Science ch. 18

Thermal and light energy

Career

Computer Engineer

A licensed pilot, Debbie Martinez works for NASA as a computer engineer. She helps design software and instruments that NASA uses for research. Pilots use simulators to test the results of the research. NASA's flight simulation research makes flying safer for everyone.

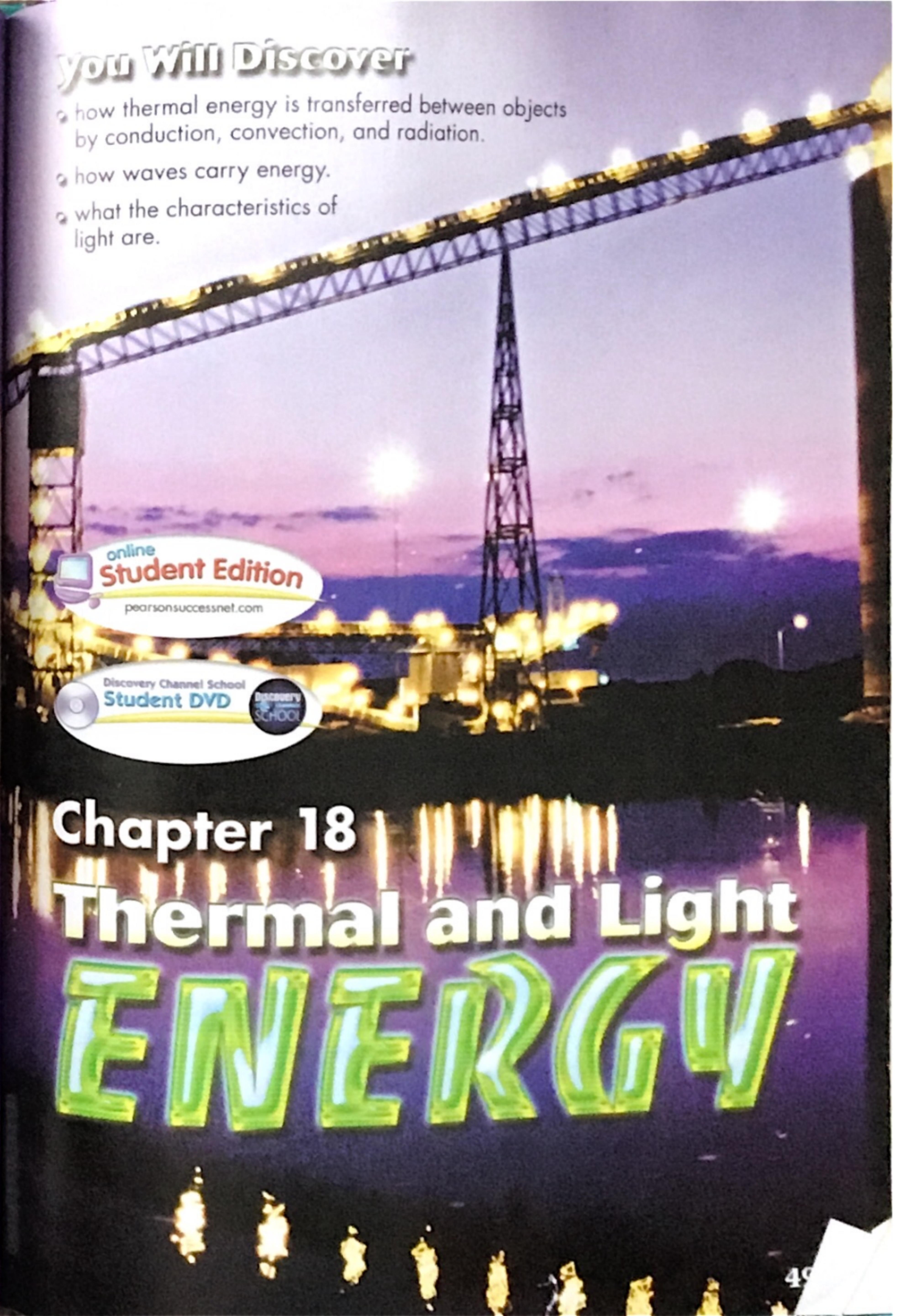
How do you think pilots are trained to fly new aircraft? They don't simply fly the aircraft. That would be too dangerous. Instead, pilots train in flight simulators. Simulators are life-size models of aircraft that move like the real thing, but stay on the ground. Simulators mimic what it is like to actually fly a plane, helicopter, or even a spacecraft.

Many different people work together to build these simulators, including computer and electronics engineers. They work with researchers to design and develop electrical and electronic equipment and processes. They might work on radar, computers, and video equipment. As an engineer, you would work on a project from the time the product is first discussed and researched until it is manufactured.

If you like to work on a team, are creative, are good with details, and can express yourself well, you might consider a career as an electronics or computer engineer. You will have to get a college degree. But your education will not end then. Engineers must keep up with new information and technology in their field.

Lab zone Take-Home Activity

Engineers helped develop the simulator for training pilots. What process would you like to develop a training simulator for? What are some of the factors you would have to consider as you develop the simulator?



You Will Discover

- how thermal energy is transferred between objects by conduction, convection, and radiation.
- how waves carry energy.
- what the characteristics of light are.

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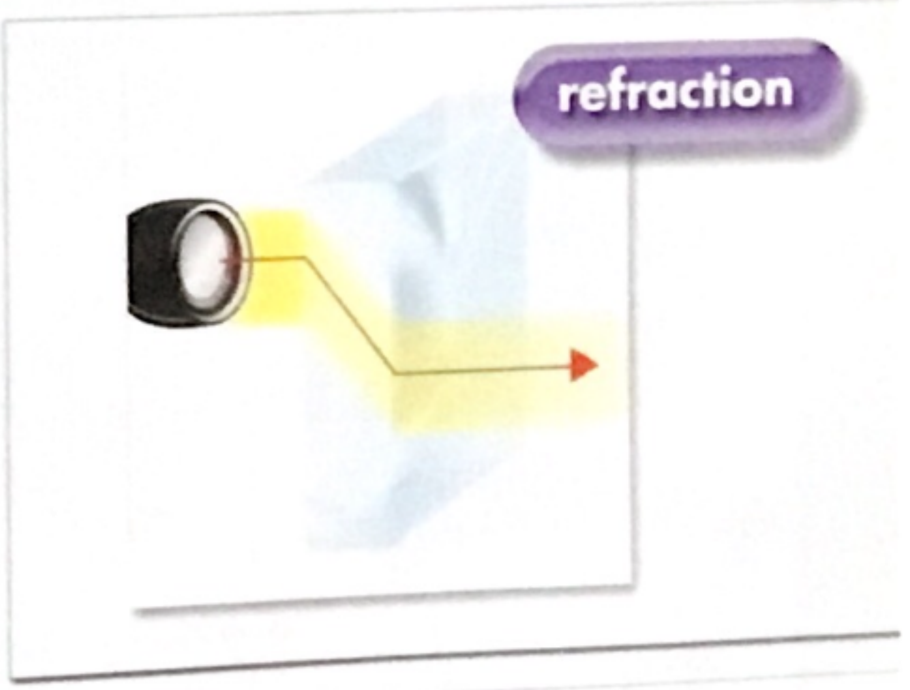
Chapter 18 Thermal and Light ENERGY

Build Background

How are thermal energy and light energy transferred?

Chapter 18 Vocabulary

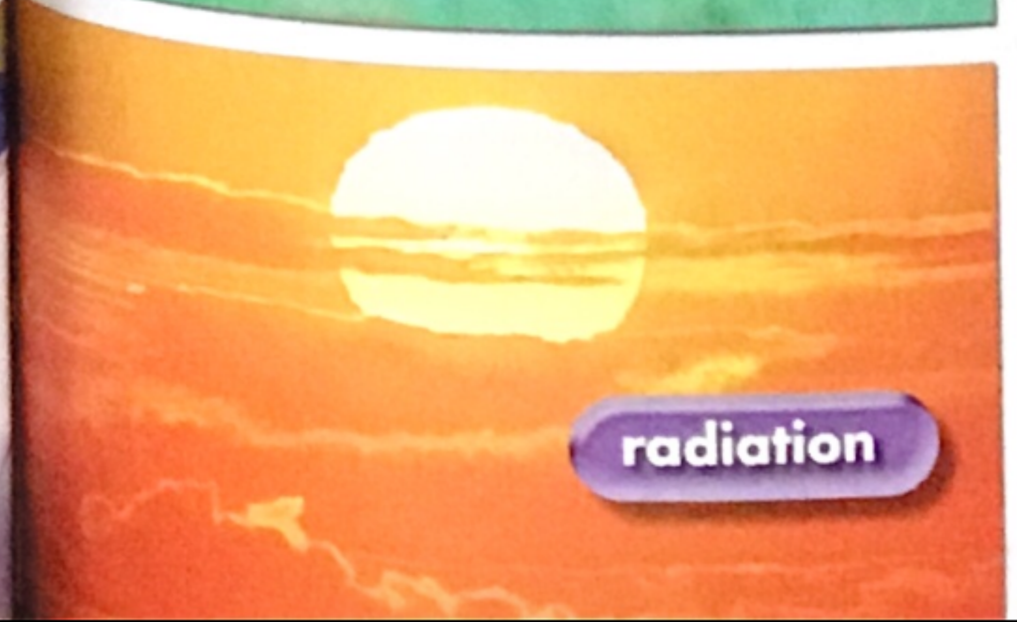


conduction

Heat transfer between two objects that touch

conductor

A material that easily transfers heat



You Are There!

You stare in wonder as the glassblower gathers the glowing, liquid glass onto a rod. Even at a safe distance, the heat from the roaring furnace warms your face and reminds you that liquid glass is unbelievably hot. The glassblower turns the rod over and over to shape the glass. The glass flows first one way, and then the other. But slowly, as the glass cools, it flows less. Gradually, the cooling glass becomes a solid.

Lesson 1

How is thermal energy transferred?

Thermal energy is the total kinetic and potential energy of the particles in a substance. Heat is thermal energy that moves from one substance to another. Heat can move by conduction, convection, and radiation.

Thermal Energy

When you look at the molten glass, it is easy to see that its particles are moving. The molten glass flows. But a solid object, such as a glass pitcher, seems to be perfectly still. Are you surprised to find out that it's not?

All matter is made of particles that are always moving. The particles have kinetic energy, or energy due to motion. The particles in a substance always pull on each other. This means the particles have potential energy, or energy due to position. Particles in a gas can move freely. They do not pull strongly on each other. Particles in a liquid can only flow around each other. They pull more strongly on each other than gas particles do. The particles in a solid pull strongly on each other. They vibrate, but they cannot move from their fixed position.

The total kinetic and potential energy of the particles in a substance is **thermal energy.** The amount of thermal energy depends on the amount of the substance. If you have a cup of water and you pour half of it out, the part that is left has half the number of particles. It therefore has half the thermal energy that the full cup of water had.

Thermal energy determines how warm a substance feels. A warm cup of water has more thermal energy than a cool cup of water. The warm and cool water have about the same number of particles, but the particles in the warm water are moving faster. They have more kinetic energy. Therefore, they have more thermal energy and feel warmer.

1. ✓ **Checkpoint** What is the difference between kinetic energy and potential energy?
2. **Writing in Science** **Expository** You place a cup of water in a freezer and it changes to ice. Explain what happens to the thermal energy of the water.

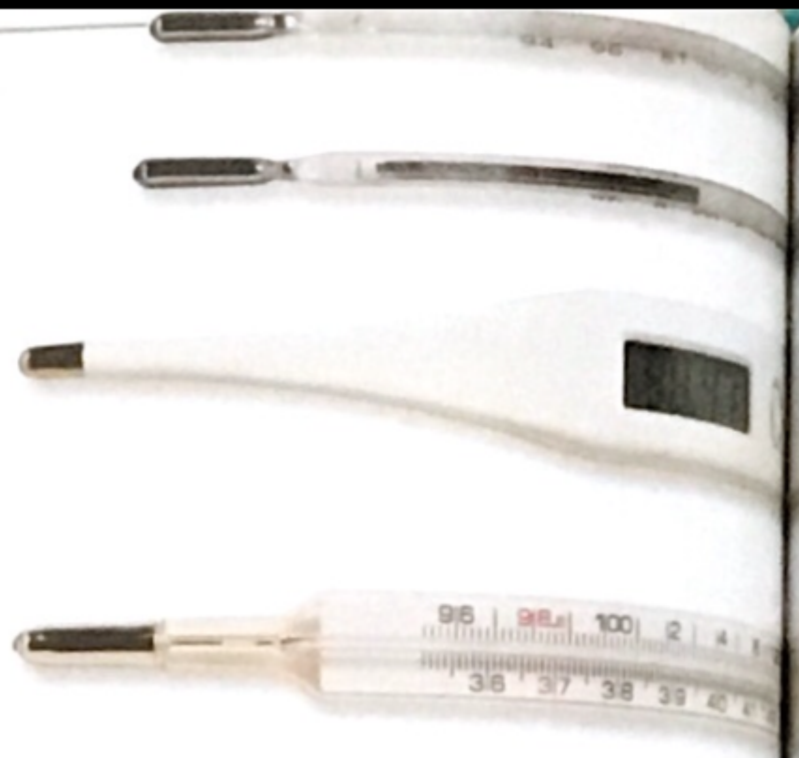
Heat

You've probably measured your kinetic energy many times, but you may not have known it. Temperature is a measure of the average kinetic energy of an object's particles. When you take your temperature with a thermometer, your body heat increases the kinetic energy of particles of a liquid in the thermometer. The thermometer then shows the average kinetic energy of particles in your body.

Temperature is not the same as thermal energy. Temperature depends only on the average kinetic energy. Thermal energy is the sum of kinetic and potential energy. Unlike thermal energy, temperature does not depend on the amount of a substance. If you split an object in half, each part has half as many particles. But the temperature does not change. The average kinetic energy is the same.

Thermal energy that can move from one substance to another is called **heat.** Heat always moves from a warmer substance to a cooler one. An increase in temperature means that heat moves into a substance. When heat moves into a substance, the average kinetic energy of the particles rises. The extra kinetic energy increases the particles' vibrations. Particles vibrate faster when a substance is heated.

The movement of heat from one substance to another can occur between objects that touch and objects that don't touch. The three types of heat transfer are conduction, convection, and radiation.



Liquid thermometers measure temperature change when increased kinetic energy causes a liquid to expand. Digital thermometers measure temperature change when increased kinetic energy causes a metal to expand.

The lynx warms the snow as heat moves from particles in its body to particles in the snow.

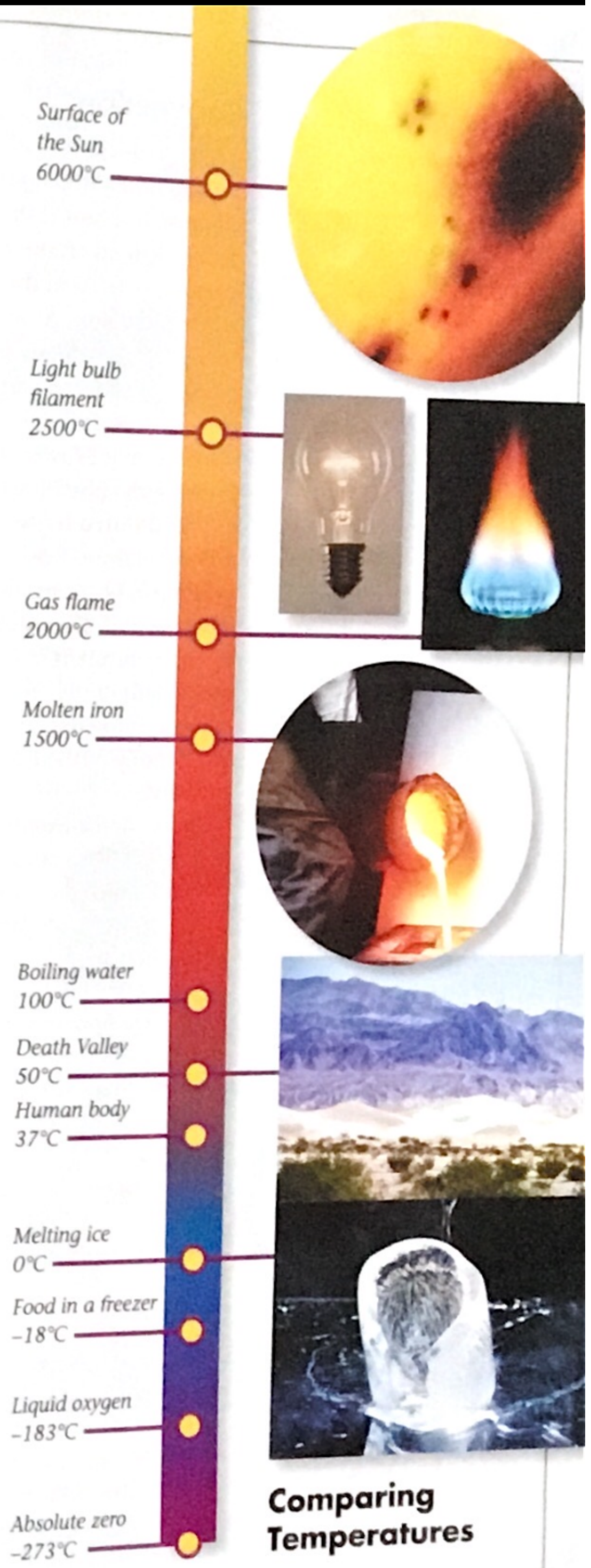
Conduction

Heat transfer between two objects that touch is called **conduction.** Think about what happens if you place ice cubes in a glass of warm lemonade. Do the ice cubes cool the lemonade, or does the lemonade warm the ice cubes?

The temperature of the ice cubes is lower than the temperature of the lemonade. The particles that make up the lemonade are vibrating faster than the particles of the ice. When the ice touches the lemonade, the particles in the lemonade bump against the ice particles. This causes the ice particles to move faster and faster. Heat flows from the warmer lemonade to the cooler ice. The lemonade particles slow down. Conduction of heat has warmed the ice and cooled the lemonade.

When heat moves by conduction, the particles in the substances do not change their location. Energy is passed from particle to particle as the particles vibrate and bump against other particles. This movement of energy may occur between a warmer substance and a cooler one. It may also occur between the warm part of an object and a cooler part of the same object.

1. **✓Checkpoint** Why doesn't the temperature of an object change if you break the object in half?
2. **Technology in Science** Heat naturally moves from warm to cool objects, but refrigerators reverse this movement. Research and write a paragraph that explains this process.



Comparing Temperatures

Convection

Hang gliders can stay in the air longer because of convection. They are pushed upward as they fly through rising currents of warm air called thermals.

A hang glider soars through the air, swooping up and circling again and again. The wings of the glider provide balance, but how is the glider able to move upward? Hang gliders depend on the movement of thermal energy in the air.

Heat moves from the warm ground to the air just above it by conduction. As with solids, the kinetic and potential energy of particles in a fluid—a liquid or gas—increases if the fluid touches a warmer object. Energy from the warmer object moves into the fluid. As the fluid becomes warmer, its particles move faster. The density of a fluid decreases as the fast-moving particles spread apart.

A fluid with a higher density sinks below a fluid with a lower density. This causes the lower-density fluid to rise. When this happens, the rising fluid carries thermal energy along with it. **Convection** is the transfer of thermal energy by the movement of the particles of a liquid or a gas. This movement results in a stream of fluid called a convection current. Hang gliders can fly great distances as they are continually pushed upward by convection currents along the way.

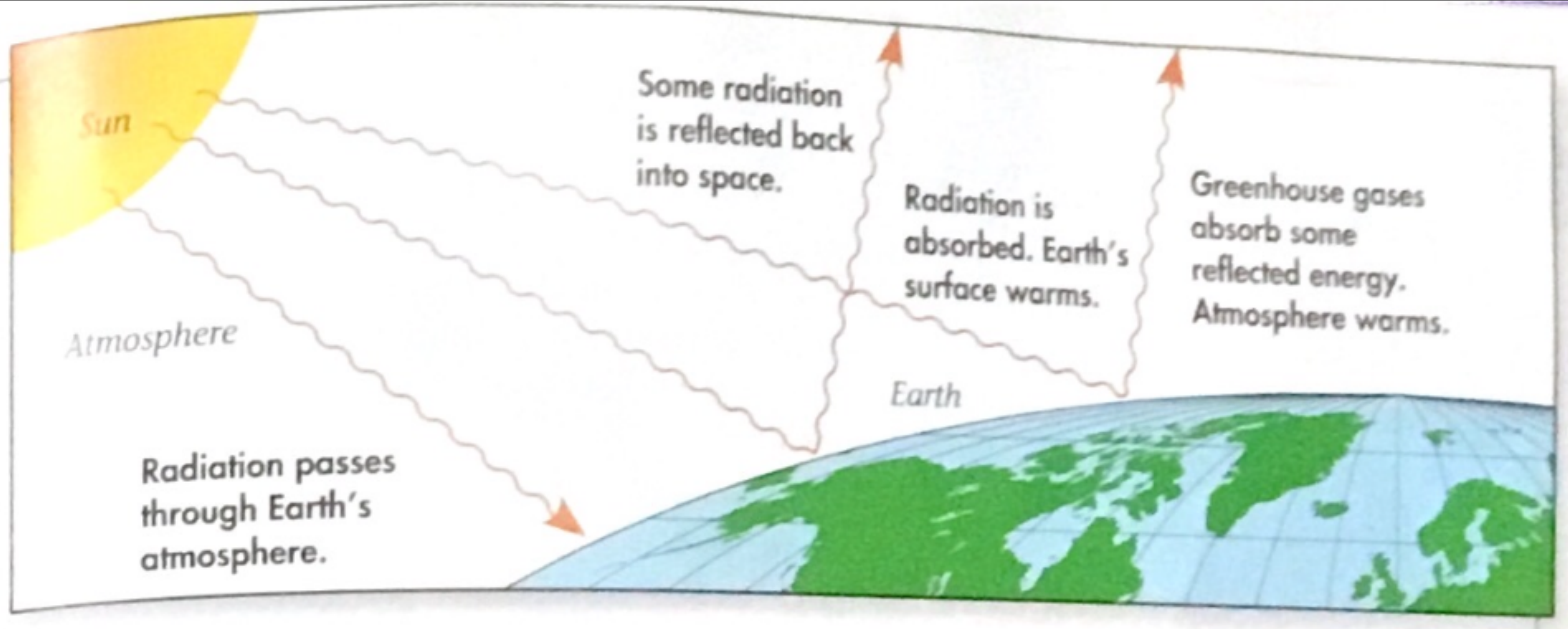
Convection currents in the air cause winds to form. As warm air rises, cooler air rushes in to fill its place near the ground. The rising warm air becomes cooler and begins to fall. The cooler air near the ground becomes warmer and begins to rise.

A pot of boiling water is another example of convection. If you place a pot of water on a stove, the temperature of the pot rises by conduction. Heat moves from the stove to the pot. The pot then warms the water that touches it by conduction as heat moves from the pot to the water. The warm water is less dense than the cooler water above it. The cool water then sinks, causing the warm water to rise. The rising and falling of warmer and cooler water increases the temperature of the entire pot of water.

Energy from these lamps moves by radiation to keep the food warm.

Radiation

For the chameleon, a good way to spend a sunny afternoon is sitting on a rock. Like all reptiles, chameleons warm their bodies with energy from the Sun. This energy must travel from the Sun to Earth through space that has almost no matter. **Radiation** is the transfer of thermal energy as waves. It can involve energy transfer through matter or across empty space.



When solar radiation reaches Earth's atmosphere, some of the energy is reflected back toward space. The rest of the radiation reaches Earth. Like the atmosphere, Earth's surface reflects some radiation and absorbs the rest. The absorbed radiation heats Earth's surface, which releases some of this heat back into the atmosphere. There gases, such as carbon dioxide and water vapor, absorb the energy and become warmer. These gases surround Earth and act like a blanket to hold heat. This process by which the atmosphere holds heat is called the greenhouse effect.

The greenhouse effect is a natural process. Without it, Earth would be a cold, lifeless planet. But some scientists are concerned that the increase in some atmospheric gases, such as carbon dioxide, will cause the atmosphere to become too warm. Increased temperatures can have a harmful effect on Earth's ecosystems.

Energy from the Sun warms a chameleon by radiation. The chameleon is also warmed by conduction. Heat moves from the rock into the chameleon's body.

1. **✓ Checkpoint** Why is radiation the only type of heat transfer by which the Sun's energy can move to Earth?
2. **Art in Science** Draw an illustration that explains convection currents.

Insulation

Brrr! It's a cold winter day, and you're getting ready for school. You put on a thick coat, scarf, and gloves to keep warm. Now that you've learned about different types of heat transfer, can you explain how a coat, scarf, and gloves keep you warm?

Winter clothes keep you warm because they insulate you against the cold. An **insulator** is a material that does not easily transfer heat. Other materials, such as metals, are **conductors.** They transfer heat easily.

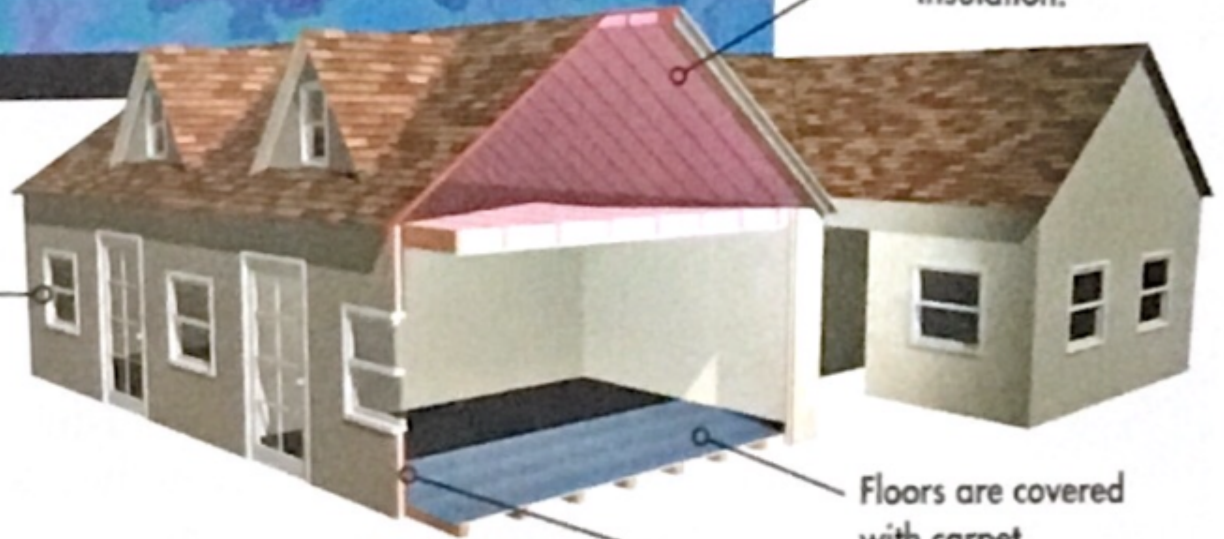
What causes a material to be either an insulator or a conductor? Recall what happens when heat moves from a warmer object to a cooler one. Particles in the warmer object move faster. If the warmer object touches the cooler object, particles in the warmer object bump against particles in the cooler object. Particles in the cooler object then move faster and faster. Their kinetic energy rises. The temperature of the cooler object rises by conduction.

This scarf is made of a material that contains air pockets. A scarf keeps you warm because thermal energy doesn't easily move through air.

Some materials are good conductors because their atoms can easily vibrate to transfer heat. Metals, such as copper and silver, are good conductors because of the movement of electrons. Some electrons are not tightly held to the atoms of the metals. These electrons can move easily. They carry energy from place to place. You may have realized that metals are good conductors when you've stirred hot soup with a spoon. After a short while, you can feel the heat in the spoon.

Liquids and gases are usually better insulators than solids because their particles are farther apart. Empty space is also a good insulator. Heat cannot move through empty space by conduction or convection.

This photograph was taken with a thermal camera that detects heat loss in buildings. Yellow areas show where the house has little insulation and heat can easily escape. Blue areas show where the house is well insulated with little heat loss.



Using Insulators

Understanding insulators is important in choosing clothes for cold weather. Layers of materials will keep you warmest. They contain pockets of air. Because air is a good insulator, heat cannot easily escape from your body.

Insulating materials are also important in home building. If you've ever seen a house being built, you may have seen thick layers of insulating material placed in the walls and attic. Air pockets within the layers slow the movement of heat out of a home on cold days. They also slow the movement of heat into a home on hot summer days. Some houses have windows with double layers of glass. The pocket of air between the layers is insulation against the movement of heat through the window.

Insulation is one way that animals protect themselves from the cold in winter. Some animals have thick layers of insulating fat. Animals may also have fur or hair that traps heat close to their bodies.

Fluffy down feathers have pockets of air that trap heat near a goose's body. People sometimes use these insulating feathers for winter coats and blankets.

✓Lesson Checkpoint

1. How does a liquid thermometer show that you have a fever?
2. Why are you warmer if you wear layers of clothing on a cold day?
3. **Compare and Contrast** Explain how conduction, convection, and radiation are alike and how they are different.

Lesson 2

How do waves carry energy?

Waves, such as sound and light, carry energy. When light strikes matter, it may be absorbed, transmitted, or reflected. Light may change direction when it moves from one material to another.

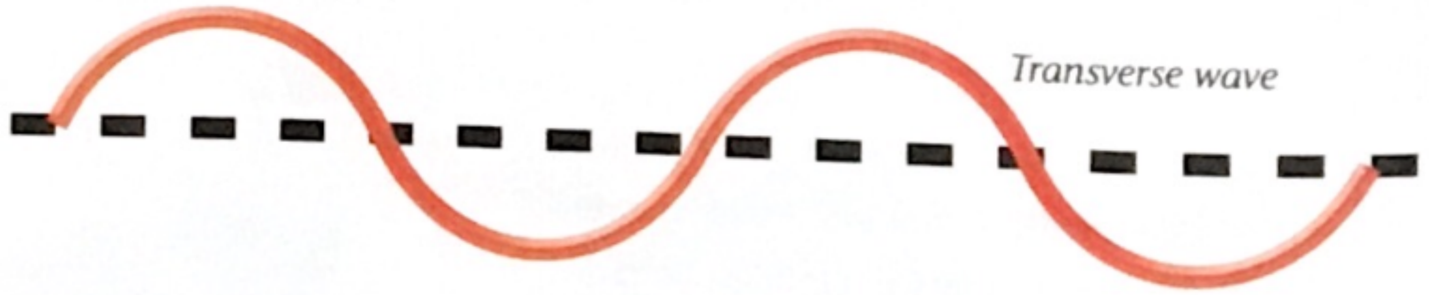
Water waves carry energy.

Types of Waves

Have you ever dropped a rock into a pool of water? Waves spread out in all directions from the point where the rock enters the water. The rock causes molecules in the water to move back and forth as a vibration. A wave carries energy away from a vibration.

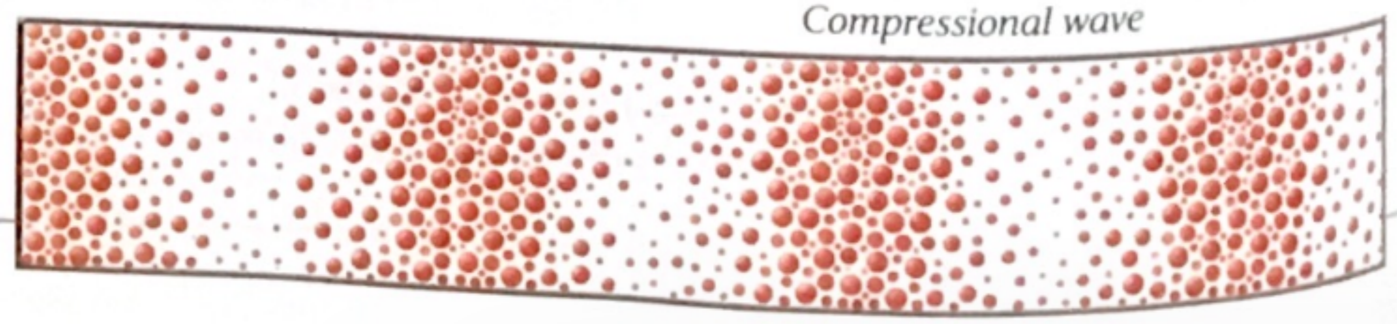
The illustrations below show the two main types of waves. Notice their differences. When waves move through matter, the matter does not move along with the wave. When transverse waves move through matter, they cause the matter to move in a direction different than the wave moves. If the wave is moving to the right, molecules in the matter move up and down. If a compressional wave is moving through matter, the matter moves back and forth in the same direction as the wave. The particles in the matter move forward and then backward, over and over again.

An important type of compressional waves is sound. As with all waves, sounds are caused by vibrations. Think about what happens if you strike your pencil against a desk. The force of your pencil causes molecules in the desk and air next to it to vibrate. These vibrations cause nearby air particles to vibrate, and they cause other molecules to vibrate. The vibrations move outward through the air in all directions. You hear sound when the vibrations reach your ear. You can also hear the pencil striking the desk if you place your ear against the desk. Sound waves can travel through matter, but they cannot travel through empty space.



Transverse wave

Compressional wave



1 Gamma rays are used to treat cancer.

2 X rays pass through soft body tissue but not through bones.

3 Ultraviolet rays can damage skin cells.

4 Visible light is the range of wavelengths that humans can see.

5 The infrared light of the heat lamp warms this chicken.

6 Microwaves are used for satellite signals and for cooking food.

7 Television signals are short-wavelength radio waves.

8 Radio waves carry signals that represent sound.

Electromagnetic Spectrum

You just read about sound waves that travel through matter. Like sound, light travels as a wave, but unlike sound, light can travel through empty space. Light travels as transverse waves.

Visible light is only one of the many kinds of waves that travel to Earth from the Sun. If you arranged all the kinds of waves from the shortest wavelength to the longest wavelength, you would get a pattern similar to the one shown in the diagram above. The pattern is called the electromagnetic spectrum.

Notice that the wavelength becomes longer as you move from left to right across the spectrum, but the frequency becomes shorter. Like all waves, those of the electromagnetic spectrum carry energy. Waves with a shorter wavelength have more energy than those with a longer wavelength.

1. ✓**Checkpoint** What type of wave carries more energy—radio waves or visible light?
2. **Compare and Contrast** Tell how transverse waves and compressional waves are alike and different.

Absorption of Light

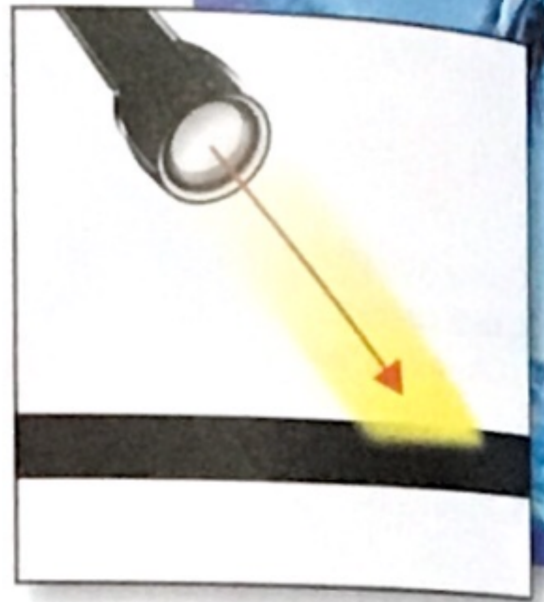
Shine a light on a piece of glass, and most of the light travels through it. Shine the same light on a piece of metal, and no light goes through. Light can behave in different ways when it strikes matter. Some light may be absorbed, or taken in, by the matter. When light enters a material, some of the light energy is changed into heat energy. You may have noticed this on a warm summer day. Dark-colored materials absorb more sunlight than light-colored materials. Wearing a black shirt, for example, makes you warmer than wearing a white shirt.

Light may also pass through a material without being absorbed. The amount of light that passes through a material depends on the type of material. Almost all light passes through transparent materials, such as clear glass and water. Translucent materials only allow some of the light that strikes them to pass through. Waxed paper is a translucent material. Opaque materials don't allow any light that strikes them to pass through. Wood, rocks, and metals are examples of opaque materials.

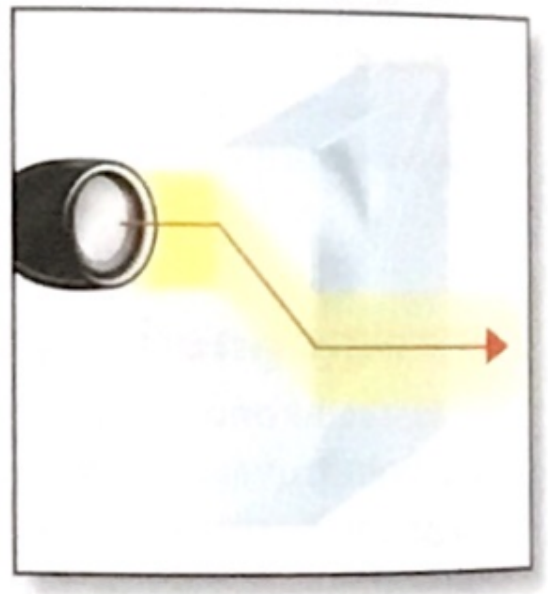
All electromagnetic waves travel through empty space at the speed of light—300,000 kilometers per second. Light travels through matter at speeds less than this. But light doesn't pass through all materials at the same speed. The particles that make up matter cause light to slow down. The speed that light passes through a material depends on the type of material. Unlike sound waves, light usually travels slowest through solids because they have the highest density. Light travels faster through liquids, and even faster through gases.

Refraction and Reflection

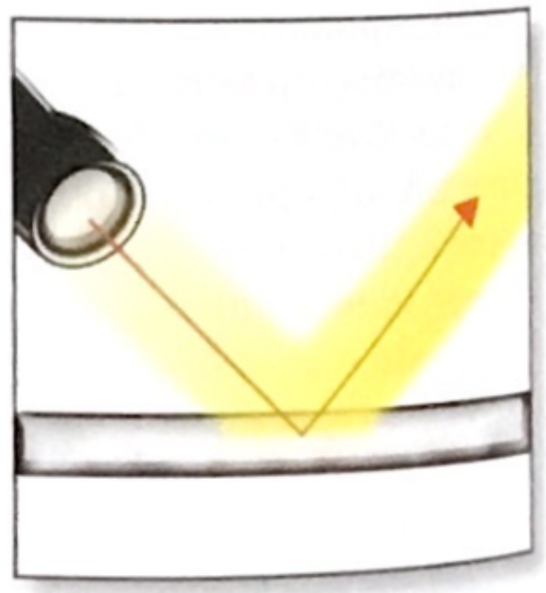
Light changes speed when it moves from one material to another. If a beam of light strikes the border of two materials at an angle, the change in the speed of the light changes its direction. **Refraction** is the change in direction of light when it moves from one material to another. You can see refraction by placing a spoon in a glass of water and looking at it from the side. The spoon seems to be bent. This happens because light changes direction when it moves from the water to the air.



Absorption



Refraction



Reflection

Refraction distorts this photo taken under water.

Light that isn't absorbed and doesn't pass through a material is reflected. **Reflection** is the bouncing of light rays off the surface of a material. If the surface is smooth, you may be able to see your reflection in the material. When light strikes a mirror, for example, the light reflects back so that you can see yourself.

Think about places where you can see your reflection. Why can't you see your reflection when you look at a wall or a book? These surfaces may seem smooth. Using a magnifying glass, however, you can see many bumps and holes. Light that strikes these surfaces bounces off in many directions. A surface must be smooth enough for light to bounce back to your eyes in order for you to see a clear reflection.

✓ Lesson Checkpoint

1. Why can't sound travel through empty space?
2. Why will you likely be cooler if you wear a light-colored shirt instead of a dark-colored shirt on a warm day?
3. **Compare and Contrast** Write a paragraph explaining ways light and radio waves are alike and ways they are different.

Seeing Color

The wavelengths of light that an object absorbs and reflects determine its color.

Black objects absorb almost all light that strikes them. When you look at a black object, little light reflects back to your eyes.

White objects reflect almost all of the light that strikes them. White is a combination of all wavelengths of light.

An object appears red if it absorbs all wavelengths of light except red. When you look at the object, you see only the red light that reflects off it.

Grass is green because it absorbs all wavelengths of light except green. It reflects the green wavelengths of light.

A blue object reflects only blue wavelengths of light. The other wavelengths are absorbed.

White light contains all wavelengths of visible light. The colors of light bend different amounts when they pass through a prism. This same effect allows you to see different colors in a rainbow.

Math in Science

Solving Combustion Problems

Combustion is a chemical reaction in which a substance combines with oxygen and releases energy. A common example of combustion is a candle burning. A flame occurs when gases combust quickly, releasing heat and bright light.

In a candle, evaporated wax combines with oxygen in the air to produce heat and light. If you look at a candle flame closely, you will see different colors. The color is an indication of how complete the combustion is and also how hot the flame is. The bottom of the flame is blue, and the outer edge is white. These colors show that more complete combustion is taking place and the flame is hotter. The inside of the flame is more yellowish orange, which means less complete combustion is taking place and the flame is not as hot.

Answer each question. Use the chart on page 516.

1. The surface temperature of a star is much hotter than a candle flame, but it is estimated by color, using the same rules. Use what you've learned to write the names of the following five stars in order from hottest surface temperature to coolest.

   Aldebaran: orange
   Betelgeuse: red
   Polaris: yellow
   Rigel: bluish white
   Sirius B: white

2. A candle is burning at the rate of 1.5 cm per hour. The candle is now 2.25 cm tall. If it was originally 12 cm tall, how long has it been burning?

3. While the space shuttle is launching, combustion in the engines burns fuel at the amazing rate of about 76,000 L (the volume of a swimming pool) every 10 seconds. If the engines fire at full throttle for 8 minutes, how much fuel will be used?

4. Only about 8% of the electrical energy of a standard light bulb is converted to light. The rest of the energy is lost as heat. If a 100-watt light bulb uses $42 worth of electrical energy in a year, what is the cost of the wasted heat?

Lab zone Take-Home Activity

Use crayons or markers to make a spectrum of red, orange, yellow, white, and blue. Label the spectrum with *Coolest* on the left and *Hottest* on the right. Arrange the colors in that order.

Chapter 18 Review and Test Prep

Use Vocabulary

conduction (p. 505)	**radiation** (p. 506)
conductor (p. 508)	**reflection** (p. 513)
convection (p. 506)	**refraction** (p. 512)
heat (p. 504)	**thermal energy** (p. 503)
insulator (p. 508)	

Determine whether each statement is true or false. Write *true* if it is true. If it is false, replace the underlined term with another vocabulary term to make the statement true.

1. The movement of thermal energy by rising currents is <u>conduction</u>.
2. The total kinetic and potential energy of the particles in a substance is <u>thermal energy</u>.
3. A <u>conductor</u> does not transfer heat easily.
4. Thermal energy that moves from one substance to another is <u>heat</u>.
5. Heat transfer between two objects that touch is <u>convection</u>.
6. <u>Connection</u> is the change in direction of light when it moves from one material to another.
7. If you stand near a hot fire, you feel the warmth because of <u>radiation</u>.
8. <u>Reflection</u> is the bouncing of light rays off the surface of the material.
9. An <u>insulator</u> transfers heat easily.

Explain Concepts

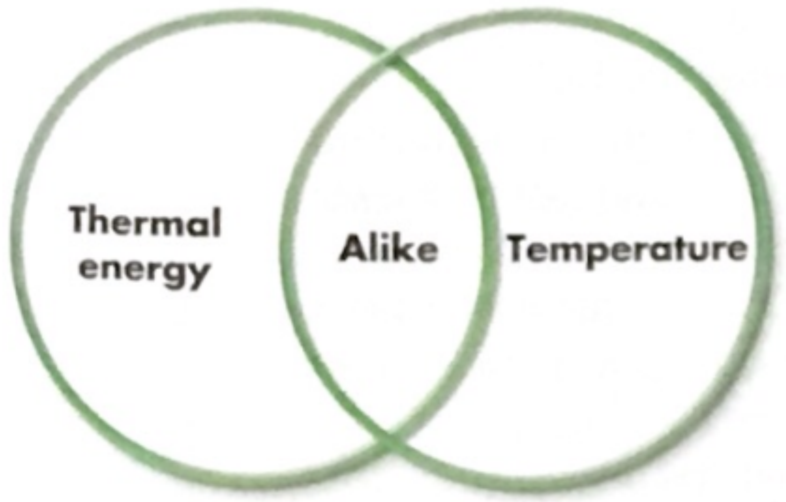
10. Suppose you have a large container of warm water. You pour half the water into a second container. Tell whether the amount of thermal energy and the temperature in the first container would be affected after half the water is poured into the second container.
11. Why do some objects appear black? Why do other objects appear white?
12. Identify and describe the ways that heat is being transferred in the picture below.

Process Skills

13. **Predict** Would you expect a light wave to change speed as it moves from the air into a glass window? Would you expect it to change direction? Explain your answers.
14. **Experiment** Which is a better heat insulator—cotton or nylon? Design an experiment to answer this question. Write a paragraph that describes your experiment.

Compare and Contrast

15. Make a graphic organizer like the one shown below. Show how thermal energy and temperature are alike and how they are different.



Test Prep

Choose the letter that best completes the statement or answers the question.

16. Which electromagnetic waves have higher frequencies than ultraviolet waves?
    Ⓐ infrared waves
    Ⓑ microwaves
    Ⓒ radio waves
    Ⓓ X rays
17. If a compressional wave moves through matter from left to right, the matter
    Ⓕ moves from left to right.
    Ⓖ moves up and down.
    Ⓗ moves back and forth.
    Ⓘ does not move.
18. When heat moves by conduction from one end of a metal spoon to the other,
    Ⓐ the temperature of the spoon decreases.
    Ⓑ the thermal energy of the spoon increases.
    Ⓒ particles move from one end of the spoon to the other.
    Ⓓ vibrations are passed among particles of the spoon.
19. Explain why the answer you chose for Question 18 is best. For each of the answers you did not choose, give a reason why it is not the best choice.
20. **Writing in Science** **Descriptive** Write a paragraph that describes how insulators prevent the movement of heat.