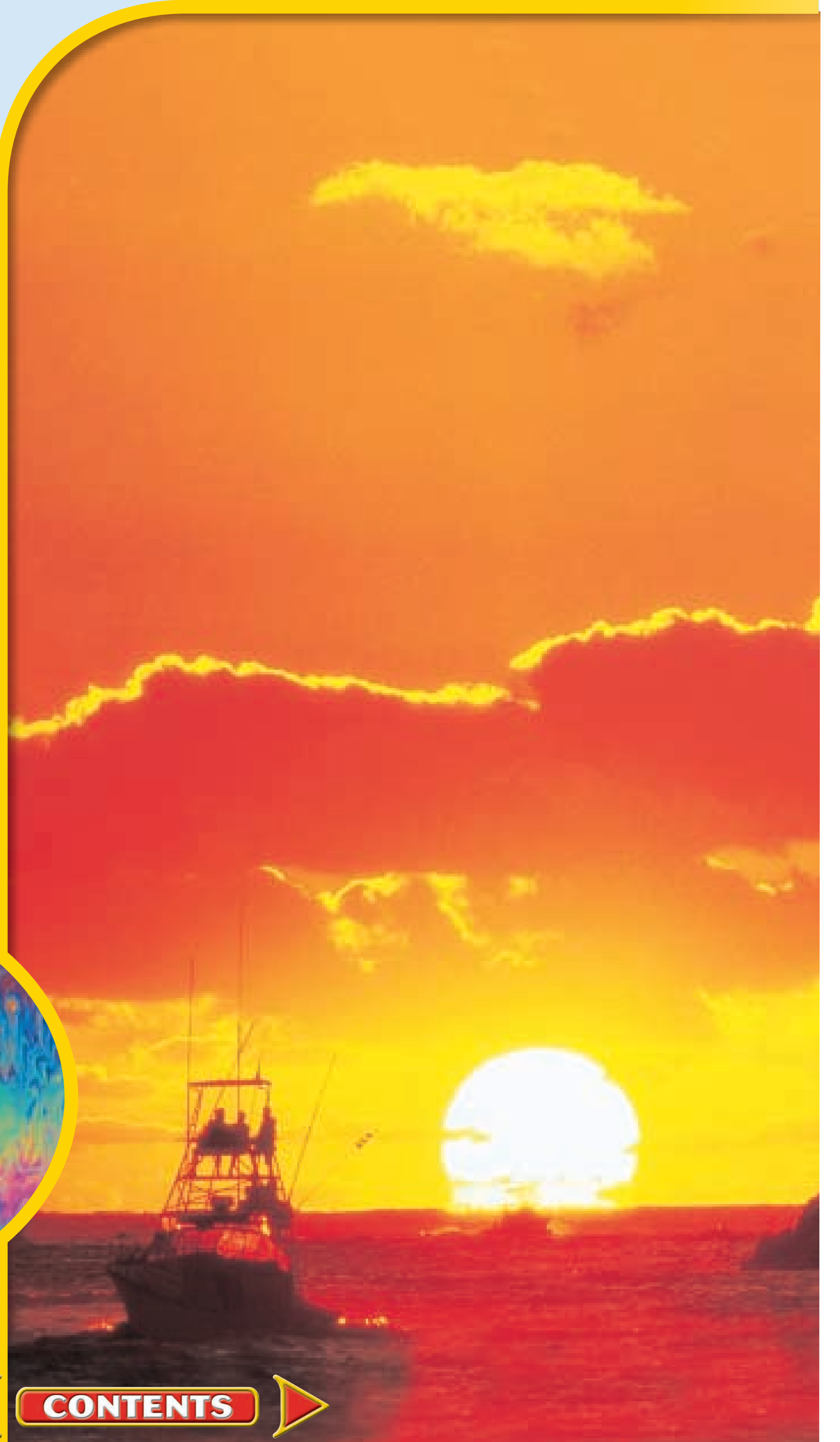
CHAPTER 14

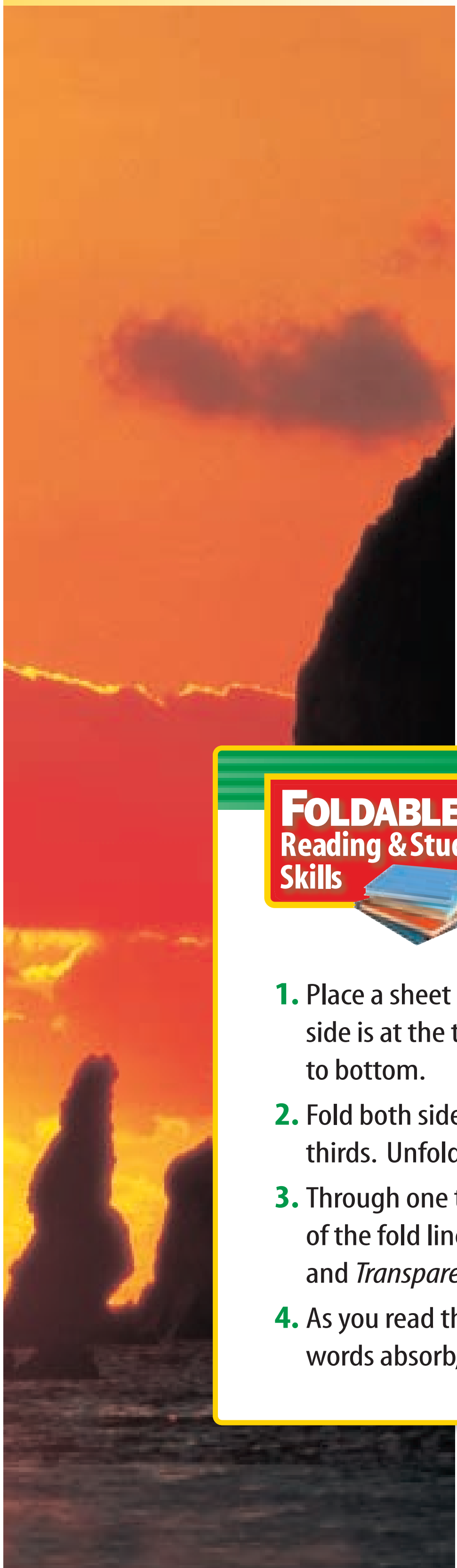
Light

A sunrise over the ocean is a spectacle of light and color. As the sun tops the horizon, sea and sky explode into an array of reds, pinks, and oranges. Why does the sky appear red? How are its colors reflected in the water? In this chapter, you will learn about light—how it travels, bends, reflects, and enables you to see different colors. You will also learn how different kinds of bulbs produce light and how light is used by lasers, optical scanners, and optical fibers.



What do you think?

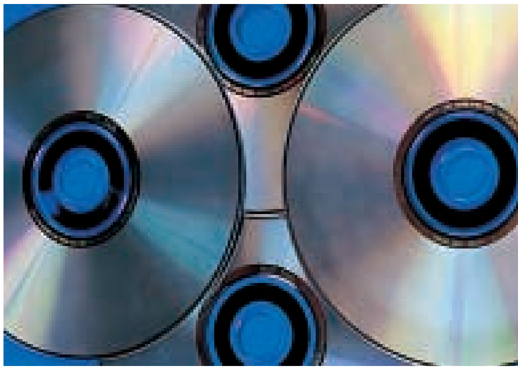
Science Journal Look at the picture below with a classmate. Discuss what this might be or what is happening. Here's a hint: *It's full of air and doesn't last long.* Write your answer or best guess in your Science Journal.



EXPLORE ACTIVITY

Light passing through a prism can produce exciting patterns of color. Imagine what your surroundings would look like now if humans could see only shades of gray instead of distinct colors. The ability to see color depends on the cells in your eyes that are sensitive to different wavelengths of light. What color is the light produced by a flashlight or the sun?

Make your own rainbow



1. In a darkened room, shine a flashlight through a glass prism. Project the resulting colors onto a white wall or ceiling.
2. In a darkened room, shine a flashlight over the surface of some water with dishwashing liquid bubbles in it. What do you see?
3. Aim a flashlight at the surface of a compact disc.

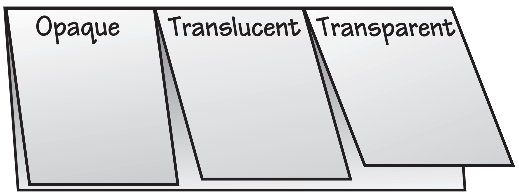
Observe

How did your observations in each case differ? In your Science Journal, explain where you think the colors came from.

Before You Read

FOLDABLES Reading & Study Skills

Making a Compare and Contrast Study Fold **Make the following Foldable to compare and contrast the characteristics of opaque, translucent, and transparent.**



1. Place a sheet of paper in front of you so the short side is at the top. Fold the paper in half from top to bottom.
2. Fold both sides in to divide the paper into equal thirds. Unfold the paper so three sections show.
3. Through one thickness of paper, cut along each of the fold lines to the topfold, forming three tabs. Label each tab *Opaque, Translucent*, and *Transparent* as shown.
4. As you read the chapter, write characteristics of these materials under the tabs, using the words absorb, reflect, and transmit.

SECTION 1

The Behavior of Light

As You Read

What You'll Learn

- **Describe** the differences among opaque, transparent, and translucent materials.
- **Explain** how light is reflected.
- **Discuss** how refraction separates white light.

Vocabulary

- opaque
- translucent
- transparent
- index of refraction
- mirage

Why It's Important

Knowing how light behaves will help you understand various sights, such as reflections in a store window, rainbows, and mirages.

Light and Matter

Look around your room after turning off the lights at night. At first you can't see anything, but as your eyes adjust to the darkness, you begin to recognize some familiar objects. You know that some of the objects are brightly colored, but they look gray or black in the dim light. Turn on the light, and you clearly can see all the objects in the room, including their colors. What you see depends on the amount of light in the room and the color of the objects. To see an object, it must reflect some light back to your eyes.

Opaque, Transparent, and Translucent Objects can absorb light, reflect light, and allow light to pass through them. The type of matter in an object determines the amount of light it absorbs, reflects, and transmits. For example, the **opaque** (oh PAYK) material in the candleholder in **Figure 1A,** only absorbs and reflects light—no light passes through it. As a result, you cannot see the candle inside.

Other materials allow some light to pass through, but you cannot see clearly through them. These are **translucent** (trans LEW sunt) materials, like the candleholder in **Figure 1B.**

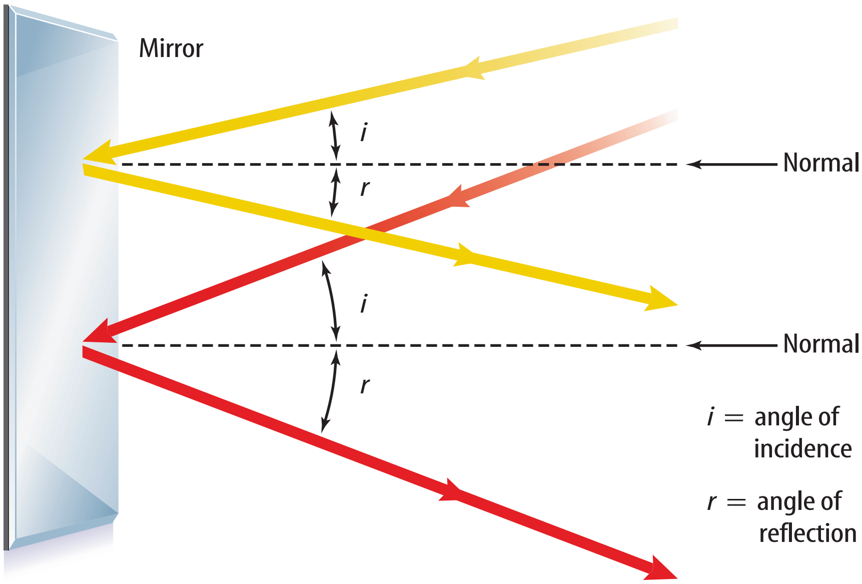
Transparent materials like the candleholder in **Figure 1C** transmit almost all of the light that strikes them, so you can see objects clearly through them. Only a small amount of light is absorbed and reflected.

Figure 1
These candleholders have different light-transmitting properties.

A Opaque **B** Translucent **C** Transparent

Reflection of Light

Just before you left for school this morning, did you take one last glance in a mirror to check your appearance? To see your reflection in the mirror, light had to reflect off you, hit the mirror, and reflect off the mirror into your eye. Reflection occurs when a light wave strikes an object and bounces off.



The Law of Reflection

Because light behaves as a wave, it obeys the law of reflection, as shown in **Figure 2.** According to the law of reflection, the angle at which a light wave strikes a surface is the same as the angle at which it is reflected. Light reflected from any surface—a mirror or a sheet of paper—follows this law.

Figure 2
Light is reflected according to the law of reflection so that the angle of incidence always equals the angle of reflection.

Regular and Diffuse Reflection Why can you see your reflection in a store window but not in a brick wall? The answer has to do with the smoothness of the surfaces. A smooth, even surface like that of a pane of glass produces a sharp image by reflecting parallel light waves in only one direction. Reflection of light waves from a smooth surface is regular reflection. A brick wall has an uneven surface that causes incoming parallel light waves to be reflected in many directions, as shown in **Figure 3.** Reflection of light from a rough surface is diffuse reflection.

Reading Check *What is diffuse reflection?*

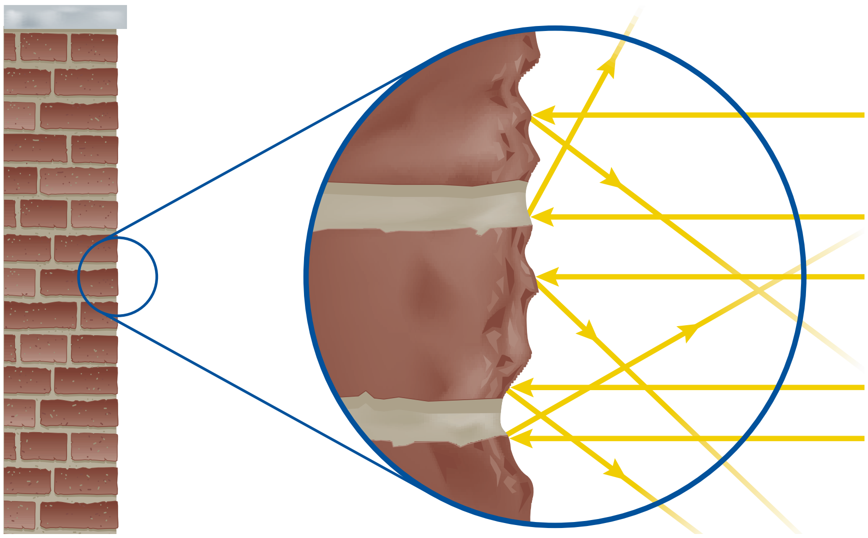
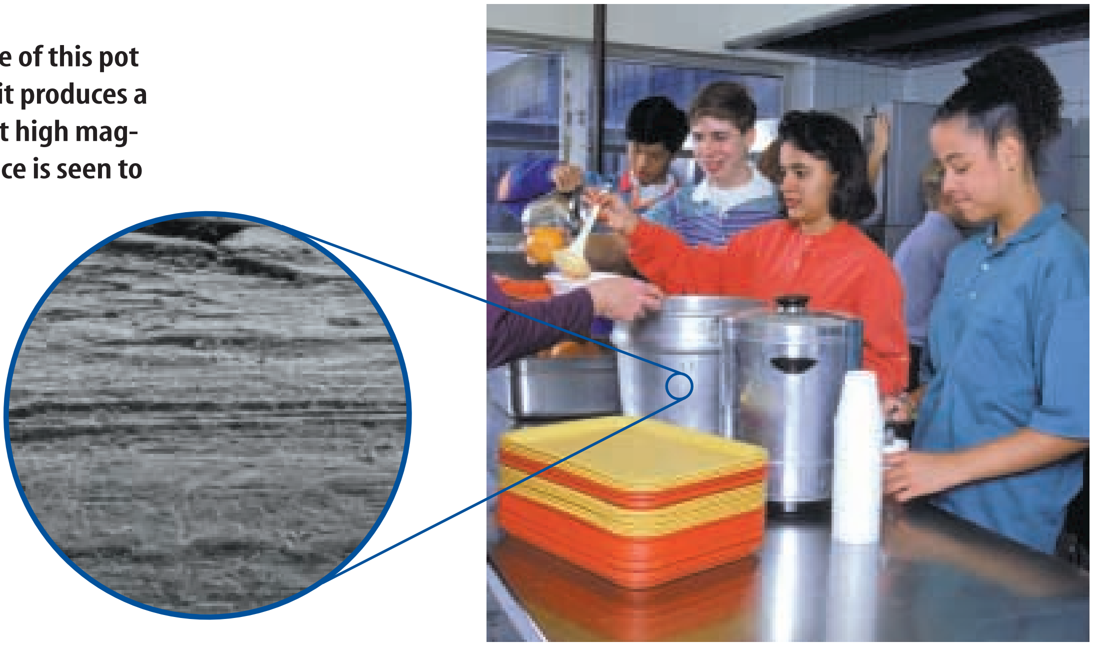


Figure 3
This brick wall has an uneven surface, so it produces a diffuse reflection.

Figure 4
Although the surface of this pot may seem smooth, it produces a diffuse reflection. At high magnification, the surface is seen to be rough.



Roughness of Surfaces Even a surface that appears to be smooth can be rough enough to cause diffuse reflection. For example, a metal pot might seem smooth, but at high magnification, the surface shows rough spots, as shown **Figure 4.** To cause a regular reflection, the roughness of the surface must be less than the wavelengths it reflects.

Refraction of Light

What occurs when a light wave passes from one material to another—from air to water, for example? Refraction is caused by a change in the speed of a wave when it passes from one material to another. If the light wave is traveling at an angle and the speed that light travels is different in the two materials, the wave will be bent, or refracted.

Reading Check *How does refraction occur?*

Figure 5
The spoon looks bent in the water because the light waves are refracted as they change speed when they pass from the water to the air.

The Index of Refraction The amount of bending that takes place depends on the speed of light in both materials. The greater the difference is, the more the light will be bent as it passes at an angle from one material to the other. **Figure 5** shows an example of refraction. Every material has an **index of refraction**—a property of the material that indicates how much it reduces the speed of light.

The larger the index of refraction, the more light is slowed down in the material. For example, because glass has a larger index of refraction than air, light moves more slowly in glass than air. Many useful devices like eyeglasses, binoculars, cameras, and microscopes form images using refraction.

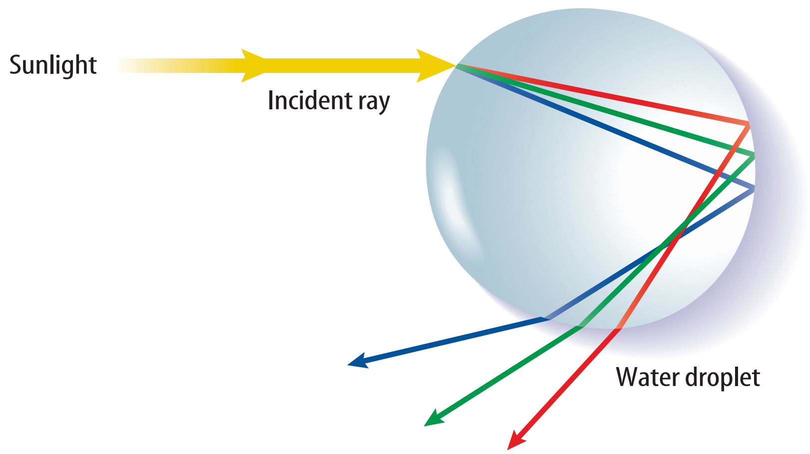
Prisms A sparkling glass prism hangs in a sunny window, refracting the sunlight and projecting a colorful pattern onto the walls of the room. How does the bending of light create these colors? It occurs because the amount of bending usually depends on the wavelength of the light. Wavelengths of visible light range from the longer red waves to the shorter violet waves. White light, such as sunlight, is made up of this whole range of wavelengths.

Figure 6 shows what occurs when white light passes through a prism. The triangular prism refracts the light twice—once when it enters the prism and again when it leaves the prism and reenters the air. Because the longer wavelengths of light are refracted less than the shorter wavelengths are, red light is bent the least. As a result of these different amounts of bending, the different colors are separated when they emerge from the prism. Which color of light would you expect to bend the most?

Figure 6
Refraction causes a prism to separate a beam of white light into different colors.

Rainbows Does the light leaving the prism in **Figure 6** remind you of a rainbow? Like prisms, rain droplets also refract light. The refraction of the different wavelengths can cause white light from the Sun to separate into the individual colors of visible light, as shown in **Figure 7.** In a rainbow, the human eye usually can distinguish only about seven colors clearly. In order of decreasing wavelength, these colors are red, orange, yellow, green, blue, indigo, and violet.

Figure 7
As white light passes through the water droplet, different wavelengths are refracted by different amounts. This produces the separate colors seen in a rainbow.



TRY AT HOME Mini LAB

Observing Refraction in Water

Procedure

1. Place a **penny** at the bottom of a **short, opaque cup.** Set it on a **table** in front of you.
2. Have a partner slowly slide the cup away from you until you can't see the penny.
3. Without disturbing the penny or the cup and without moving your position, have your partner slowly pour **water** into the cup until you can see the penny.
4. Reverse roles and repeat the experiment.

Analysis

1. What did you observe? Explain how this is possible.
2. In your **Science Journal,** sketch the light path from the penny to your eye after the water was added.

Figure 8
Mirages result when air near the ground is much warmer or cooler than the air above. This causes some lightwaves reflected from the object to refract, creating one or more additional images.

Mirages When you're riding in a car on a hot day, you might see something that looks like a shimmering pool of water on the road ahead. As you get closer, the water seems to disappear. What you saw was a mirage. A **mirage** is an image of a distant object produced by the refraction of light through air layers of different densities. The density of air increases as the air gets cooler. The greater the difference in densities is, the more the light is refracted. Mirages result when the air at ground level is much warmer or much cooler than the layers of air above it, as **Figure 8** shows. The image you see is always some distance away from the actual object. For example, the water you think you see on a hot road surface sometimes is an image of the sky.

Section 1 Assessment

1. Contrast opaque, transparent, and translucent materials. Give at least one example of each.
2. Explain why you can see your reflection in a smooth piece of aluminum foil but not in a crumpled ball of foil.
3. Why are you more likely to see a mirage on a hot day than on a mild day?
4. What happens to white light when it passes through a prism?
5. **Think Critically** Consider the following parts of your body: the lens of your eye, a fingernail, your skin, and a tooth. Decide whether each of these is opaque, transparent, or translucent. Explain.

Skill Builder Activities

6. **Making and Using Tables** Construct a table that shows the light-reflecting or light-absorbing properties of different materials. Use the words *opaque, transparent,* and *translucent.* **For more help, refer to the Science Skill Handbook.**
7. **Communicating** Walk around your classroom noting five reflecting objects. Which objects display diffuse reflection and which display regular reflection? How does the surface differ on each? For each object you note, list the colors the object is absorbing. **For more help, refer to the Science Skill Handbook.**

SECTION 2

Light and Color

Colors

Why do some apples appear red, while others look green or yellow? An object's color depends on the wavelength of light it reflects. You know that white light is a blend of all colors of visible light. When a red apple is struck by white light, it reflects red light back to your eyes and absorbs all of the other colors. **Figure 9** shows white light striking a green leaf. Only the green light is reflected to your eyes.

Although some objects appear to be black, black isn't a color that is present in visible light. Objects that appear black absorb all colors of light and reflect little or no light back to your eye. White objects appear to be white because they reflect all colors of visible light.

Reading Check *Why does a white object appear white?*

Colored Filters Wearing tinted glasses changes the color of almost everything you look at. If the lenses are yellow, the world takes on a golden glow. If they are rose colored, everything looks rosy. Something similar would occur if you placed a colored, clear plastic sheet over this white page. The paper would appear to be the same color as the plastic. The plastic sheet and the tinted lenses are filters. A filter is a transparent material that transmits one or more colors of light but absorbs all others. The color of a filter is the color of the light that it transmits.

As You Read

What You'll Learn

- **Explain** how you see color.
- **Describe** the difference between light color and pigment color.
- **Predict** what happens when different colors are mixed.

Vocabulary

pigment

Why It's Important

From traffic lights to great works of art, color plays an important role in your world.

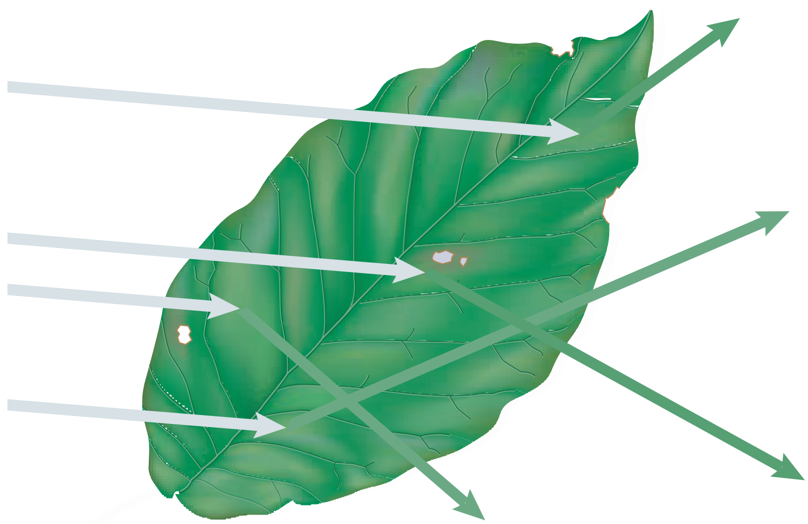


Figure 9
This green leaf absorbs all wavelengths of visible light except green.

Figure 10
The color of this cooler seems to change under different lighting conditions.

A **The blue cooler is shown in white light.**

B **The cooler appears blue when viewed through a blue filter.**

C **The cooler appears black through a red filter.**

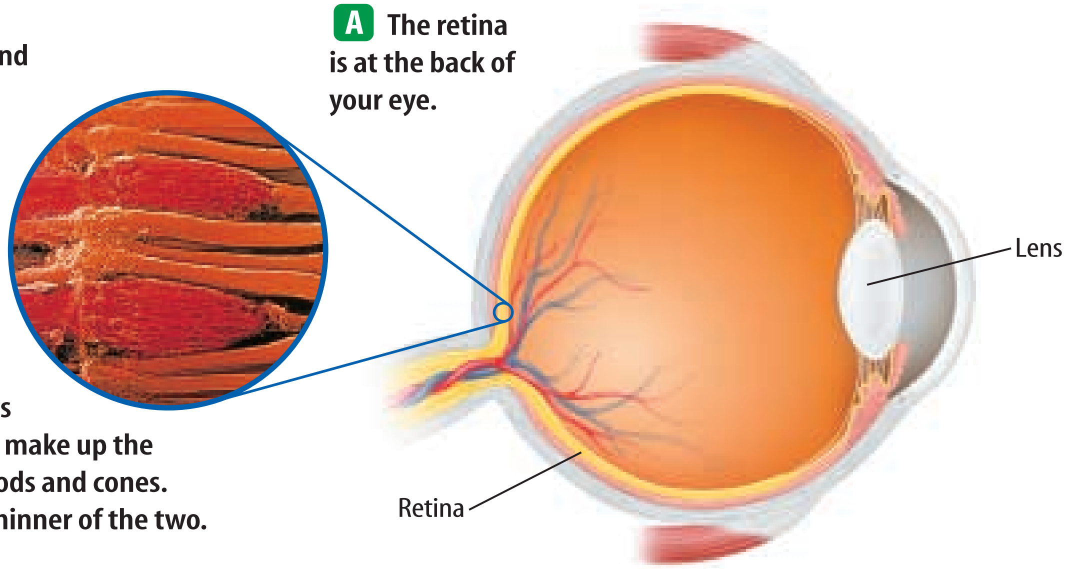
Looking Through Colored Filters **Figure 10** shows what happens when you look at a colored object through various colored filters. In the white light in **Figure 10A,** a blue cooler looks blue because it reflects only the blue light in the white light striking it. It absorbs the light of all other colors. If you look at the cooler through a blue filter as in **Figure 10B,** the cooler still looks blue because the filter transmits the reflected blue light. **Figure 10C** shows how the cooler looks when you examine it through a red filter. Why does it appear to be black?

Seeing Color

As you approach a busy intersection, the color of the traffic light changes from green to yellow to red. On the cross street, the color changes from red to green. At a busy intersection, traffic safety depends on your ability to detect immediate color changes. How do you see colors?

Light and the Eye In a healthy eye, light enters and is focused on the retina, an area on the inside of your eyeball, as shown in **Figure 11A.** The retina is made up of two types of cells that absorb light, as shown in **Figure 11B.** When these cells absorb light energy, chemical reactions convert light energy into nerve impulses that are transmitted to the brain. One type of cell in the retina, called a cone, allows you to distinguish colors and detailed shapes of objects. Cones are most effective in daytime vision. Why?

Figure 11
Light enters the eye and focuses on the retina.



A The retina is at the back of your eye.

B The two types of nerve cells that make up the retina are called rods and cones. The rods are the thinner of the two.

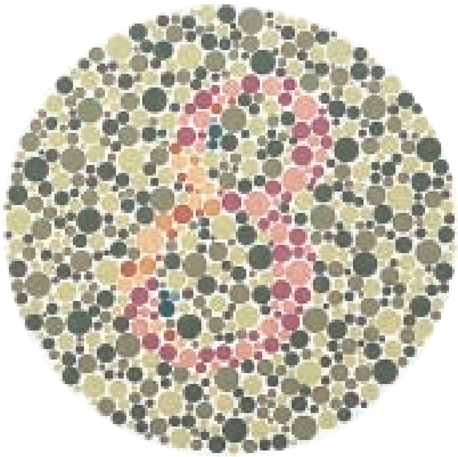
Cones and Rods Your eyes have three types of cones, each of which responds to a different range of wavelengths. Red cones respond to mostly red and yellow, green cones respond to mostly yellow and green, and blue cones respond to mostly blue and violet. The second type of cell, called a rod, is sensitive to dim light and is useful for night vision.

Life Science INTEGRATION

Interpreting Color Why does a banana look yellow? The light reflected by the banana causes the cone cells that are sensitive to red and green light to send signals to your brain. Your brain would get the same signal if a mixture of red light and green light reached your eye. Again, your red and green cones would respond, and you would see yellow light because your brain can't perceive the difference between incoming yellow light and yellow light produced by combining red and green light. The next time you are at a play or a concert, look at the lighting above the stage. Watch how the colored lights combine to produce effects onstage.

Color Blindness If one or more of your sets of cones did not function properly, you would not be able to distinguish between certain colors. About eight percent of men and one-half percent of women have a form of color blindness. Most people who are said to be color blind are not truly blind to color, but they have difficulty distinguishing between a few colors, most commonly red and green. **Figure 12** shows a plate of a color blindness test. Because these two colors are used in traffic signals, drivers and pedestrians must be able to identify them.

Figure 12
Color blindness is an inherited sex-linked condition in which certain cones do not function properly. *What number do you see in the dots?*



CONTENTS

Mixing Colors

If you have ever browsed through a paint store, you have probably seen displays where customers can select paint samples of almost every imaginable color. The colors are a result of mixtures of pigments. For example, you might have mixed blue and yellow paint to produce green paint. A pigment is a colored material that absorbs some colors and reflects other colors. The color of a pigment results from the different wavelengths of light that the pigment reflects.

Life Science INTEGRATION

Plant pigments allow plants to select the wavelengths of light they use for photosynthesis. Leaves usually look green due to the pigment chlorophyll. Chlorophyll absorbs most wavelengths of visible light except green, which it reflects. But not all plants are green. Research different plant pigments to find how they allow plant species to survive in diverse habitats.

Mixing Colored Lights From the glowing orange of a sunset to the deep blue of a mountain lake, all the colors you see can be made by mixing of three colors of light. These three colors—red, green, and blue—are the primary colors of light. They correspond to the three different types of cones in the retina of your eye. When mixed together in equal amounts, they produce white light, as **Figure 13** shows. Mixing the primary colors in different proportions can produce the colors you see.

Reading Check *What are primary colors?*

Paint Pigments If you were to mix equal amounts of red, green, and blue paint, would you get white paint? If mixing colors of paint were like mixing colors of light, you would, but mixing paint is different. Paints are made with pigments. Paint pigments usually are made of chemical compounds such as titanium oxide, a bright white pigment, and lead chromate, which is used for painting yellow lines on highways.

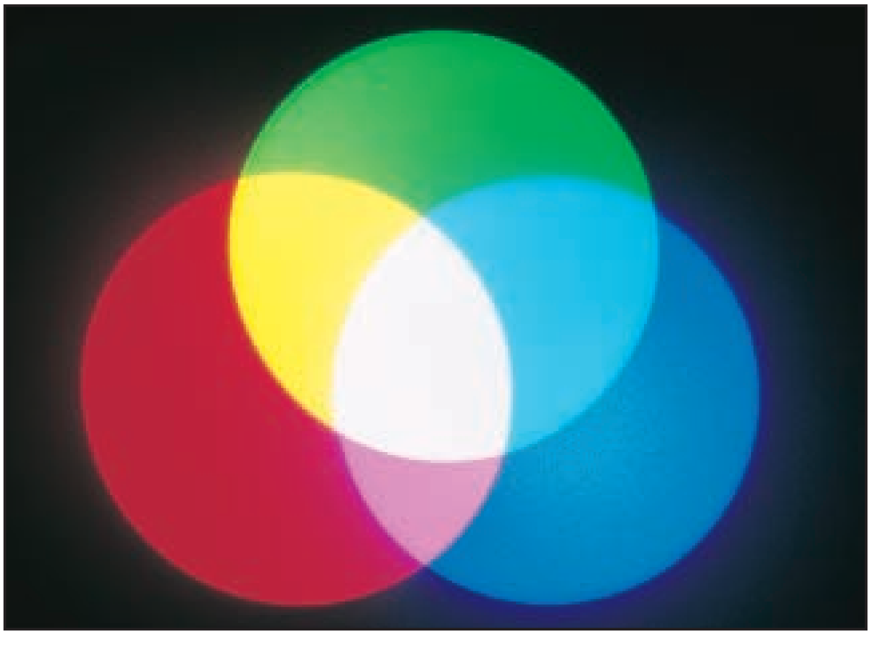


Figure 13
White light is produced when the three primary colors of light are mixed.

Mixing Pigments You can make any pigment color by mixing different amounts of the three primary pigments—magenta (bluish red), cyan (greenish blue), and yellow. In fact, color printers use those pigments to make full-color prints like the pages in this book. However, color printers also use black ink to produce a true black color. A primary pigment's color depends on the color of light it reflects. Actually, pigments both absorb and reflect a range of colors in sending a single color message to your eye. For example, in white light, the yellow pigment appears yellow because it reflects yellow, red, orange, and green light but absorbs blue and violet light. The color of a mixture of two primary pigments is determined by the primary colors of light that both pigments reflect.

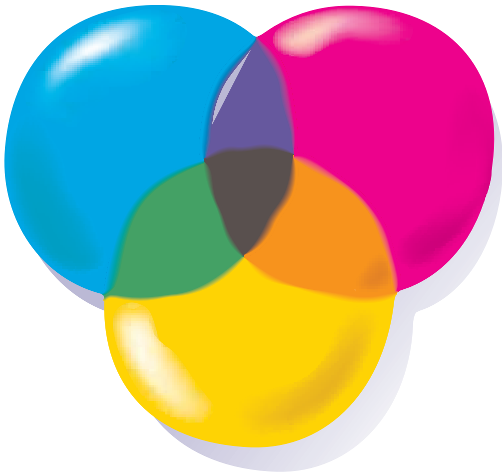


Figure 14
The three primary colors of pigment appear to be black when they are mixed.

Reading Check *What colors are the three primary pigments?*

Look at **Figure 14.** The area in the center where the colors all overlap appears to be black because the three blended primary pigments absorb all the primary colors of light. Recall that the primary colors of light combine to produce white light. They are called additive colors. However, the primary pigment colors combine to produce black. Because black results from the absence of reflected light, the primary pigments are called subtractive colors.

Section 2 Assessment

1. If a white light shines on a red shirt, what colors are reflected and what colors are absorbed?
2. How do the primary colors of light differ from the primary pigment colors?
3. Explain why a person with color blindness can distinguish among some colors but not others.
4. If all colors are present in white light, why does a white fence appear to be white instead of multicolored?
5. **Think Critically** If you had only magenta, cyan, and yellow paints, could you paint a picture of a zebra? Explain why this would or would not be possible.

Skill Builder Activities

6. **Concept Mapping** Design a concept map to show the chain of events that must happen for you to see a blue object. Work with a partner. **For more help, refer to the Science Skill Handbook.**
7. **Researching Information** Research the electromagnetic spectrum to find the wavelength and frequency range of visible light. Make a poster showing the wavelengths for the seven main colors in the visible light spectrum. Explain the units used, and the relationship between wavelength and wave frequency. **For more help, refer to the Science Skill Handbook.**

SECTION 3

Producing Light

As You Read

What You'll Learn

- **Explain** how incandescent and fluorescent lightbulbs work.
- **Analyze** the advantages and disadvantages of different lighting devices.
- **Explain** how a laser produces coherent light.
- **Describe** various uses of lasers.

Vocabulary

incandescent light
fluorescent light
coherent light
incoherent light

Why It's Important

Knowing how different lighting devices work will help you choose the right one for your needs.

Incandescent Lights

It's only been 100 years or so since lightbulbs became common in households. Their shapes, sizes, and varieties today are a far cry from a single lightbulb swinging from an electric cord over a table. Most of the lightbulbs in your house produce incandescent light. Heating a piece of metal until it glows produces **incandescent light.** If you look into an unlit incandescent lightbulb, you will see a thin wire called the filament. It usually is made of the element tungsten. Turn on the light and electricity flows through the filament and causes it to heat up. When the tungsten filament gets hot, it gives off light. However, if you've ever accidentally touched a lit lightbulb, you know that it also produces a great deal of heat. More than 80 percent of the energy given off by incandescent bulbs is in the form of heat.

Reading Check *Why does an incandescent lightbulb get hot?*

Fluorescent Lights

Your house also may have fluorescent (floo RE sunt) lights. A fluorescent bulb, like the one shown in **Figure 15,** is filled with a gas at low pressure. The inside of the bulb is coated with phosphors that emit visible light when they absorb ultraviolet radiation. The tube also contains electrodes at each end. Electrons are given off when the electrodes are connected in a circuit. When these electrons collide with the gas atoms, ultraviolet radiation is emitted. The phosphors on the inside of the bulb absorb this radiation and give off visible light.

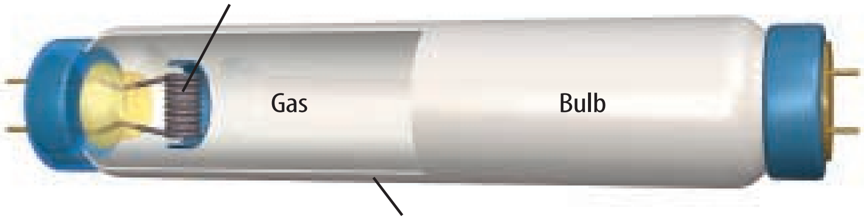


Figure 15
Fluorescent lightbulbs do not use filaments. *What property of phosphors makes them useful in fluorescent bulbs?*

Efficient Lighting A **fluorescent light** uses phosphors to convert ultraviolet radiation to visible light. Fluorescent lights use as little as one fifth the electrical energy to produce the same amount of light as incandescent bulbs. Fluorescent bulbs also last much longer than incandescent bulbs. This higher efficiency can mean lower energy costs over the life of the bulb. Reduced energy usage could reduce the amount of fossil fuels burned to generate electricity, which also decreases the amount of carbon dioxide and pollutants released into Earth's atmosphere.

Fluorescent bulbs are used widely in hospitals, office buildings, schools, and factories. Compact fluorescent bulbs, which can be screwed into traditional lightbulb sockets, have been developed that are more practical for use in homes.

Neon Lights

The vivid, glowing colors of neon lights, such as those shown in **Figure 16,** make them a popular choice for signs and eye-catching decorations on buildings. These lighting devices are glass tubes filled with gas, typically neon, and work similarly to fluorescent lights. When an electric current flows through the tube, electrons collide with the gas molecules. In this case, however, the collisions produce visible light. If the tube contains only neon, the light is bright red. Different colors can be produced by adding other gases to the tube.

Reading Check *What causes the color in a neon light?*

Mini LAB

Discovering Energy Waste in Lightbulbs

Procedure

1. Obtain an **incandescent bulb** and a **fluorescent bulb** of identical wattage.
2. Make a heat collector by covering the top of a **foam cup** with a piece of **plastic food wrap** to make a window. Carefully make a small hole (diameter less than the thermometer's) in the side of the cup. Push a **thermometer** through the hole.
3. Measure the temperature of the air inside the cup. Then, hold the window of the tester 1 cm from one of the lights for 2 minutes and measure the temperature.
4. Cool the heat collector and thermometer. Repeat step 3 using the second bulb.

Analysis

1. What was the temperature for each bulb?
2. Which bulb appears to give off more heat? Explain why this occurs.

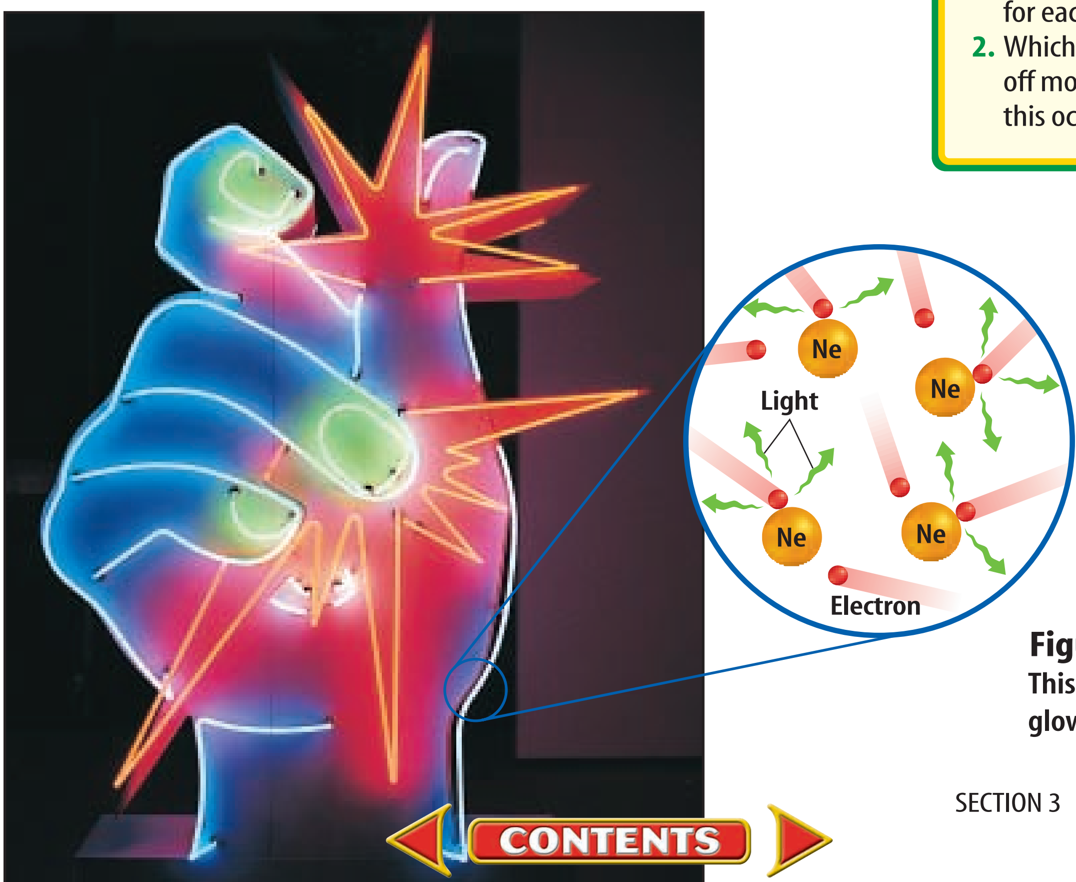


Figure 16
This neon light has vivid, glowing colors.

Sodium-Vapor Lights

Sodium-vapor lights often are used for streetlights and other outdoor lighting. Inside a sodium-vapor lamp is a tube that contains a mixture of neon gas, a small amount of argon gas, and a small amount of sodium metal. When the lamp is turned on, the gas mixture becomes hot. The hot gases cause the sodium metal to turn to vapor, and the hot sodium vapor emits a yellow-orange glow, as shown in **Figure 17.**

Figure 17
Sodium-vapor lights emit mostly yellow light. Half of this photo was taken under sunlight and half was taken under sodium-vapor lighting.

Tungsten-Halogen Lights

Tungsten-halogen lights sometimes are used to create intensely bright light. These lights have a tungsten filament inside a quartz bulb or tube. The tube is filled with a gas that contains one of the halogen elements such as fluorine or chlorine. The presence of this gas enables the filament to become much hotter than the filament in an ordinary incandescent bulb. As a result, the light is much brighter and also lasts longer. Tungsten-halogen lights sometimes are used on movie sets and in underwater photography.

Lasers

From laser surgery to a laser light show, lasers have become a large part of the world you live in. A laser's light begins when a number of light waves are emitted at the same time. To achieve this, a number of identical atoms each must be given the same amount of energy. When they release their energy, each atom sends off an identical light wave. This light wave is reflected between two facing mirrors at opposite ends of the laser. One of the mirrors is coated only partially with reflective material, so it reflects most light but allows some to get through. Some emitted light waves travel back and forth between the mirrors many times, stimulating other atoms to emit identical light waves also. **Figure 18** shows how this process produces a beam of laser light.

Reading Check *How do mirrors help in creating lasers?*

Lasers can be made with many different materials, including gases, liquids, and solids. One of the most common is the helium-neon laser, which produces a beam of red light. A mixture of helium and neon gases sealed in a tube with mirrors at both ends is excited by a flashtube. The excited atoms then lose their excess energy by emitting coherent light waves.

SCIENCE Online

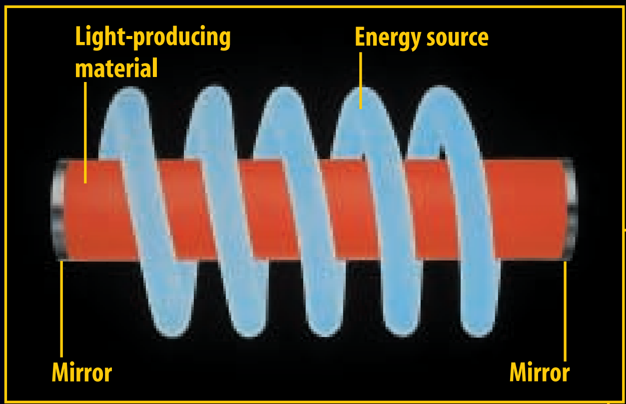
Research Visit the Glencoe Science Web site at **science.glencoe.com** for more information about sodium vapor lights and light pollution.

CLICK HERE

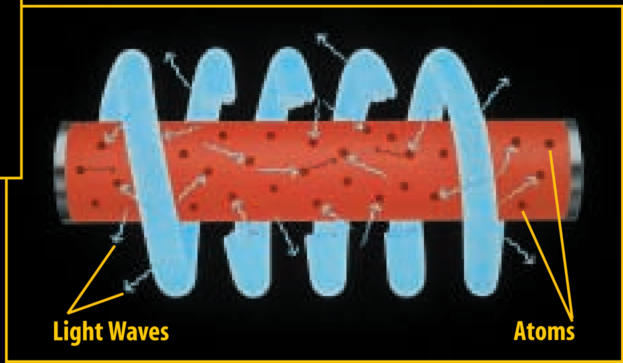
NATIONAL GEOGRAPHIC VISUALIZING LASERS

Figure 18

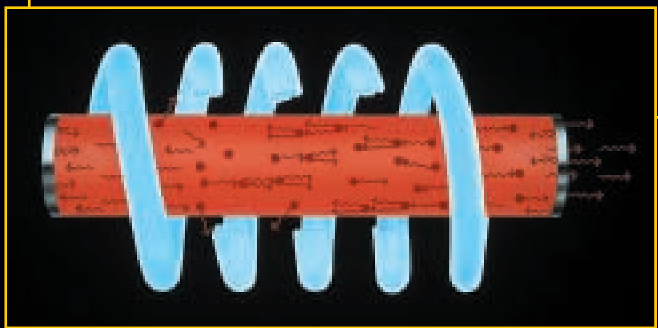
Lasers produce light waves that have the same wavelength. Almost all of these waves travel in the same direction and are in phase. As a result, beams of laser light can be made more intense than ordinary light. In modern eye surgery, shown at the right, lasers are often used instead of a traditional scalpel.



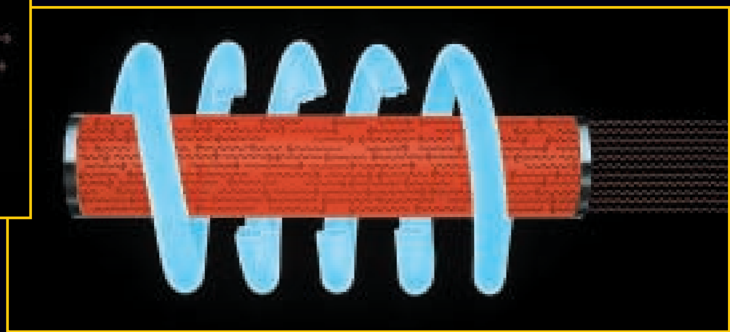
A The key parts of a laser include a material that can be stimulated to produce light, such as a ruby rod, and an energy source. In this example, the energy source is a lamp that spirals around the ruby rod and emits an intense light.



B When the lamp flashes, energy is absorbed by the atoms in the rod. These atoms then re-emit that energy as light waves that are in phase and have the same wavelength.

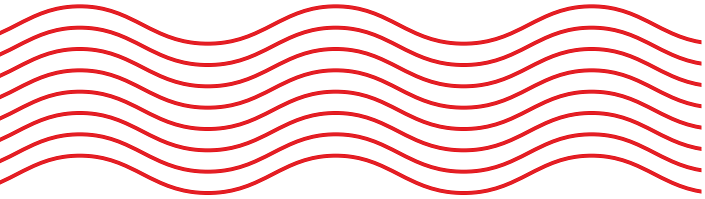


C Most of these waves are reflected between the mirrors located at each end of the laser. One of the mirrors, however, is only partially reflective, allowing one percent of the light waves to pass through it and form a beam.

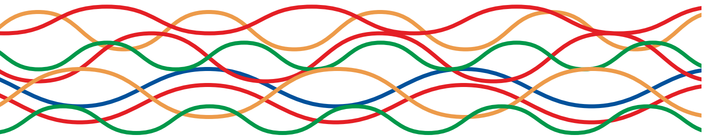


D As the waves travel back and forth between the mirrors, they stimulate other atoms in the ruby rod to emit light waves. In a fraction of a second, billions of identical waves are bouncing between the mirrors. The waves are emitted from the partially reflective mirror in a stream of laser light.

Figure 19
Light waves can be either coherent or incoherent.



A These waves are coherent because they have the same wavelength and travel with their crests and troughs aligned.



B Incoherent waves such as these can contain more than one wavelength, and do not travel with their crests and troughs aligned.

Coherent Light Lasers produce the narrow beams of light that zip across the stage and through the auditorium during some rock concerts. Beams of laser light do not spread out because laser light is coherent. **Coherent light** is light of only one wavelength that travels with its crests and troughs aligned. The beam does not spread out because all the waves travel in the same direction, as shown in **Figure 19A.** As a result, the energy carried by the beam remains concentrated over a small area.

Incoherent Light Light from an ordinary lightbulb is incoherent. **Incoherent light** can contain more than one wavelength, and its electromagnetic waves are not aligned, as in **Figure 19B.** The waves don't travel in the same direction, so the beam spreads out. The energy carried by the light waves is spread over a large area, so the intensity of the light is much less than that of the laser beam.

Using Lasers

Compact disc players, surgical tools, and many other useful devices take advantage of the unique properties of lasers. A laser beam is narrow and does not spread out as it travels over long distances. So lasers can apply large amounts of energy to small areas. In industry, powerful lasers are used for cutting and welding materials. Surveyors and builders use lasers for measuring and leveling. To measure the moon's orbit with great accuracy, scientists use laser light reflected from mirrors placed on the Moon's surface. Information also can be coded in pulses of light from lasers. This makes them useful for communications. In telephone systems, pulses of laser light transmit conversations through long glass fibers called optical fibers.

Lasers in Medicine Lasers are routinely used to remove cataracts, reshape the cornea, and repair the retina. In the eye and other parts of the body, surgeons can use lasers in place of scalpels to cut through body tissues. The energy from the laser seals off blood vessels in the incision and reduces bleeding. Because most lasers do not penetrate deeply through the skin, they can be used to remove small tumors or birthmarks on the surface without damaging deeper tissues. By sending laser light into the body through an optical fiber, physicians can also treat conditions such as blocked arteries.

Chemistry INTEGRATION

A particular helium-neon laser contains a mixture of 15 percent He and 85 percent Ne. Where are these gases located on the periodic table? Analyze their chemical characteristics. Would you be concerned that a chemical reaction might occur in the laser? Explain.

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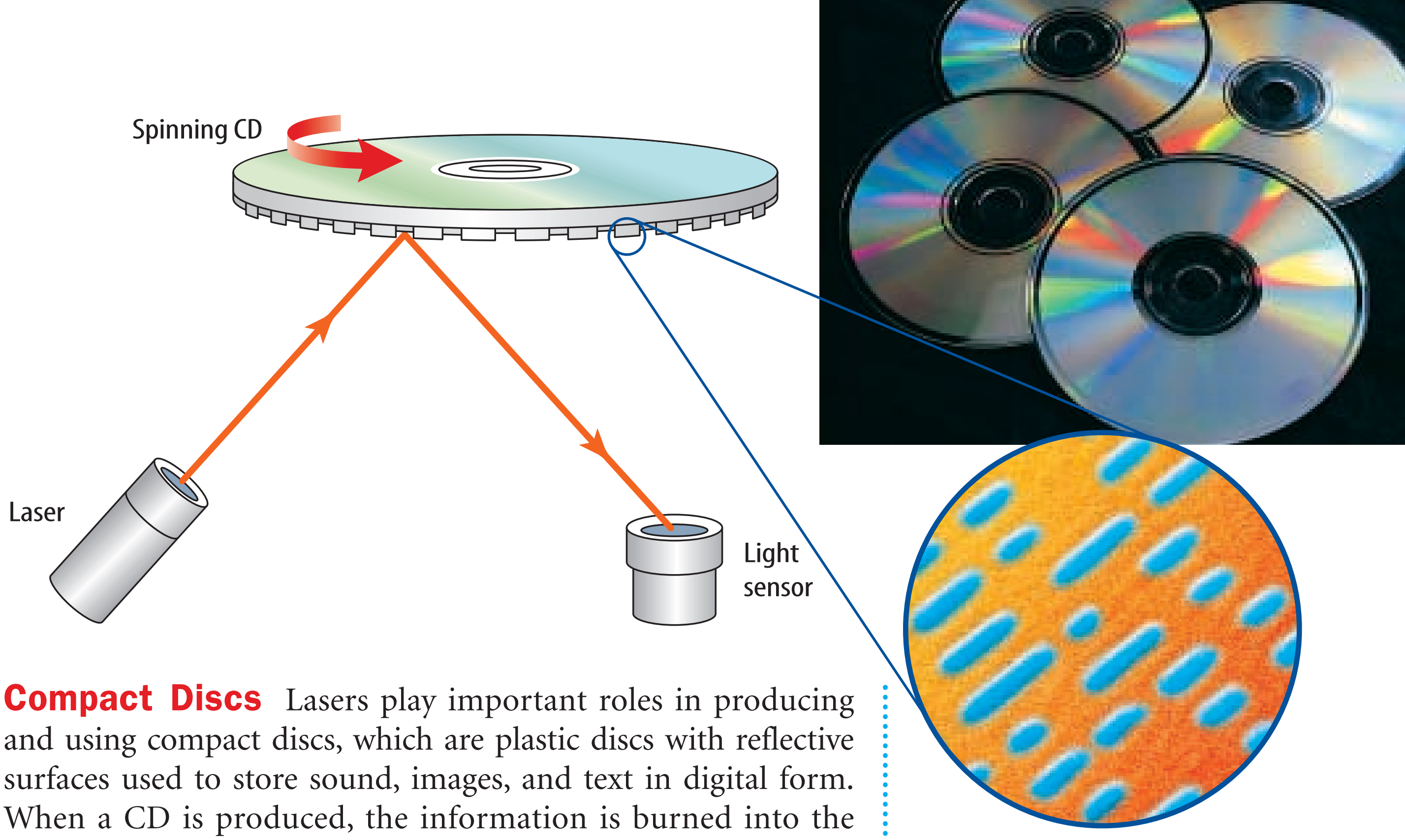

Figure 20
The blowup shows the pits (blue) on the bottom surface of a CD. A CD player uses a laser to convert the information on the CD to an electric signal.

Compact Discs Lasers play important roles in producing and using compact discs, which are plastic discs with reflective surfaces used to store sound, images, and text in digital form. When a CD is produced, the information is burned into the surface of the disc with a laser. The laser creates millions of tiny pits in a spiral pattern that starts at the center of the disc and moves out to the edge. A CD player, shown in **Figure 20,** also uses a laser to read the disc. The laser's beam is aimed at the surface of the disc. As the laser beam strikes a pit or flat spot, different amounts of light are reflected to a light sensor. The reflected light is converted to an electric signal used by the speakers to create sound.

Section 3 Assessment

1. Explain how light is produced in an ordinary incandescent bulb.
2. What are the advantages of using a fluorescent bulb instead of an incandescent bulb?
3. Describe the difference between coherent and incoherent light.
4. **Think Critically** Which type of lighting device would you use for each of the following needs: an economical light source in a manufacturing plant, an eye-catching sign that will be visible at night, and a baseball stadium? Explain.

Skill Builder Activities

5. **Concept Mapping** Make a concept map showing the sequence of events that occur in a laser to produce coherent light. Begin with the emission of lightwaves from atoms. **For more help, refer to the Science Skill Handbook.**
6. **Using an Electronic Spreadsheet** Create a spreadsheet listing the types of lighting devices described in this chapter. Compare and contrast their features in separate columns. Include a column for how each is used. **For more help, refer to the Technology Skill Handbook.**

CONTENTS

SECTION 4

Using Light

As You Read

What You'll Learn

- **Describe** polarized light and the uses of polarizing filters.
- **Apply** the concept of total internal reflection to the uses of optical fibers.

Vocabulary

polarized light
holography
total internal reflection

Why It's Important

Light is used in entertainment, medicine, manufacturing, scientific research, communications, and just about every other facet of life.

Polarized Light

You may have a pair of sunglasses with a sticker on them that says polarized. Do you know what makes them different from other sunglasses? The difference has to do with the vibration of light waves that pass through the lenses. You can make transverse waves in a rope vibrate in any direction—horizontal, vertical, or anywhere in between. Light also is a transverse wave and can vibrate in any direction. In **polarized light,** however, the waves vibrate in only one direction.

Polarizing Filters If the light passes through a special polarizing filter, the light becomes polarized. A polarizing filter acts like a group of parallel slits. Only light waves vibrating in the same direction as the slits can pass through. If a second polarizing filter is lined up with its slits at right angles to those of the first filter, no light can pass through, as **Figure 21** shows.

Polarized lenses are useful for reducing glare without interfering with your ability to see clearly. When light is reflected from a horizontal surface, such as a lake or a shiny car hood, it becomes partially horizontally polarized. The lenses of polarizing sunglasses have vertically polarized filters that block out the reflected light that has been polarized horizontally, while allowing vertically polarized light through.

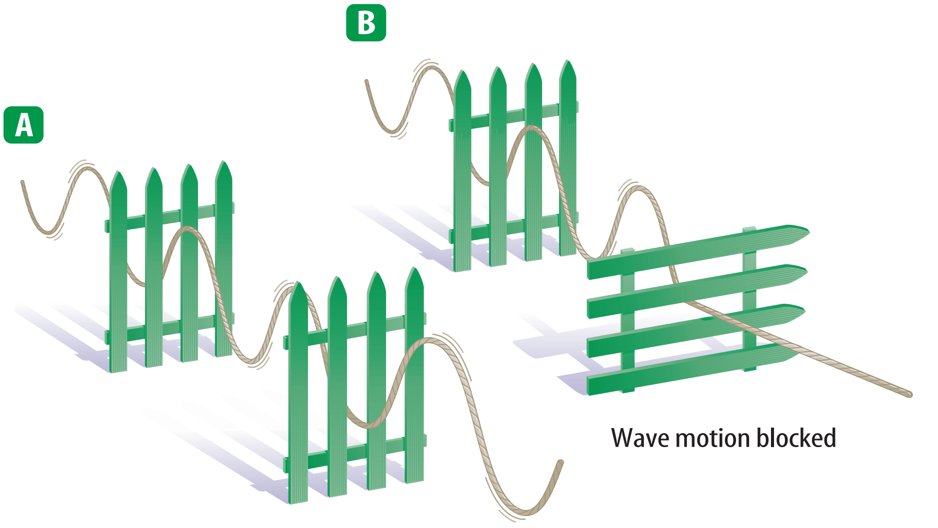

Figure 21
Slats in a fence behave like a polarizing filter for a transverse wave on a rope. A If the slats in the fence are in the same direction, the wave passes through. B If the slats are aligned at right angles to each other, the wave can't pass through.

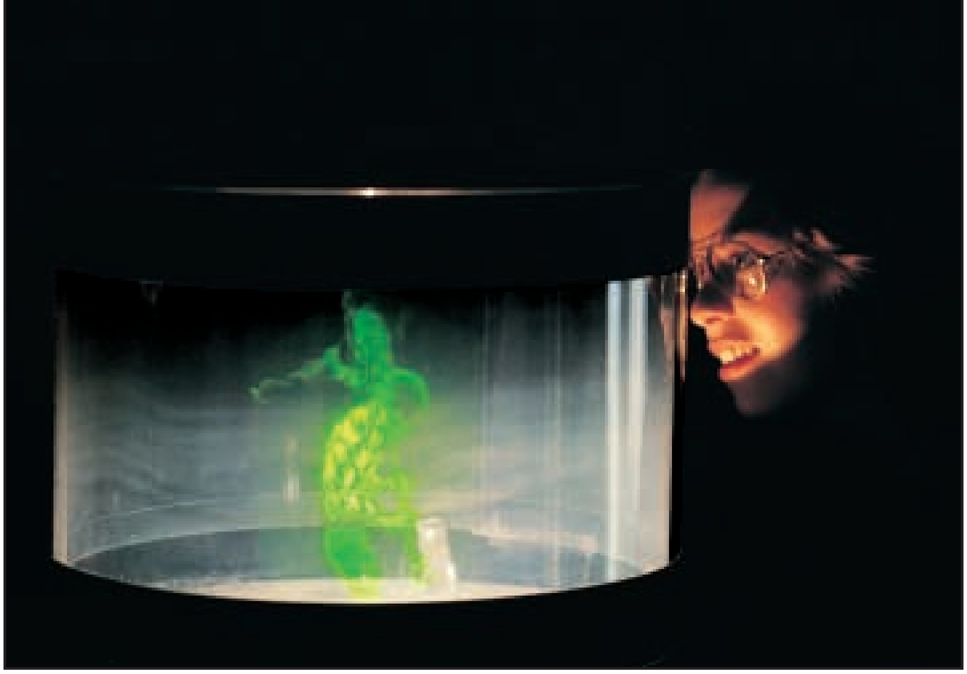

Figure 22
Lasers can be used to make holograms like this one.

Holography

Science museums often have exhibits where a three-dimensional image seems to float in space, like the one shown in **Figure 22.** You can see the image from different angles, just as you would if you passed the real object. Three-dimensional images on credit cards are produced by holography. **Holography** (hoh LAH gruh fee) is a technique that produces a hologram—a complete photographic image of a three-dimensional object.

Making Holograms Illuminating objects with laser light produces holograms. Laser light reflects from the object onto photographic film. At the same time, a second beam split from the laser also is directed at the film. The light from the two beams creates an interference pattern on the film. The pattern looks nothing like the original object, but when laser light shines on the pattern on the film, a holographic image is produced.

Information in Light An ordinary photographic image captures only the brightness or intensity of light reflected from an object's surface, but a hologram records the intensity as well as the direction. As a result, it conveys more information to your eye than a conventional two-dimensional photograph does, but it also is more difficult to copy. Holographic images are used on credit cards, identification cards, and on the labels of some products to help prevent counterfeiting. Using X-ray lasers, scientists can produce holographic images of microscopic objects. It may be possible to create three-dimensional views of biological cells.

Reading Check *How are holographic images produced?*

SCIENCE Online

Research Visit the Glencoe Science Web site at **science.glencoe.com** for more information about holograms. Communicate to your class what you learned.

CLICK HERE

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Optical Fibers

When laser light must travel long distances or be sent into hard-to-reach places, optical fibers often are used. These transparent glass fibers can transmit light from one place to another. A process called total internal reflection makes this possible.

Total Internal Reflection Remember what happens when light speeds up as it travels from one medium to another. For example, when light travels from water to air the direction of the light ray is bent away from the normal, as shown in **Figure 23.** If the underwater light ray makes a larger angle with the normal, the light ray in the air bends closer the surface of the water. At a certain angle, called the critical angle, the refracted ray has been bent so that it is traveling along the surface of the water, as shown in **Figure 23.** For a light ray traveling from water into air, the critical angle is about 49°.

Figure 23 shows what happens if the underwater light ray strikes the boundary between the air and water at an angle larger than the critical angle. There is no longer any refraction, and the light ray does not travel in the air. Instead, the light ray is reflected at the boundary, just as if a mirror were there. This behavior of light is called total internal reflection. **Total internal reflection** occurs when light traveling from one medium to another is completely reflected at the boundary between the two materials. Then the light ray obeys the law of reflection. For total internal reflection to occur, light must travel slower in the first medium, and must strike the boundary at an angle greater than the critical angle.

Reading Check *How does total internal reflection occur?*

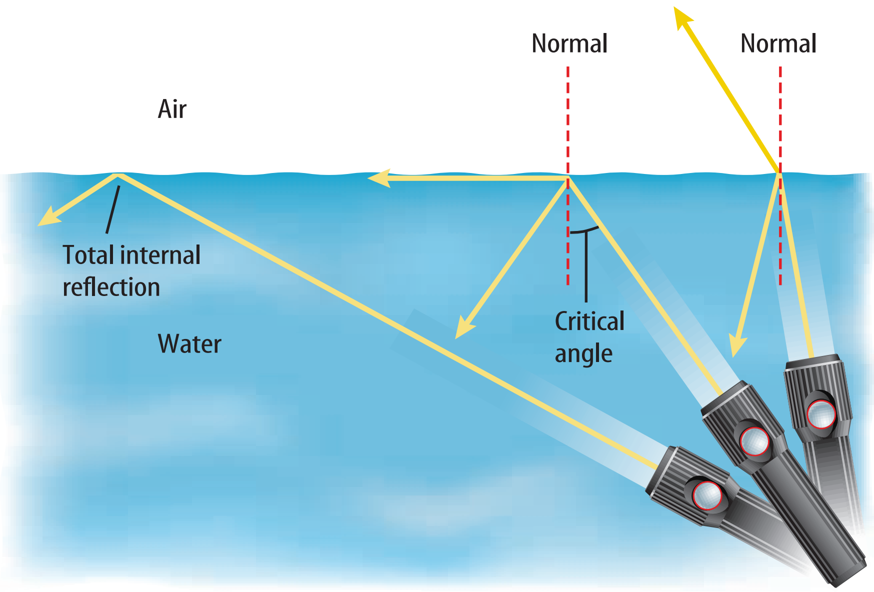
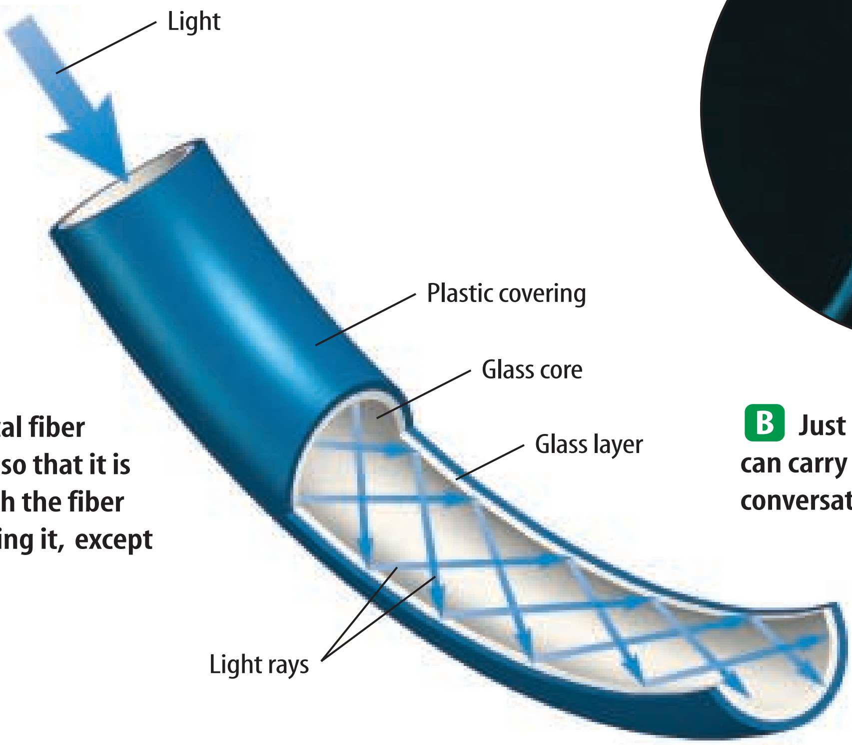
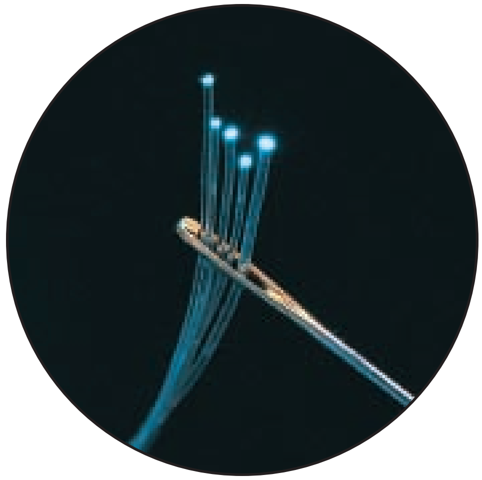


Figure 23
A light wave is bent away from the normal as it passes from water to air. At the critical angle, the refracted wave is traveling along the water surface. At angles greater than the critical angle, total internal reflection occurs.

Figure 24
Optical fibers make use of total internal reflection.



A **An optical fiber reflects light so that it is piped through the fiber without leaving it, except at the ends.**



B **Just one of these optical fibers can carry thousands of phone conversations at the same time.**

Light Pipes Total internal reflection makes light transmission in optical fibers possible. As shown in **Figure 24A,** light entering one end of the fiber is reflected continuously from the sides of the fiber until it emerges from the other end. Like water moves through a pipe, almost no light is lost or absorbed in optical fibers.

Using Optical Fibers Optical fibers are most often used in communications. Telephone conversations, television programs, and computer data can be coded in light beams. Signals can't leak from one fiber to another and interfere with other messages, so the signal is transmitted clearly. To send telephone conversations through an optical fiber, sound is converted into digital signals consisting of pulses of light by a light-emitting diode or a laser. Some systems use multiple lasers, each with its own wavelength to fit multiple signals into the same fiber. You could send a million copies of the play *Romeo and Juliet* in one second on a single fiber. **Figure 24B** shows the size of typical optical fibers.

Optical fibers also are used to explore the inside of the human body. One bundle of fibers transmits light, while another carries the reflected light back to the doctor.

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Figure 25
Optical scanners like this one use lasers to find the price of various products.

Optical Scanners

In supermarkets and many other kinds of stores, a cashier passes your purchases over a glass window in the checkout counter or holds a handheld device up to each item, like the one in **Figure 25.** In an instant, the optical scanner beeps and the price of the item appears on a screen. An optical scanner is a device that reads intensities of reflected light and converts the information to digital signals. You may have noticed that somewhere on each item the cashier scans is a pattern of thick and thin stripes called a bar code. An optical scanner detects the pattern and translates it into a digital signal, which goes to a computer. The computer searches its database for a matching item, finds its price, and sends the information to the cash register. The U.S. Postal Service also uses optical scanners to sort mail and keep track of mail delivery.

You may have used another type of optical scanner to convert pictures or text into forms you can use in computer programs. With a flatbed scanner, for example, you lay a document or picture facedown on a sheet of glass and close the cover. An optical scanner passes underneath the glass and reads the pattern of light and dark areas (or colors, if you are scanning a color picture). Some scanners are used with software that can read text on a page and convert the scanned information into a text file that you can work on. Photocopy machines and facsimile (fax) machines also use optical scanners.

Section 4 Assessment

1. What is polarized light?
2. Why is a holographic image three-dimensional?
3. What conditions are necessary for total internal reflection to occur?
4. Explain how an optical fiber is able to transmit light.
5. **Think Critically** Geologists and surveyors often use lasers for aligning equipment, measuring, and mapping. Explain why.

Skill Builder Activities

6. **Comparing and Contrasting** Make a table that compares and contrasts incoherent, coherent, and polarized light. **For more help, refer to the Science Skill Handbook.**
7. **Communicating** Many people wear polarized sunglasses while they are working. Write a list of jobs or occupations in which wearing polarized sunglasses is helpful. Explain why. **For more help, refer to the Science Skill Handbook.**

Activity

Make a Light Bender

From a hilltop you can see the reflection of pine trees and a cabin in the calm surface of a lake. This is possible because some of the light that reflects off these objects strikes the water's surface and reflects into your eyes. However, you don't see a clear, colorful image because much of the light enters the water rather than being reflected.

What You'll Investigate

How does water affect the viewer's image of an object that is above the water's surface?

Materials

light source
unsharpened pencil
clear rectangular container
water
clay

Goals

- Identify reflection of an image in water.
- Identify refraction of an image in water.

Safety Precautions

Procedure

1. Fill the container with water.
2. Place the container so that a light source—window or overhead light—reaches it.
3. Stand the pencil on end in the clay and place it by the container as shown in the figure above. The pencil must be taller than the level of the water. Also, place the pencil on the same side of the container as the light source.

4. Looking down through the surface of the water from the side opposite the pencil, observe the reflection and refraction of the image of the pencil.
5. **Draw** a diagram of the image and label "reflection" and "refraction."
6. Repeat steps 4 and 5 two more times but position the pencil at two different angles.

Conclude and Apply

1. How would the image you see change or be different if the surface of the water were a mirror?
2. **Predict** how the angles of reflection or refraction would change if the surface of the container were curved. Explain.

Communicating Your Data

Make a poster of your diagrams and use it to explain reflection and refraction of light waves to your class. **For more help, refer to your Science Skill Handbook.**

Activity

Design Your Own Experiment

Polarizing Filters

Polarizing filters cause light waves to vibrate only in one direction. Wearing polarized sunglasses can help reduce glare while allowing you to see clearly. If you have two polarizing filters on top of one another, when will light shine through and when will it not? What might happen if you added a third filter in between the first two?

Recognize the Problem

How can you demonstrate the effects of polarizing filters?

Form a Hypothesis

Form a hypothesis about how two polarizing filters that are placed on top of one another must be oriented for light to shine through and for no light to shine through.

Goals

- **Demonstrate** when light does and does not shine through a pair of polarizing filters.
- **Predict** what will happen when you add a third polarizing filter.

Possible Materials

polarizing filters (3)
lamp or flashlight

Safety Precautions

Never look directly at the sun, even with a polarizing filter.

Test your Hypothesis

Do

1. Using a pair of polarizing filters, choose at least three orientations of the filters to test your hypothesis.
2. When the two filters are oriented to allow the maximum amount of light to shine through, predict how a third filter placed between the two must be oriented for the same results.
3. Repeat step 2 but allow no light to shine through.
4. Make sure that your teacher approves your plan before you start.
5. Using an appropriate light source, test when light does and does not shine through a pair of polarizing filters. Test each of the orientations you planned in step 1. Record the results.
6. Test three orientations of the third filter for allowing the maximum amount of light to pass through. Record the results.
7. Repeat step 6 but allow no light to shine through. Record the results.

Analyze Your Data

1. **Describe** how the pair of polarizing filters were oriented when light did and did not shine through. In cases where light did shine through, was it always the same amount of light? Or did the amount of light change in different orientations?
2. In each case, describe what happened when you added a third filter between the two. How did the three orientations of the third filter change the amount of light that passed through? Explain.

Draw Conclusions

1. **Explain** why light did or did not shine through two polarizing filters in the various orientations.
2. Was your hypothesis supported? Why or why not?
3. **Explain** why light did or did not shine through various orientations of three polarizing filters.
4. Were your predictions correct? Why or why not?
5. If a polarizing filter reduces the brightness of light reflected from the surface of a lake, what can you conclude about the polarization of reflected light?

Communicating Your Data

The next time you see a family member or friend wearing sunglasses, **explain** to them how polarizing lenses can reduce problems of glare.

A Haiku Garden:

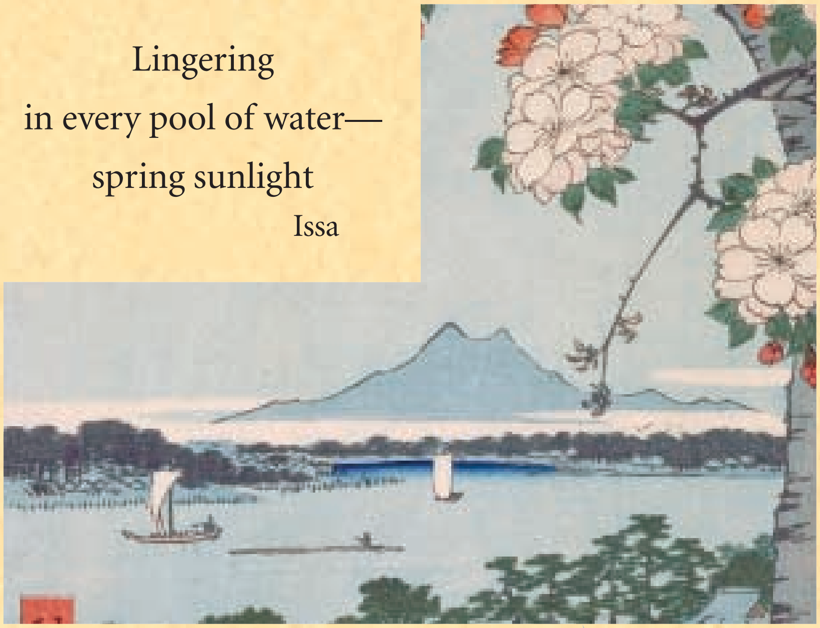
The Four Seasons in Poems and Prints

by Stephen Addiss with Fumiko and Akira Yamamoto

Respond to the Reading

1. What do the words *one-color world* mean?
2. How do the illustrations help the reader better understand the poems?
3. What do you think is meant by the word *lingering* in the Haiku about spring sunlight?

Withered by winter
the sound of the wind—
one-color world
Basho



Lingering
in every pool of water—
spring sunlight
Issa

Understanding Literature

Japanese Haiku You have just read English translations of two poems from a book that combines Japanese haiku and art. A haiku is a verse that consists of three lines and 17 syllables in the Japanese language. The first and third lines have five syllables each, and the middle line has seven syllables. Using few words, a haiku allows the reader's imagination to complete the picture. For instance, the *sound of the wind* might make you think of the sound of winter wind whipping around the house while you sit snuggly inside.

Science Connection Research has determined that there is a connection between color and mood. For example, the color of a room can affect a person's feelings and behavior. Warm colors have longer wavelengths, and can be more stimulating. Cool colors, which have shorter wavelengths, tend to have a calming or soothing effect on people. Light and color have long been used as literary symbols. When the haiku is combined with Japanese prints, do you read it differently? Does the use of color change what you imagine when you read the haiku?

Linking Science and Writing

Writing and Illustrating Haiku Write two haiku poems—one about summer and one about fall. In one poem, use color to help you describe the season. In the other, use light or some property of light to help describe the season. When you have finished, exchange poems with one of your classmates. Read your classmate's haiku and create illustrations to accompany them.

Career Connection

Photographer

Metamorphosis: III, 1998. Maria Martinez-Cañas. Gelatin silver print, 14 x 11 in.

Maria Martinez-Cañas uses light in an inventive and exciting way. Martinez-Cañas was born in Havana, Cuba and grew up in Puerto Rico. She went to art school in the United States, earning a master of fine arts degree from the School of Art Institute in Chicago. Her innovative technique involves using a type of photographic material that blocks light. She cuts the material into artistic shapes, then prints these shapes on white paper in a manner similar to using stencils. Martinez-Cañas lives in Miami and her photography can be seen in art exhibits all over the world.

CLICK HERE

SCIENCE *Online* To learn more about careers in photography, visit the Glencoe Science Web site at **science.glencoe.com**.

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Chapter 14 Study Guide

Reviewing Main Ideas

Section 1 The Behavior of Light

1. You can't see through opaque materials. You can see hazily through translucent materials and clearly through transparent materials.
2. Light behaves as a wave, so it can be reflected. *Is this reflection from the lake regular or diffuse?*

3. Light waves can be refracted, or bent, when a wave changes speed as it travels from one material to another.

Section 2 Light and Color

1. You see color when light is reflected off objects and into your eyes.
2. Specialized cells in your eyes called cones allow you to distinguish colors and shapes of objects. Other cells, called rods, allow you to see in dim light.
3. The three primary colors of light can be mixed to form all other colors.
4. The colors of pigments are determined by the colors they reflect.

Section 3 Producing Light

1. Incandescent bulbs produce light by heating a tungsten filament until it glows brightly.
2. Fluorescent bulbs give off light when ultraviolet radiation produced inside the bulb causes the phosphor coating inside the bulb to glow.
3. Neon lights contain a gas that glows when electric current passes through it.
4. A laser produces coherent light by emitting a beam of light waves that have only one wavelength, with their crests and troughs aligned, and moving in a single direction.

Section 4 Using Light

1. Polarized light consists of transverse waves that vibrate along only one plane. *What could be done to reduce the glare in this photo?*

2. Total internal reflection occurs when a light wave strikes the boundary between two materials at an angle greater than the critical angle.
3. Optical scanners sense reflected light and convert the information to digital signals.

FOLDABLES Reading & Study Skills

After You Read

List examples of common materials that are opaque, transparent, and translucent on the front of your Foldable.

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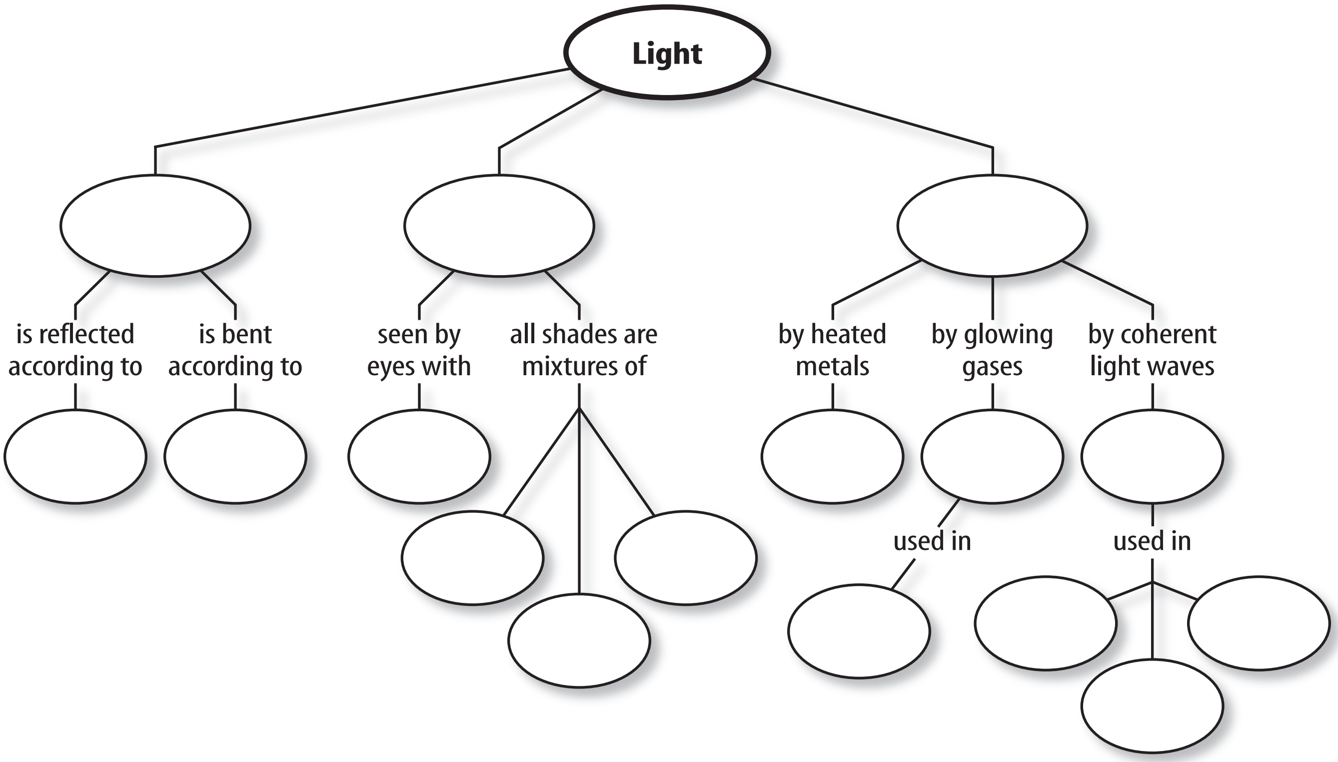
Visualizing Main Ideas

Complete the following concept map about light.



Checking Concepts

Vocabulary Words

a. coherent light
b. fluorescent light
c. holography
d. incandescent light
e. incoherent light
f. index of refraction
g. mirage
h. opaque
i. pigment
j. polarized light
k. total internal reflection
l. translucent
m. transparent

Study Tip

THE PRINCETON REVIEW

Get together with a friend. Quiz each other from textbook and class material.

Using Vocabulary

Answer the following questions using complete sentences.

1. What type of light does heating a filament until it glows produce?
2. What process would you use to produce a complete three-dimensional image of an object?
3. How would you describe an object that you can see through?
4. What process makes it possible for optical fibers to transmit telephone conversations over long distances?
5. What is a false image of a distant object?

Chapter 14 Assessment

Checking Concepts

Choose the word or phrase that best answers the question.

1. Which word describes materials that absorb or reflect all light?
   A) translucent **C)** ultraviolet
   B) opaque **D)** diffuse

2. What is the term for the property of a material that indicates how much light slows down when traveling in the material?
   A) pigment **C)** index of refraction
   B) filter **D)** mirage

3. Which of the following explains why a prism separates white light into the colors of the rainbow?
   A) interference **C)** diffraction
   B) fluorescence **D)** refraction

4. What do you see when noting the color of an object?
   A) the light it reflects
   B) the light it absorbs
   C) polarization
   D) diffuse reflection

5. What do the phosphors inside fluorescent bulbs absorb to create a glow?
   A) incandescent light
   B) ultraviolet radiation
   C) halogens
   D) argon

6. What term describes objects that allow some light, but not a clear image to pass through?
   A) translucent **C)** transparent
   B) reflective **D)** opaque

7. Which light waves are bent most when passing through a prism?
   A) red waves **C)** blue waves
   B) yellow waves **D)** violet waves

8. Which type of cells in your eyes allows you to see the color violet?
   A) red cones **C)** blue cones
   B) green cones **D)** rods

9. What color of light is produced when the three primary colors of light are combined in equal amounts?
   A) black **C)** white
   B) yellow **D)** cyan

10. Which term describes laser light?
   A) incoherent **C)** incandescent
   B) coherent **D)** fluorescent

Thinking Critically

11. Explain how light is produced by an incandescent bulb. What is a disadvantage of these bulbs?

12. How is the reflection of light from a white wall similar to the reflection of light from a mirror? How is it different?

13. What color would a blue shirt appear to be if a blue filter were placed in front of it? A red filter? A green filter?

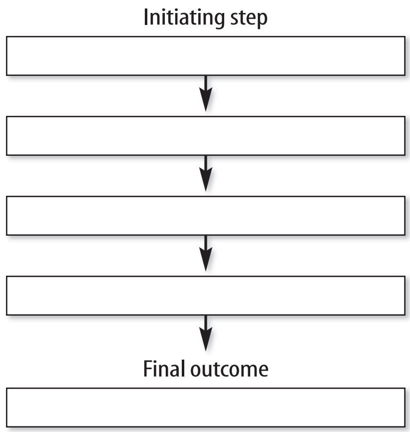
14. Which color of light changes speed the most when it passes through a prism? Explain.

Developing Skills

15. **Drawing Conclusions** Most mammals, such as dogs and cats, can't see colors. Infer how a cat's eye might be different from your eye.

Chapter 14 Assessment

16. Concept Mapping Use this blank concept map to show the steps in the production of fluorescent light.



17. Interpreting Scientific Illustrations Make a drawing that shows how a fluorescent bulb produces light.

18. Drawing Conclusions Why is the inside of a camera painted black?

19. Making and Using Tables Construct a table to show the properties and applications of incandescent, fluorescent, neon, sodium-vapor, and tungsten-halogen lighting devices. For each type of device, include information on how light is produced, typical uses, and its advantages or disadvantages.

Performance Assessment

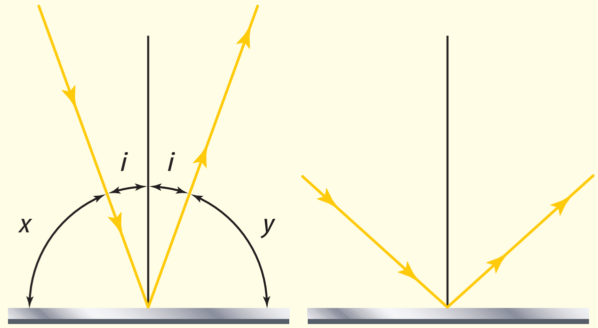
20. Poster Make a poster to show how the three primary pigments are combined to produce common colors such as blue, red, yellow, green, purple, brown, and black.

Technology

Go to the Glencoe Science Web site at **science.glencoe.com** or use the **Glencoe Science CD-ROM** for additional chapter assessment.

THE PRINCETON REVIEW Test Practice

Judy and Markus are studying light. They have just read about an experiment that shows how light has certain properties and follows certain rules.



Study the pictures above and answer the following questions.

1. Angle *i* measures 20°. Using this information, what is angle *x*?
   A) 50°
   B) 60°
   C) 70°
   D) 80°

2. Which of the following is taking place in both of the experiments above?
   F) refraction
   G) reflection
   H) diffusion
   J) fluorescence

3. Which of the following statements is true about reflection?
   A) $\angle i + \angle x = 100°$
   B) $\angle i + \angle x = 60°$
   C) $\angle i + \angle x = 80°$
   D) $\angle i + \angle x = 90°$

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