minute. Remove your hand from the cold water and place it in the lukewarm water. Does the lukewarm water feel cool or warm?
4. **Think Critically** Write a paragraph in your Science Journal discussing whether your sense of touch would make a useful thermometer.

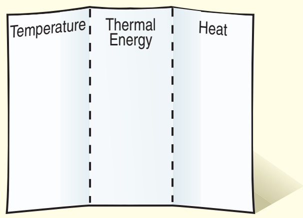
FOLDABLES™ Study Organizer

Thermal Energy Make the following Foldable to help you identify how thermal energy, heat, and temperature are related.

STEP 1 **Fold** a vertical piece of paper into thirds.



STEP 2 **Turn** the paper horizontally. **Unfold and label** the three columns as shown.



Read for Main Ideas Before you read the chapter, write down what you know about temperature, thermal energy, and heat on the appropriate tab. As you read, add to and correct what you wrote. Write what you have learned about the relationship between heat and thermal energy on the back of your Foldable.

Science Online

Preview this chapter's content and activities at glencoe.com

Peter Walton/Index Stock

section 1

Temperature and Thermal Energy

as you read

What You'll Learn

- **Explain** how temperature is related to kinetic energy.
- **Describe** three scales used for measuring temperature.
- **Define** thermal energy.

Why It's Important

The movement of thermal energy toward or away from your body determines whether you feel too cold, too hot, or just right.

Review Vocabulary

kinetic energy: energy a moving object has that increases as the speed of the object increases

New Vocabulary

- temperature
- thermal energy

What is temperature?

Imagine it's a hot day and you jump into a swimming pool to cool off. When you first hit the water, you might think it feels cold. Perhaps someone else, who has been swimming for a few minutes, thinks the water feels warm. When you swim in water, touch a hot pan, or swallow a cold drink, your sense of touch tells you whether something is hot or cold. However, the words *cold*, *warm*, and *hot* can mean different things to different people.

Temperature How hot or cold something feels is related to its temperature. To understand temperature, think of a glass of water sitting on a table. The water might seem perfectly still, but water is made of molecules that are in constant, random motion. Because these molecules are always moving, they have energy of motion, or kinetic energy.

However, water molecules in random motion don't all move at the same speed. Some are moving faster and some are moving slower. **Temperature** is a measure of the average value of the kinetic energy of the molecules in random motion. The more kinetic energy the molecules have, the higher the temperature. Molecules have more kinetic energy when they are moving faster. So the higher the temperature, the faster the molecules are moving, as shown in **Figure 1.**

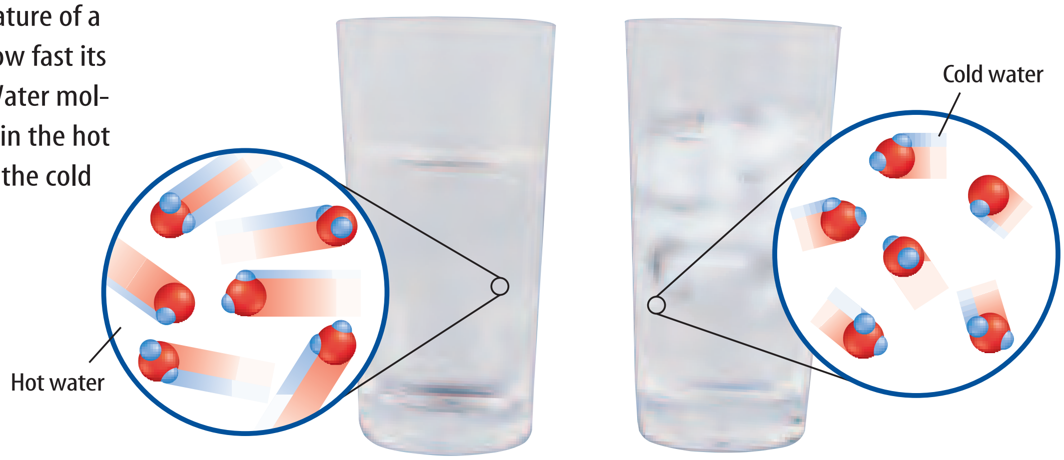


Figure 1 The temperature of a substance depends on how fast its molecules are moving. Water molecules are moving faster in the hot water on the left than in the cold water on the right.

John Evans

Thermal Expansion It wasn't an earthquake that caused the sidewalk to buckle in **Figure 2.** Hot weather caused the concrete to expand so much that it cracked, and the pieces squeezed each other upward. When the temperature of an object is increased, its molecules speed up and tend to move farther apart. This causes the object to expand. When the object is cooled, its molecules slow down and move closer together. This causes the object to shrink, or contract.

Almost all substances expand when they are heated and contract when they are cooled. The amount of expansion or contraction depends on the type of material and the change in temperature. For example, liquids usually expand more than solids. Also, the greater the change in temperature, the more an object expands or contracts.

Figure 2 Most objects expand as their temperatures increase. Pieces of this concrete sidewalk forced each other upward when the concrete expanded on a hot day.

Reading Check *Why do materials expand when their temperatures increase?*

Measuring Temperature

The temperature of an object depends on the average kinetic energy of all the molecules in an object. However, molecules are so small and objects contain so many of them, that it is impossible to measure the kinetic energy of all the individual molecules.

A more practical way to measure temperature is to use a thermometer. Thermometers usually use the expansion and contraction of materials to measure temperature. One common type of thermometer uses a glass tube containing a liquid. When the temperature of the liquid increases, it expands so that the height of the liquid in the tube depends on the temperature.

Temperature Scales To be able to give a number for the temperature, a thermometer has to have a temperature scale. Two common temperature scales are the Fahrenheit and Celsius scales, shown in **Figure 3.**

On the Fahrenheit scale, the freezing point of water is given the temperature 32°F and the boiling point 212°F. The space between the boiling point and the freezing point is divided into 180 equal degrees. The Fahrenheit scale is used mainly in the United States.

On the Celsius temperature scale, the freezing point of water is given the temperature 0°C and the boiling point is given the temperature 100°C. Because there are only 100 Celsius degrees between the boiling and freezing point of water, Celsius degrees are bigger than Fahrenheit degrees.

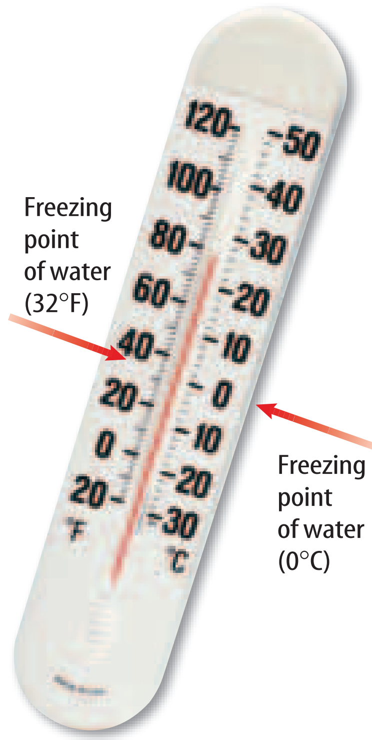


Figure 3 The Fahrenheit and Celsius scales are commonly used temperature scales.

(t)Nancy P. Alexander/Visuals Unlimited, (b)Morton & White

Converting Fahrenheit and Celsius You can convert temperatures back and forth between the two temperature scales by using the following equations.

Temperature Conversion Equations

To convert temperature in °F to °C: $°C = (\frac{5}{9})(°F - 32)$

To convert temperature in °C to °F: $°F = (\frac{9}{5})(°C) + 32$

For example, to convert 68°F to degrees Celsius, first subtract 32, multiply by 5, then divide by 9. The result is 20°C.

The Kelvin Scale Another temperature scale that is sometimes used is the Kelvin scale. On this scale, 0 K is the lowest temperature an object can have. This temperature is known as absolute zero. The size of a degree on the Kelvin scale is the same as on the Celsius scale. You can change from Celsius degrees to Kelvin degrees by adding 273 to the Celsius temperature.

$$K = °C + 273$$

Applying Math — Solving a Simple Equation

CONVERTING TO CELSIUS On a hot summer day, a Fahrenheit thermometer shows the temperature to be 86°F. What is this temperature on the Celsius scale?

Solution

1 *This is what you know:*	Fahrenheit temperature: °F = 86
2 *This is what you need to find:*	Celsius temperature: °C
3 *This is the procedure you need to use:*	Substitute the Fahrenheit temperature into the equation that converts temperature in °F to °C. $°C = (\frac{5}{9})(°F - 32) = \frac{5}{9}(86 - 32) = \frac{5}{9}(54) = 30°C$
4 *Check the answer:*	Add 32 to your answer and multiply by 9/5. The result should be the given Fahrenheit temperature.

Practice Problems

1. A student's body temperature is 98.6°F. What is this temperature on the Celsius scale?
2. A temperature of 57°C was recorded in 1913 at Death Valley, California. What is this temperature on the Fahrenheit scale?

Science Online — For more practice visit glencoe.com

Thermal Energy

The temperature of an object is related to the average kinetic energy of molecules in random motion. But molecules also have potential energy. Potential energy is energy that the molecules have that can be converted into kinetic energy. The sum of the kinetic and potential energy of all the molecules in an object is the **thermal energy** of the object.

The Potential Energy of Molecules When you hold a ball above the ground, it has potential energy. When you drop the ball, its potential energy is converted into kinetic energy as the ball falls toward Earth. It is the attractive force of gravity between Earth and the ball that gives the ball potential energy.

The molecules in a material also exert attractive forces on each other. As a result, the molecules in a material have potential energy. As the molecules get closer together or farther apart, their potential energy changes.

Increasing Thermal Energy Temperature and thermal energy are different. Suppose you have two glasses filled with the same amount of milk, and at the same temperature. If you pour both glasses of milk into a pitcher, as shown in **Figure 4,** the temperature of the milk won't change. However, because there are more molecules of milk in the pitcher than in either glass, the thermal energy of the milk in the pitcher is greater than the thermal energy of the milk in either glass.

Figure 4 At the same temperature, the larger volume of milk in the pitcher has more thermal energy than the smaller volumes of milk in either glass.

section 1 review

Summary

Temperature

- Temperature is related to the average kinetic energy of the molecules an object contains.
- Most materials expand when their temperatures increase.

Measuring Temperature

- On the Celsius scale the freezing point of water is 0°C and the boiling point is 100°C.
- On the Fahrenheit scale the freezing point of water is 32°F and the boiling point is 212°F.

Thermal Energy

- The thermal energy of an object is the sum of the kinetic and potential energy of all the molecules in an object.

Self Check

1. **Explain** the difference between temperature and thermal energy. How are they related?
2. **Determine** which temperature is always larger—an object's Celsius temperature or its Kelvin temperature.
3. **Explain** how kinetic energy and thermal energy are related.
4. **Describe** how a thermometer uses the thermal expansion of a material to measure temperature.

Applying Math

5. **Convert Temperatures** A turkey cooking in an oven will be ready when the internal temperature reaches 180°F. Convert this temperature to °C and K.

section 2

Heat

as you read

What You'll Learn

- **Explain** the difference between thermal energy and heat.
- **Describe** three ways heat is transferred.
- **Identify** materials that are insulators or conductors.

Why It's Important

To keep you comfortable, the flow of heat into and out of your house must be controlled.

Review Vocabulary

electromagnetic wave: a wave produced by vibrating electric charges that can travel in matter and empty space

New Vocabulary

- heat
- conduction
- radiation
- convection
- conductor
- specific heat
- thermal pollution

Heat and Thermal Energy

It's the heat of the day. Heat the oven to 375°F. A heat wave has hit the Midwest. You've often heard the word *heat,* but what is it? Is it something you can see? Can an object have heat? Is heat anything like thermal energy? **Heat** is thermal energy that is transferred from one object to another when the objects are at different temperatures. The amount of heat that is transferred when two objects are brought into contact depends on the difference in temperature between the objects.

For example, no heat is transferred when two pots of boiling water are touching, because the water in both pots is at the same temperature. However, heat is transferred from the pot of hot water in **Figure 5** that is touching a pot of cold water. The hot water cools down and the cold water gets hotter. Heat continues to be transferred until both objects are the same temperature.

Transfer of Heat When heat is transferred, thermal energy always moves from warmer to cooler objects. Heat never flows from a cooler object to a warmer object. The warmer object loses thermal energy and becomes cooler as the cooler object gains thermal energy and becomes warmer. This process of heat transfer can occur in three ways—by conduction, radiation, or convection.

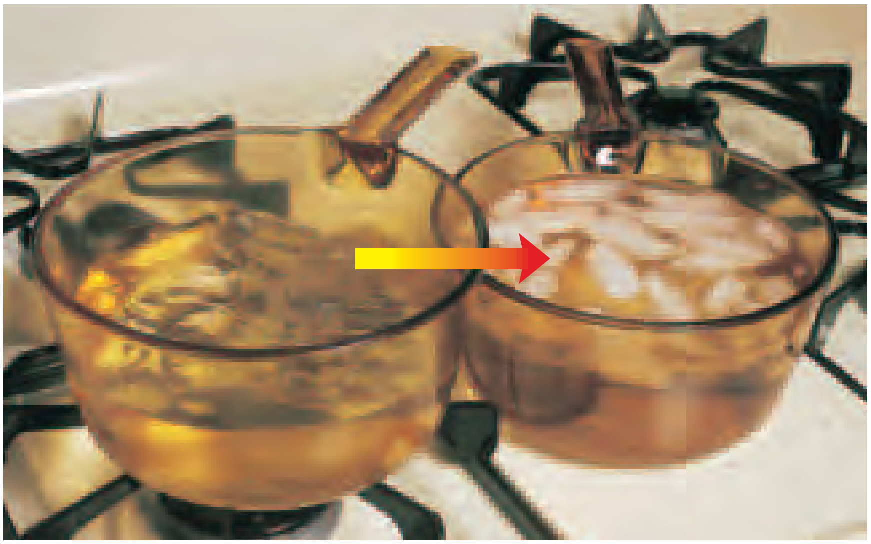


Figure 5 Heat is transferred only when two objects are at different temperatures. Heat always moves from the warmer object to the cooler object.

Doug Martin

Conduction

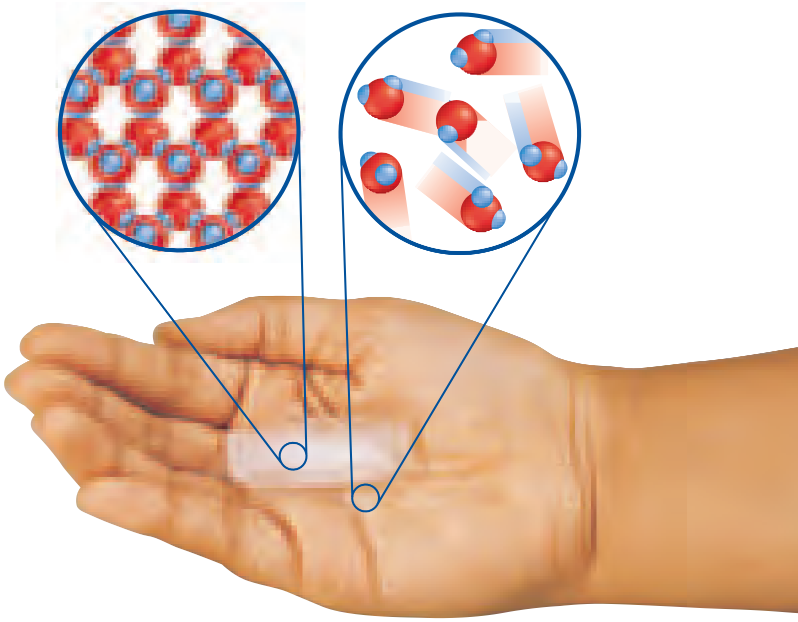


Figure 6 An ice cube in your hand melts because of conduction. The solid ice melts, becoming liquid water. Molecules in the water move faster than molecules in the ice.
Explain *how the thermal energy of the ice cube changes.*

When you eat hot pizza, you experience conduction. As the hot pizza touches your mouth, heat moves from the pizza to your mouth. This transfer of heat by direct contact is called conduction. **Conduction** occurs when the particles in a material collide with neighboring particles.

Imagine holding an ice cube in your hand, as in **Figure 6.** The faster-moving molecules in your warm hand bump against the slower-moving molecules in the cold ice. In these collisions, energy is passed from molecule to molecule. Heat flows from your warmer hand to the colder ice, and the slow-moving molecules in the ice move faster. As a result, the ice becomes warmer and its temperature increases. Molecules in your hand move more slowly as they lose thermal energy, and your hand becomes cooler.

Conduction usually occurs most easily in solids and liquids, where atoms and molecules are close together. Then atoms and molecules need to move only a short distance before they bump into one another and transfer energy. As a result, heat is transferred more rapidly by conduction in solids and liquids than in gases.

Reading Check ***Why does conduction occur more easily in solids and liquids than in gases?***

Radiation

On a beautiful, clear day, you walk outside and notice the warmth of the Sun. You know that the Sun heats Earth, but how does this transfer of thermal energy occur? Heat transfer does not occur by conduction because almost no matter exists between the Sun and Earth. Instead, heat is transferred from the Sun to Earth by radiation. Heat transfer by **radiation** occurs when energy is transferred by electromagnetic waves. These waves carry energy through empty space, as well as through matter. The transfer of thermal energy by radiation can occur in empty space, as well as in solids, liquids, and gases.

The Sun is not the only source of radiation. All objects emit electromagnetic radiation, although warm objects emit more radiation than cool objects. The warmth you feel when you sit next to a fireplace is due to heat transferred by radiation from the fire to your skin.

Mini LAB

Comparing Rates of Melting

Procedure

1. Prepare ice water by filling a **glass** with ice and then adding water. Let the glass sit until all the ice melts.
2. Place an ice cube in a **coffee cup.**
3. Place a similar-sized ice cube in another **coffee cup** and add ice water to a depth of about 1 cm.
4. Time how long it takes both ice cubes to melt.

Analysis

1. Which ice cube melted fastest? Why?
2. Is air or water a better insulator? Explain.

Try at Home

Convection

When you heat a pot of water on a stove, heat can be transferred through the water by a process other than conduction and radiation. In a gas or liquid, molecules can move much more easily than they can in a solid. As a result, the more energetic molecules can travel from one place to another, and carry their energy along with them. This transfer of thermal energy by the movement of molecules from one part of a material to another is called **convection.**

Transferring Heat by Convection As a pot of water is heated, heat is transferred by convection. First, thermal energy is transferred to the water molecules at the bottom of the pot from the stove. These water molecules move faster as their thermal energy increases. The faster-moving molecules tend to be farther apart than the slower-moving molecules in the cooler water above. Because the molecules are farther apart in the warm water, this water is less dense than the cooler water. As a result, the warm water rises and is replaced at the bottom of the pot by cooler water. The cooler water is heated, rises, and the cycle is repeated until all the water in the pan is at the same temperature.

Natural Convection Natural convection occurs when a warmer, less dense fluid is pushed away by a cooler, denser fluid. For example, imagine the shore of a lake. During the day, the water is cooler than the land. As shown in **Figure 7,** air above the warm land is heated by conduction. When the air gets hotter, its particles move faster and get farther from each other, making the air less dense. The cooler, denser air from over the lake flows in over the land, pushing the less dense air upward. You feel this movement of incoming cool air as wind. The cooler air then is heated by the land and also begins to rise.

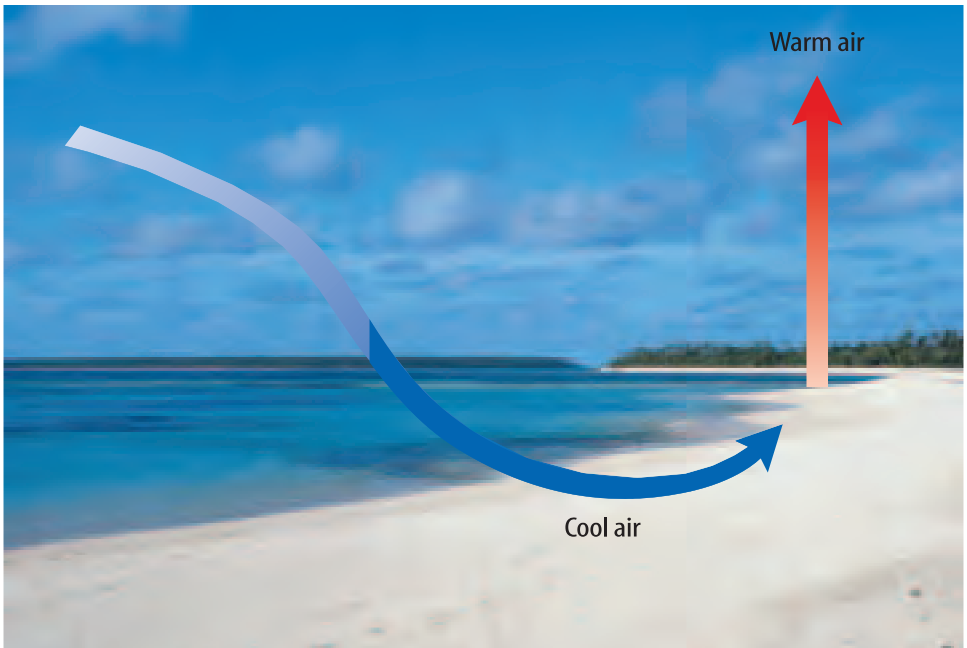


Figure 7 Wind movement near a lake or ocean can result from natural convection. Air is heated by the land and becomes less dense. Denser cool air rushes in, pushing the warm air up. The cooler air then is heated by the land and the cycle is repeated.

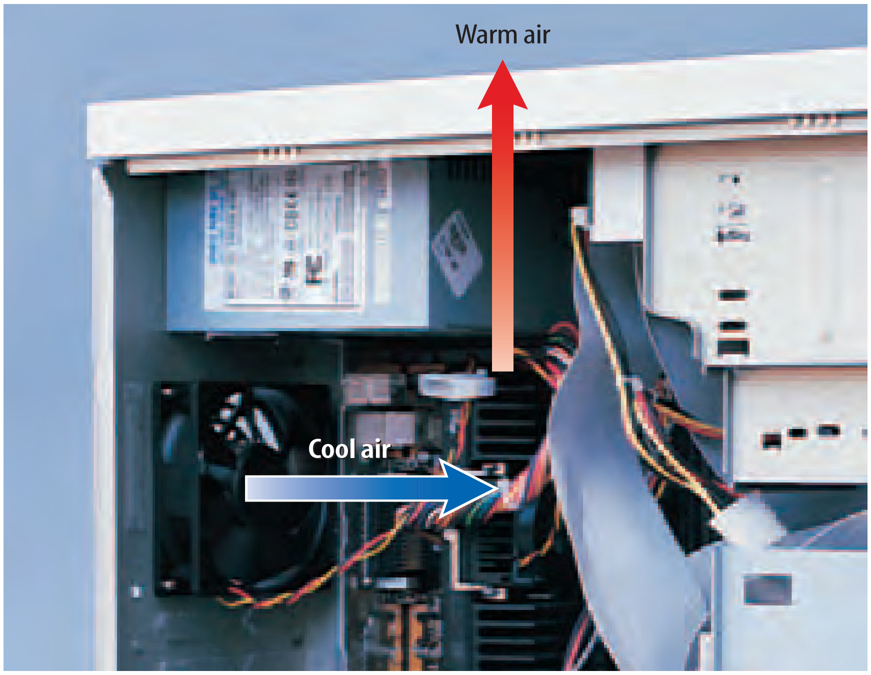


Figure 8 This computer uses forced convection to keep the electronic components surrounded by cooler air.
Identify *another example of forced convection.*

Forced Convection Sometimes convection can be forced. Forced convection occurs when an outside force pushes a fluid, such as air or water, to make it move and transfer heat. A fan is one type of device that is used to move air. For example, computers use fans to keep their electronic components from getting too hot, which can damage them. The fan blows cool air onto the hot electronic components, as shown in **Figure 8.** Heat from the electronic components is transferred to the air around them by conduction. The warm air is pushed away as cool air rushes in. The hot components then continue to lose heat as the fan blows cool air over them.

Thermal Conductors

Why are cooking pans usually made of metal? Why does the handle of a metal spoon in a bowl of hot soup become warm? The answer to both questions is that metal is a good conductor. A **conductor** is any material that easily transfers heat. Some materials are good conductors because of the types of atoms or chemical compounds they are made up of.

Reading Check *What is a conductor?*

Remember that an atom has a nucleus surrounded by one or more electrons. Certain materials, such as metals, have some electrons that are not held tightly by the nucleus and are freer to move around. These loosely held electrons can bump into other atoms and help transfer thermal energy. The best conductors of heat are metals such as gold and copper.

Mini LAB

Observing Convection

Procedure

1. Fill a **250-mL beaker** with room-temperature **water** and let it stand undisturbed for at least 1 min.
2. Using a **hot plate,** heat a small amount of water in a **50-mL beaker** until it is almost boiling.
   WARNING: *Do not touch the heated hot plate.*
3. Carefully drop a **penny** into the hot water and let it stand for about 1 min.
4. Take the penny out of the hot water with **metal tongs** and place it on a table. Immediately place the 250-mL beaker on the penny.
5. Using a **dropper,** gently place one drop of **food coloring** on the bottom of the 250-mL beaker of water.
6. Observe what happens in the beaker for several minutes.

Analysis

What happened when you placed the food coloring in the 250-mL beaker? Why?

INTEGRATE Life Science

Animal Insulation
To survive in its arctic environment, a polar bear needs good insulation against the cold. Underneath its fur, a polar bear has 10 cm of insulating blubber. Research how animals in polar regions are able to keep themselves warm. Summarize the different ways in your Science Journal.

Thermal Insulators

If you're cooking food, you want the pan to conduct heat easily from the stove to your food, but you do not want the heat to move easily to the handle of the pan. An insulator is a material in which heat doesn't flow easily. Most pans have handles that are made from insulators. Liquids and gases are usually better insulators than solids are. Air is a good insulator, and many insulating materials contain air spaces that reduce the transfer of heat by conduction within the material. Materials that are good conductors, such as metals, are poor insulators, and poor conductors are good insulators.

Houses and buildings are made with insulating materials to reduce heat conduction between the inside and outside. Fluffy insulation like that shown in **Figure 9** is put in the walls. Some windows have double layers of glass that sandwich a layer of air or other insulating gas. This reduces the outward flow of heat in the winter and the inward flow of heat in the summer.

Heat Absorption

On a hot day, you can walk barefoot across the lawn, but the asphalt pavement of a street is too hot to walk on. Why is the pavement hotter than the grass? The change in temperature of an object as it absorbs heat depends on the material it is made of.

Figure 9 The insulation in houses and buildings helps reduce the transfer of heat between the air inside and air outside.

Specific Heat The amount of heat needed to change the temperature of a substance is related to its specific heat. The **specific heat** of a substance is the amount of heat needed to raise the temperature of 1 kg of that substance by 1°C.

More heat is needed to change the temperature of a material with a high specific heat than one with a low specific heat. For example, the sand on a beach has a lower specific heat than water. When you're at the beach during the day, the sand feels much warmer than the water does. Radiation from the Sun warms the sand and the water. Because of its lower specific heat, the sand heats up faster than the water. At night, however, the sand feels cool and the water feels warmer. The temperature of the water changes more slowly than the temperature of the sand as they both lose thermal energy to the cooler night air.

Thermal Pollution

INTEGRATE Life Science

Some electric power plants and factories that use water for cooling produce hot water as a by-product. If this hot water is released into an ocean, lake, or river, it will raise the temperature of the water nearby. This increase in the temperature of a body of water caused by adding warmer water is called **thermal pollution.** Rainwater that is heated after it falls on warm roads or parking lots also can cause thermal pollution if it runs off into a river or lake.

Effects of Thermal Pollution Increasing the water temperature causes fish and other aquatic organisms to use more oxygen. Because warmer water contains less dissolved oxygen than cooler water, some organisms can die due to a lack of oxygen. Also, in warmer water, many organisms become more sensitive to chemical pollutants, parasites, and diseases.

Reducing Thermal Pollution Thermal pollution can be reduced by cooling the warm water produced by factories, power plants, and runoff before it is released into a body of water. Cooling towers like the ones shown in **Figure 10** are used to cool the water used by some power plants and factories.

Figure 10 This power plant uses cooling towers to cool the warm water produced by the power plant.

section 2 review

Summary

Heat and Thermal Energy

- Heat is the transfer of thermal energy due to a temperature difference.
- Heat always moves from a higher temperature to a lower temperature.

Conduction, Radiation, and Convection

- Conduction is the transfer of thermal energy when substances are in direct contact.
- Radiation is the transfer of thermal energy by electromagnetic waves.
- Convection is the transfer of thermal energy by the movement of matter.

Thermal Conductors and Specific Heat

- A thermal conductor is a material in which heat moves easily.
- The specific heat of a substance is the amount of heat needed to raise the temperature of 1 kg of the substance by 1°C.

Self Check

1. **Explain** why materials such as plastic foam, feathers, and fur are poor conductors of heat.
2. **Explain** why the sand on a beach cools down at night more quickly than the ocean water.
3. **Infer** If a substance can contain thermal energy, can a substance also contain heat?
4. **Describe** how heat is transferred from one place to another by convection.
5. **Explain** why a blanket keeps you warm.
6. **Think Critically** In order to heat a room evenly, should heating vents be placed near the floor or near the ceiling of the room? Explain.

Applying Skills

7. **Design an Experiment** to determine whether wood or iron is a better thermal conductor. Identify the dependent and independent variables in your experiment.

More Section Review glencoe.com

LAB

Heating Up and Cooling Down

Do you remember how long it took for a cup of hot chocolate to cool before you could take a sip? The hotter the chocolate, the longer it seemed to take to cool.

Real-World Question

How does the temperature of a liquid affect how quickly it warms or cools?

Goals

- Measure the temperature change of water at different temperatures.
- Infer how the rate of heating or cooling depends on the initial water temperature.

Materials

thermometers (5)
400-mL beakers (5)
stopwatch
**watch with second hand*
hot plate
**Alternate materials*

Safety Precautions

WARNING: *Do not use mercury thermometers. Use caution when heating with a hot plate. Hot and cold glass appears the same.*

Procedure

1. Make a data table to record the temperature of water in five beakers every minute from 0 to 10 min.
2. Fill one beaker with 100 mL of water. Place the beaker on a hot plate and bring the water to a boil. Carefully remove the hot beaker from the hot plate.

3. Record the water temperature at minute 0, and then every minute for 10 min.
4. Repeat step 3 starting with hot tap water, cold tap water, refrigerated water, and ice water with the ice removed.

Conclude and Apply

1. **Graph** your data. **Plot and label** lines for all five beakers on one graph.
2. **Calculate** the rate of heating or cooling for the water in each beaker by subtracting the initial temperature of the water from the final temperature and then dividing this answer by 10 min.
3. **Infer** from your results how the difference between room temperature and the initial temperature of the water affected the rate at which it heated up or cooled down.

Communicating Your Data

Share your data and graphs with other classmates and explain any differences among your data.

Aaron Haupt

section 3

Engines and Refrigerators

Heat Engines

The engines used in cars, motorcycles, trucks, and other vehicles, like the one shown in **Figure 11,** are heat engines. A **heat engine** is a device that converts thermal energy into mechanical energy. Mechanical energy is the sum of the kinetic and potential energy of an object. The heat engine in a car converts thermal energy into mechanical energy when it makes the car move faster, causing the car's kinetic energy to increase.

Forms of Energy There are other forms of energy besides thermal energy and mechanical energy. For example, chemical energy is energy stored in the chemical bonds between atoms. Radiant energy is the energy carried by electromagnetic waves. Nuclear energy is energy stored in the nuclei of atoms. Electrical energy is the energy carried by electric charges as they move in a circuit. Devices such as heat engines convert one form of energy into other useful forms.

The Law of Conservation of Energy When energy is transformed from one form to another, the total amount of energy doesn't change. According to the law of conservation of energy, energy cannot be created or destroyed. Energy only can be transformed from one form to another. No device, including a heat engine, can produce energy or destroy energy.

as you read

What You'll Learn

- **Describe** what a heat engine does.
- **Explain** that energy can exist in different forms, but is never created or destroyed.
- **Describe** how an internal combustion engine works.
- **Explain** how refrigerators move heat.

Why It's Important

Heat engines enable you to travel long distances.

Review Vocabulary
work: a way of transferring energy by exerting a force over a distance

New Vocabulary
- heat engine
- internal combustion engine

Figure 11 The engine in this earth mover transforms thermal energy into mechanical energy that can perform useful work.

PhotoDisc

Figure 12 Internal combustion engines are found in many tools and machines.

Internal Combustion Engines The heat engine you are probably most familiar with is the internal combustion engine. In **internal combustion engines,** the fuel burns in a combustion chamber inside the engine. Many machines, including cars, airplanes, buses, boats, trucks, and lawn mowers, use internal combustion engines, as shown in **Figure 12.**

Most cars have an engine with four or more combustion chambers, or cylinders. Usually the more cylinders an engine has, the more power it can produce. Each cylinder contains a piston that can move up and down. A mixture of fuel and air is injected into a combustion chamber and ignited by a spark. When the fuel mixture is ignited, it burns explosively and pushes the piston down. The up-and-down motion of the pistons turns a rod called a crankshaft, which turns the wheels of the car. **Figure 13** shows how an internal combustion engine converts thermal energy to mechanical energy in a process called the four-stroke cycle.

Several kinds of internal combustion engines have been designed. In diesel engines, the air in the cylinder is compressed to such a high pressure that the highly flammable fuel ignites without the need for a spark plug. Many lawn mowers use a two-stroke gasoline engine. The first stroke is a combination of intake and compression. The second stroke is a combination of power and exhaust.

Reading Check *How does the burning of fuel mixture cause a piston to move?*

Science Online

Topic: Automobile Engines
Visit glencoe.com for Web links to information on how internal combustion engines were developed for use in cars.

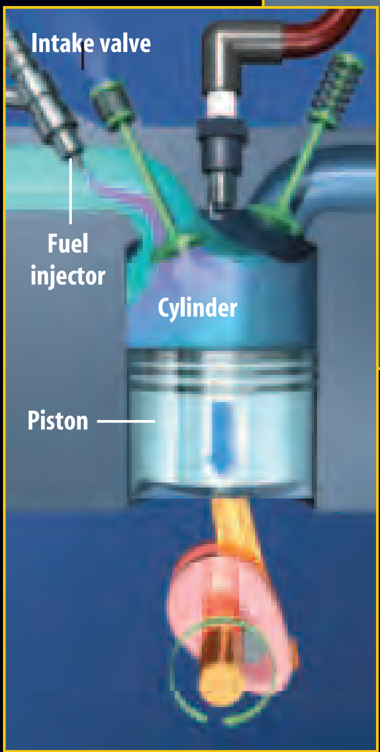
Activity Make a time line showing the five important events in the development of the automobile engine.

NATIONAL GEOGRAPHIC **VISUALIZING THE FOUR-STROKE CYCLE**

Figure 13

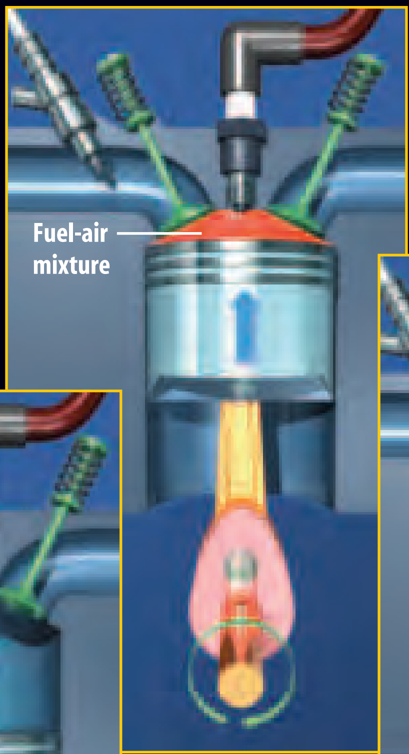
Most modern cars are powered by fuel-injected internal combustion engines that have a four-stroke combustion cycle. Inside the engine, thermal energy is converted into mechanical energy as gasoline is burned under pressure inside chambers known as cylinders. The steps in the four-stroke cycle are shown here.

INTAKE STROKE



A During the intake stroke, the piston inside the cylinder moves downward. As it does, air fills the cylinder through the intake valve, and a mist of fuel is injected into the cylinder.

COMPRESSION STROKE

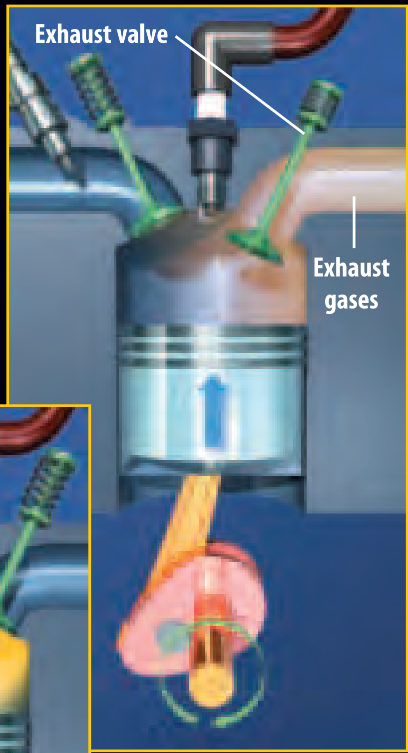


B The piston moves up, compressing the fuel-air mixture.

POWER STROKE

C At the top of the compression stroke, a spark ignites the fuel-air mixture. The hot gases that are produced expand, pushing the piston down and turning the crankshaft.

EXHAUST STROKE



D The exhaust valve opens as the piston moves up, pushing the exhaust gases out of the cylinder.

INTEGRATE Career

Mechanical Engineering People who design engines and machines are mechanical engineers. Some mechanical engineers study ways to maximize the transformation of useful energy during combustion—the transformation of energy from chemical form to mechanical form.

Refrigerators

If thermal energy will only flow from something that is warm to something that is cool, how can a refrigerator be cooler inside than the air in the kitchen? A refrigerator is a heat mover. It absorbs thermal energy from the food inside the refrigerator. Then it carries the thermal energy to outside the refrigerator, where it is transferred to the surrounding air.

A refrigerator contains a material called a coolant that is pumped through pipes inside and outside the refrigerator. The coolant is the substance that carries thermal energy from the inside to the outside of the refrigerator.

Absorbing Thermal Energy **Figure 14** shows how a refrigerator operates. Liquid coolant is forced up a pipe toward the freezer unit. The liquid passes through an expansion valve where it changes into a gas. When it changes into a gas, it becomes cold. The cold gas passes through pipes around the inside of the refrigerator. Because the coolant gas is so cold, it absorbs thermal energy from inside the refrigerator, and becomes warmer.

Releasing Thermal Energy However, the gas is still colder than the outside air. So, the thermal energy absorbed by the coolant cannot be transferred to the air. The coolant gas then passes through a compressor that compresses the gas. When the gas is compressed, it becomes warmer than room temperature. The gas then flows through the condenser coils, where thermal energy is transferred to the cooler air in the room. As the coolant gas cools, it changes into a liquid. The liquid is pumped through the expansion valve, changes into a gas, and the cycle is repeated.

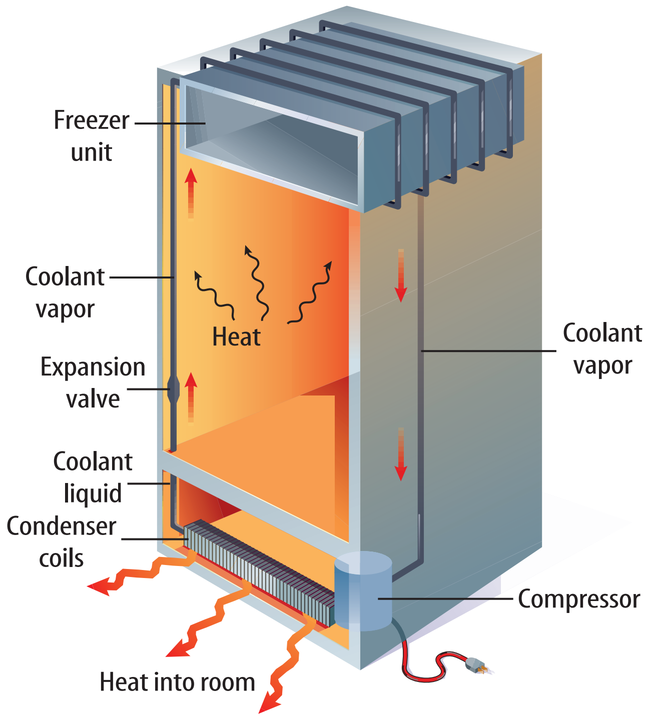


Figure 14 A refrigerator uses a coolant to move thermal energy from inside to outside the refrigerator. The compressor supplies the energy that enables the coolant to transfer thermal energy to the room.
Diagram *how the temperature of the coolant changes as it moves in a refrigerator.*

Air Conditioners Most air conditioners cool in the same way that a refrigerator does. You've probably seen air-conditioning units outside of many houses. As in a refrigerator, thermal energy from inside the house is absorbed by the coolant within pipes inside the air conditioner. The coolant then is compressed by a compressor, and becomes warmer. The warmed coolant travels through pipes that are exposed to the outside air. Here the thermal energy is transferred to the outside air.

Heat Pumps Some buildings use a heat pump for heating and cooling. Like an air conditioner or refrigerator, a heat pump moves thermal energy from one place to another. In heating mode, shown in **Figure 15,** the coolant absorbs thermal energy through the outside coils. The coolant is warmed when it is compressed and transfers thermal energy to the house through the inside coils. When a heat pump is used for cooling, it removes thermal energy from the indoor air and transfers it outdoors.

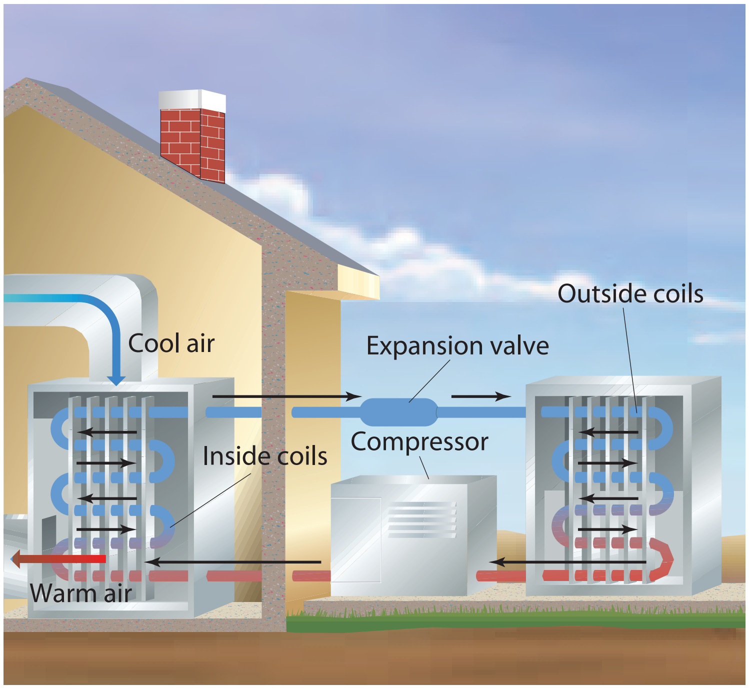


Figure 15 A heat pump heats a building by absorbing thermal energy from the outside air and transferring thermal energy to the cooler air inside.

section 3 review

Summary

Heat Engines and Energy

- A heat engine is a device that converts thermal energy into mechanical energy.
- Energy cannot be created or destroyed. It only can be transformed from one form to another.
- An internal combustion engine is a heat engine that burns fuel in a combustion chamber inside the engine.

Refrigerators and Heat Pumps

- A refrigerator uses a coolant to transfer thermal energy to outside the refrigerator.
- The coolant gas absorbs thermal energy from inside the refrigerator.
- Compressing the coolant makes it warmer than the air outside the refrigerator.
- A heat pump heats by absorbing thermal energy from the air outside, and transferring it inside a building.

Self Check

1. **Diagram** the movement of coolant and the flow of heat when a heat pump is used to cool a building.
2. **Explain** why diesel engines don't use spark plugs.
3. **Identify** the source of thermal energy in an internal combustion engine.
4. **Determine** whether you could cool a kitchen by keeping the refrigerator door open.
5. **Describe** how a refrigerator uses a coolant to keep the food compartment cool.
6. **Think Critically** Explain how an air conditioner could also be used to heat a room.

Applying Skills

7. **Make a Concept Map** Make an events-chain concept map showing the sequence of steps in a four-stroke cycle.

LAB

Design Your Own

Comparing Thermal Insulators

Goals

- **Predict** the temperature change of a hot drink in various types of containers over time.
- **Design** an experiment to test the hypothesis and collect data that can be graphed.
- **Interpret** the data.

Possible Materials

hot plate
large beaker
water
100-mL graduated cylinder
alcohol thermometers
various beverage containers
material to cover the containers
stopwatch
tongs
thermal gloves or mitts

Safety Precautions

WARNING: *Use caution when heating liquids. Use tongs or thermal gloves when handling hot materials. Hot and cold glass appear the same. Treat thermometers with care and keep them away from the edges of tables.*

Real-World Question

Insulated beverage containers are used to reduce heat transfer. What kinds of containers do you most often drink from? Aluminum soda cans? Paper, plastic, or foam cups? Glass containers? In this investigation, compare how well several different containers block heat transfer. Which types of beverage containers are most effective at blocking heat transfer from a hot drink?

Form a Hypothesis

Predict the temperature change of a hot liquid in several containers made of different materials over a time interval.

Test Your Hypothesis

Make a Plan

1. **Decide** what types of containers you will test. Design an experiment to test your hypothesis. This is a group activity, so make certain that everyone gets to contribute to the discussion.

2. **List** the materials you will use in your experiment. Describe exactly how you will use these materials. Which liquid will you test? At what temperature will the liquid begin? How will you cover the hot liquids in the container? What material will you use as a cover?
3. **Identify** the variables and controls in your experiment.
4. **Design** a data table in your Science Journal to record the observations you make.

Follow Your Plan

1. Ask your teacher to examine the steps of your experiment and your data table before you start.
2. To see the pattern of how well various containers retain heat, you will need to graph your data. What kind of graph will you use? Make certain you take enough measurements during the experiment to make your graph.
3. The time intervals between measurements should be the same. Be sure to keep track of time as the experiment goes along. For how long will you measure the temperature?
4. Carry out your investigation and record your observations.

Analyze Your Data

1. **Graph** your data. Use one graph to show the data collected from all your containers. Label each line on your graph.
2. **Interpret Data** How can you tell by looking at your graphs which containers retain heat best?
3. **Evaluate** Did the water temperature change as you had predicted? Use your data and graph to explain your answers.

Conclude and Apply

1. **Explain** why the rate of temperature change varies among the containers. Did the size of the containers affect the rate of cooling?
2. **Conclude** which containers were the best insulators.

Communicating Your Data

Compare your data and graphs with other classmates and explain any differences in your results or conclusions.

The Heat Is On

You may live far from water, but still live on an island—a heat island

Think about all the things that are made of asphalt and concrete in a city. As far as the eye can see, there are buildings and parking lots, sidewalks and streets. The combined effect of these paved surfaces and towering structures can make a city sizzle in the summer. There's even a name for this effect. It's called the heat island effect.

Hot Times

You can think of a city as an island surrounded by an ocean of green trees and other vegetation. In the midst of those green trees, the air can be up to 8°C cooler than it is downtown. During the day in rural areas, the Sun's energy is absorbed by plants and soil. Some of this energy causes water to evaporate, so less energy is available to heat the surroundings. This keeps the temperature lower.

Higher temperatures aren't the only problems caused by heat islands. People crank up their air conditioners for relief, so the use of energy skyrockets. Also, the added heat speeds up the rates of chemical reactions in the atmosphere. Smog is due to chemical reactions caused by the interaction of sunlight and vehicle emissions. So hotter air means more smog. And more smog means more health problems.

Cool Cures

Several U.S. cities are working with NASA scientists to come up with a cure for the summertime blues. For instance, dark materials absorb heat more efficiently than light materials. So painting buildings, especially roofs, white can reduce heat and save on cooling bills.

Dark materials, such as asphalt, absorb more heat than light materials. In extreme heat, it's even possible to fry an egg on dark pavement!

Design and Research Visit the Web Site to the right to research NASA's Urban Heat Island Project. What actions are cities taking to reduce the heat-island effect? Design a city area that would help reduce this effect.

Science Online
For more information, visit glencoe.com

Chip Simons/FPG/Getty Images

chapter 15 Study Guide

Reviewing Main Ideas

Section 1 Temperature and Thermal Energy

1. Molecules of matter are moving constantly. Temperature is related to the average value of the kinetic energy of the molecules.
2. Thermometers measure temperature. Three common temperature scales are the Celsius, Fahrenheit, and Kelvin scales.
3. Thermal energy is the total kinetic and potential energy of the particles in matter.

Section 2 Heat

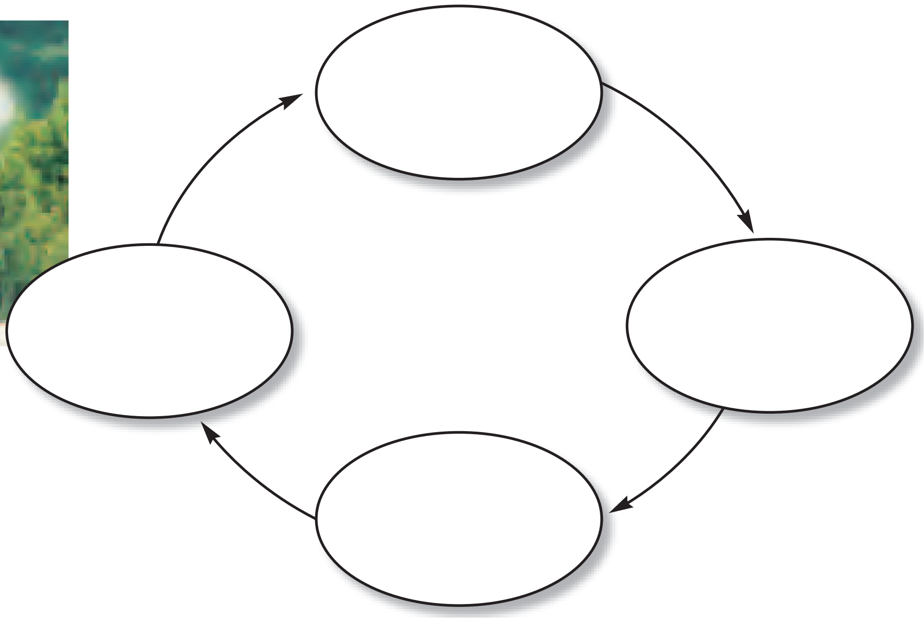
1. Heat is thermal energy that is transferred from a warmer object to a colder object.
2. Heat can be transferred by conduction, convection, and radiation.
3. A material that easily transfers heat is called a conductor. A material that resists the flow of heat is an insulator.
4. The specific heat of a substance is the amount of heat needed to change the temperature of 1 kg of the substance 1°C.
5. Thermal pollution occurs when warm water is added to a body of water.

Section 3 Engines and Refrigerators

1. A device that converts thermal energy into mechanical energy is an engine.
2. In an internal combustion engine, fuel is burned in combustion chambers inside the engine using a four-stroke cycle.
3. Refrigerators and air conditioners use a coolant to move heat.

Visualizing Main Ideas

Copy and complete the following cycle map about the four-stroke cycle.



SuperStock

chapter 15 Review

Using Vocabulary

conduction p. 439	radiation p. 439
conductor p. 441	specific heat p. 442
convection p. 440	temperature p. 434
heat p. 438	thermal energy p. 437
heat engine p. 445	thermal pollution p. 443
internal combustion engine p. 446	

Explain the differences in the vocabulary words given below. Then explain how the words are related. Use complete sentences in your answers.

1. internal combustion engine—heat engine
2. temperature—thermal energy
3. thermal energy—thermal pollution
4. conduction—convection
5. conduction—heat
6. heat—specific heat
7. conduction—radiation
8. convection—radiation
9. conductor—heat

Checking Concepts

Choose the word or phrase that best answers the question.

10. What source of thermal energy does an internal combustion engine use?
    A) steam **C)** burning fuel
    B) hot water **D)** refrigerant

11. What happens to most materials when they become warmer?
    A) They contract. **C)** They vaporize.
    B) They float. **D)** They expand.

12. Which occurs if two objects at different temperatures are in contact?
    A) convection **C)** condensation
    B) radiation **D)** conduction

13. Which of the following describes the thermal energy of particles in a substance?
    A) average value of all kinetic energy
    B) total value of all kinetic energy
    C) total value of all kinetic and potential energy
    D) average value of all kinetic and potential energy

14. Heat being transferred from the Sun to Earth is an example of which process?
    A) convection **C)** radiation
    B) expansion **D)** conduction

15. Many insulating materials contain spaces filled with air because air is what type of material?
    A) conductor **C)** radiator
    B) coolant **D)** insulator

16. A recipe calls for a cake to be baked at a temperature of 350°F. What is this temperature on the Celsius scale?
    A) 162°C **C)** 194°C
    B) 177°C **D)** 212°C

17. Which of the following is true?
    A) Warm air is less dense than cool air.
    B) Warm air is as dense as cool air.
    C) Warm air has no density.
    D) Warm air is denser than cool air.

18. Which of these is the name for thermal energy that moves from a warmer object to a cooler one?
    A) kinetic energy **C)** heat
    B) specific heat **D)** temperature

19. Which of the following is an example of heat transfer by conduction?
    A) water moving in a pot of boiling water
    B) warm air rising from hot pavement
    C) the warmth you feel sitting near a fire
    D) the warmth you feel holding a cup of hot cocoa

Thinking Critically

20. **Infer** Water is a poor conductor of heat. Yet when you heat water in a pan, the surface gets hot quickly, even though you are applying heat to the bottom of the water. Explain.

21. **Explain** why several layers of clothing often keep you warmer than a single layer.

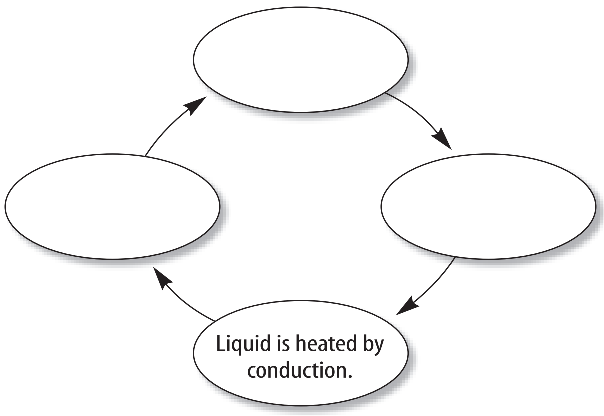
22. **Identify** The phrase "heat rises" is sometimes used to describe the movement of heat. For what type of materials is this phrase correct? Explain.

23. **Describe** When a lightbulb is turned on, the electric current in the filament causes the filament to become hot and glow. If the filament is surrounded by a gas, describe how thermal energy is transferred from the filament to the air outside the bulb.

24. **Design an Experiment** Some colors of clothing absorb heat better than other colors. Design an experiment that will test various colors by placing them in the hot Sun for a period of time. Explain your results.

25. **Explain** Concrete sidewalks usually are made of slabs of concrete. Why do the concrete slabs have a space between them?

26. **Concept Map** Copy and complete the following concept map on convection in a liquid.



27. **Explain** A winter jacket is lined with insulating material that contains air spaces. How would the insulating properties of the jacket change if the insulating material in the jacket becomes wet? Explain.

28. **Compare** Two glasses of water are poured into a pitcher. If the temperature of the water in both glasses was the same before they were mixed, describe how the temperature and thermal energy of the water in the pitcher compares to the water in the glasses.

Performance Activities

29. **Poll** In the United States, the Fahrenheit temperature scale is used most often. Some people feel that Americans should switch to the Celsius scale. Take a poll of at least 20 people. Find out if they feel the switch to the Celsius scale should be made. Make a list of reasons people give for or against changing.

Applying Math

30. **Temperature Order** List the following temperatures from coldest to warmest: 80° C, 200 K, 50° F.

31. **Temperature Change** The high temperature on a summer day is 88°F and the low temperature is 61°F. What is the difference between these two temperatures in degrees Celsius?

32. **Global Temperature** The average global temperature is 286 K. Convert this temperature to degrees Celsius.

33. **Body Temperature** A doctor measures a patient's temperature at 38.4°C. Convert this temperature to degrees Fahrenheit.

Part 1 Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

Use the photo below to answer questions 1 and 2.

1. The temperatures of the two glasses of water shown in the photograph above are 30°C and 0°C. Which of the following is a correct statement about the two glasses of water?

A. The cold water has a higher average kinetic energy.
B. The warmer water has lower thermal energy.
C. The molecules of the cold water move faster.
D. The molecules of the warmer water have more kinetic energy.

2. The difference in temperature of the two glasses of water is 30°C. What is their difference in temperature on the Kelvin scale?

A. 30 K
B. 86 K
C. 243 K
D. 303 K

3. Which of the following describes a refrigerator?

A. heat engine
B. heat pump
C. heat mover
D. conductor

Test-Taking Tip

Avoid rushing on test day. Prepare your clothes and test supplies the night before. Wake up early and arrive at school on time on test day.

4. Which of the following is not a step in the four-stroke cycle of internal combustion engines?

A. compression
B. exhaust
C. idling
D. power

Use the table below to answer question 5.

Material	Specific Heat (J/kg °C)
aluminum	897
copper	385
lead	129
nickel	444
zinc	388

5. A sample of each of the metals in the table above is formed into a 50-g cube. If 100 J of heat are applied to each of the samples, which metal would change temperature by the greatest amount?

A. aluminum
B. copper
C. lead
D. nickel

6. An internal combustion engine converts thermal energy to which of the following forms of energy?

A. chemical
B. mechanical
C. radiant
D. electrical

7. Which of the following is a statement of the law of conservation of energy?

A. Energy never can be created or destroyed.
B. Energy can be created, but never destroyed.
C. Energy can be destroyed, but never created.
D. Energy can be created and destroyed when it changes form.

Part 2 Short Response/Grid In

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

8. If you add ice to a glass of room-temperature ice, does the water warm the ice or does the ice cool the water? Explain.

9. Strong winds that occur during a thunderstorm are the result of temperature differences between neighboring air masses. Would you expect the warmer or the cooler air mass to rise above the other?

10. A diesel engine uses a different type of fuel than the fuel used in a gasoline engine. Explain why.

11. What are the two main events that occur while the cylinder moves downward during the intake stroke of an internal combustion engine's four-stroke cycle?

Use the photo below to answer questions 12 and 13.

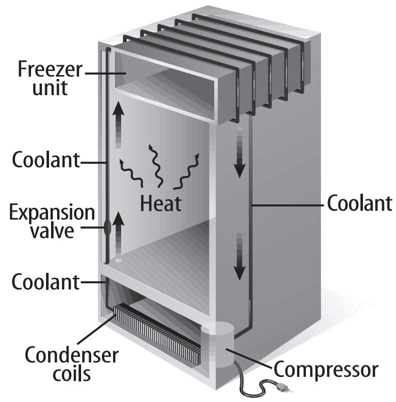
12. Why are cooking pots like the one in the photograph above often made of metal? Why isn't the handle made of metal?

13. When heating water in the pot, electrical energy from the cooking unit is changed to what other type of energy?

Part 3 Open Ended

Record your answers on a sheet of paper.

Use the illustration below to answer questions 14 and 15.



14. The illustration above shows the parts of a refrigerator and how coolant flows through the refrigerator. Explain how thermal energy is transferred to the coolant inside the refrigerator and then transferred from the coolant to the outside air.

15. What are the functions of the expansion valve, the condenser coils, and the compressor in the illustration?

16. Define convection. Explain the difference between natural and forced convection, and give an example of each.

17. Draw a sketch with arrows showing how conduction, convection, and radiation affect the movement and temperature of air near an ocean.

18. Define temperature and explain how it is related to the movement of molecules in a substance.

19. Explain what makes some materials good thermal conductors.

20. You place a cookie sheet in a hot oven. A few minutes later you hear a sound as the cookie sheet bends slightly. Explain what causes this.