

BIG Idea

Visible light waves are electromagnetic waves that can be detected by the human eye.

13.1 The Behavior of Light

MAIN Idea Light waves change direction when they are reflected or when they change speed.

13.2 Light and Color

MAIN Idea Light waves of different wavelengths or combinations of wavelengths cause the human eye to detect different colors.

13.3 Producing Light

MAIN Idea Heating a tungsten filament or passing a current through a gas are common ways of producing light.

13.4 Using Light

MAIN Idea Light can be used to form three-dimensional images and to transmit information in optical fibers.

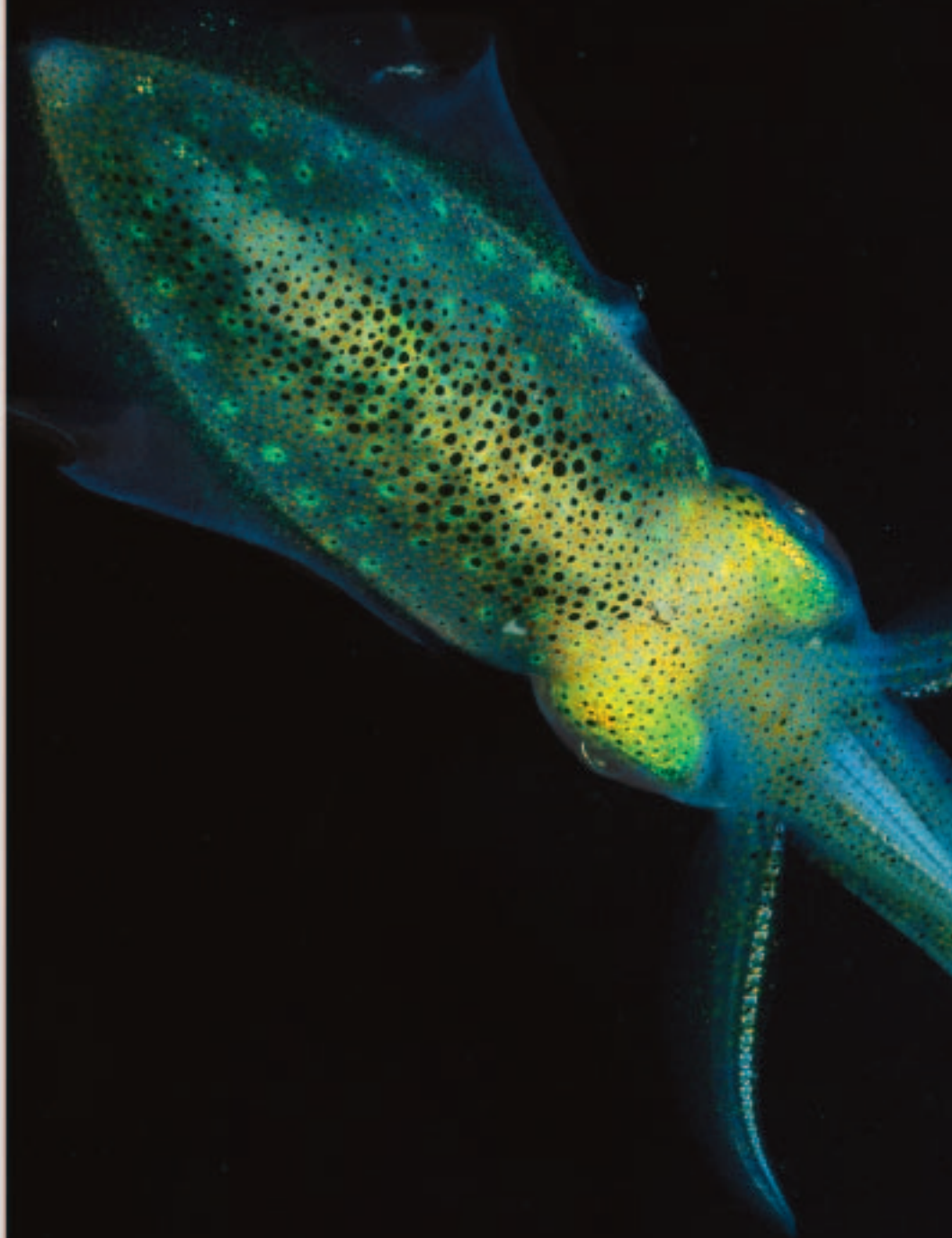
That Inner Glow

Some organisms, like this squid, can produce light. The production of light by organisms is called bioluminescence and results from a chemical reaction. Bioluminescent organisms glow to lure prey, to attract a mate, to coordinate group movements, and to evade predators.

Science Journal

Find other examples of living organisms that give off light.

Light



Start-Up Activities



Rainbows of Light

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?

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.
4. **Think Critically** How did your observations in each case differ? Explain where you think the colors came from.

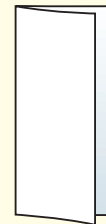


Preview this chapter's content and activities at gpscience.com

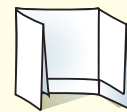
FOLDABLES™ Study Organizer

Light Transmission Make the following Foldable to help identify the characteristics of opaque, translucent, and transparent objects.

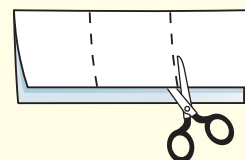
- STEP 1** **Fold** a vertical sheet of paper from side to side. Make the front edge about 1.25 cm shorter than the back edge.



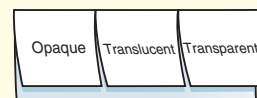
- STEP 2** **Turn** lengthwise and fold into thirds.



- STEP 3** **Unfold** and cut only the top layer along both folds to make three tabs.



- STEP 4** **Label** each tab as shown.



Find Main Ideas As you read this chapter, list the characteristics of opaque, translucent, and transparent objects.

The Behavior of Light

Reading Guide

What You'll Learn

- **Describe** how light waves interact with matter.
- **Explain** the difference between regular and diffuse reflection.
- **Define** the index of refraction of a material.
- **Explain** why a prism separates white light into different colors.

Why It's Important

The images you see every day are due to the behavior of light waves.

Review Vocabulary

visible light: an electromagnetic wave with wavelengths between about 400 and 750 billionths of a meter

Vocabulary

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

Figure 1 These candleholders have different light-transmitting properties.



A Opaque



B Translucent



C Transparent

Light and Matter

Look around your darkened room at night. After 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. For you to see an object, it must reflect some light back to your eyes.

Opaque, Transparent, and Translucent Objects can absorb light, reflect light, and transmit light—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. Materials that allow some light to pass through them, like the material of the candleholder in **Figure 1B**, are described as **translucent** (trans LEW sunt). You cannot see clearly through translucent materials.

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

Reflection of Light

Just before you left for school this morning, did you take a glance in a mirror to check your appearance? For you 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.

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 are some more examples of objects that produce regular or diffuse reflection?

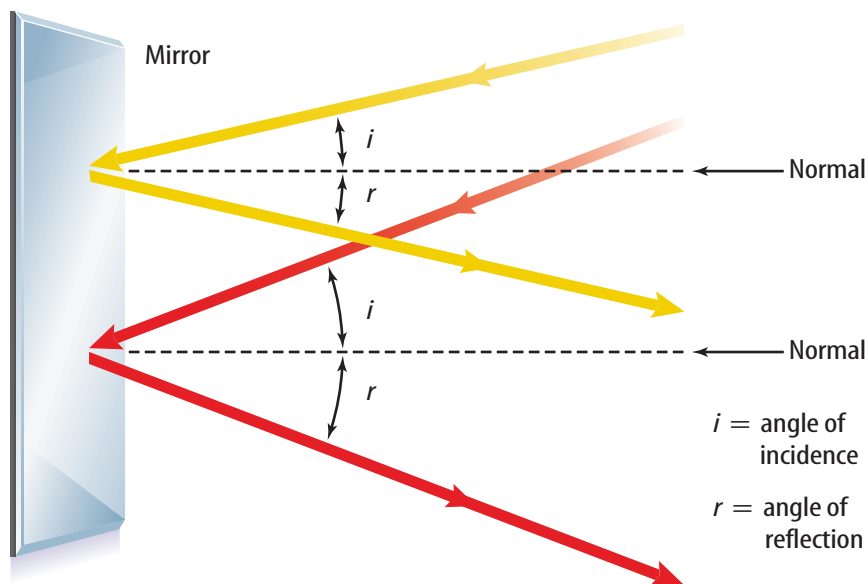
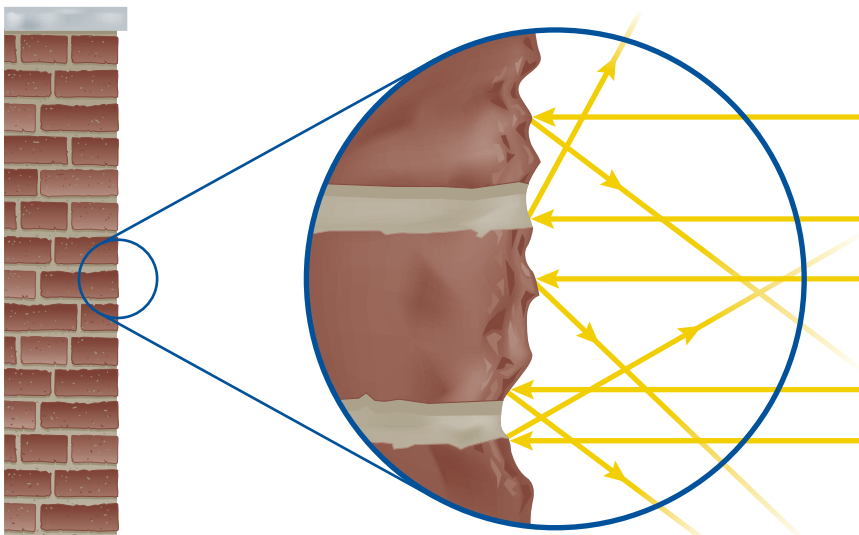
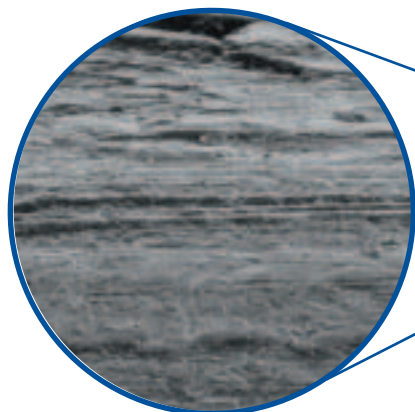


Figure 2 According to the law of reflection, light is reflected so that the angle of incidence always equals the angle of reflection.

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

Explain Use the law of reflection to explain why a rough surface causes parallel light waves to be reflected in many directions.

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 in **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?*

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 the speed of light in the material is reduced.

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.



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

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?

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.

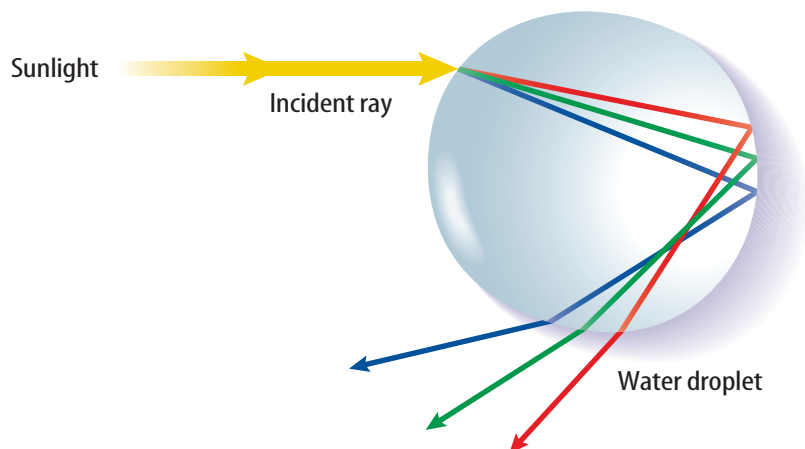


Figure 6 Refraction causes a prism to separate a beam of white light into different colors.

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.



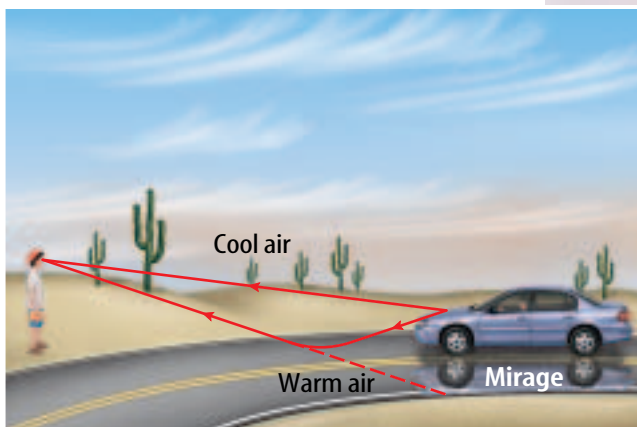


Figure 8 Mirages result when air near the ground is much warmer or cooler than the air above. This causes some light-waves reflected from the object to refract, creating one or more additional images.

Mirages You might have seen what looks like a pool of water on the road ahead. As you get closer, the water seems to disappear. You saw a **mirage**, an image of a distant object produced by the refraction of light through air layers of different densities. Mirages result when the air at ground level is much warmer or cooler than the air above it, as **Figure 8** shows. The density of air increases as air cools. Light waves travel slower as the density of air increases, so that light travels slower in cooler air. As a result, light waves refract as they pass through air layers with different temperatures.

section 1 review

Summary

Light and Matter

- When light waves strike an object, the light can be absorbed, reflected, and transmitted.
- The amount of light that is absorbed, reflected, or transmitted depends on the material an object is made from.

Reflection of Light

- Light waves always obey the law of reflection—the angle of incidence equals the angle of reflection.
- Regular reflection occurs when the roughness of a surface is less than the wavelengths reflected.
- Diffuse reflection causes parallel light waves to be reflected in many directions.

Refraction of Light

- Refraction occurs if a light wave changes speed in moving from one material to another.
- The index of refraction of a material indicates how much light slows down in the material.
- In a material, different wavelengths of light can be refracted by different amounts.

Self Check

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

Applying Math

6. **Find an Angle** A light ray strikes a mirror at an angle of 42° from the surface of the mirror. What angle does the reflected ray make with the normal?
7. **Find an Angle** A ray of light hits a mirror at 27° from the normal. What is the angle between the reflected ray and the normal?

Light and Color

Reading Guide

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.

Why It's Important

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

Review Vocabulary

retina: inner layer of the eye containing cells that convert light images into electrical signals

New Vocabulary

- pigment

Colors

Why do some apples appear red, while others look green or yellow? An object's color depends on the wavelengths 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.

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

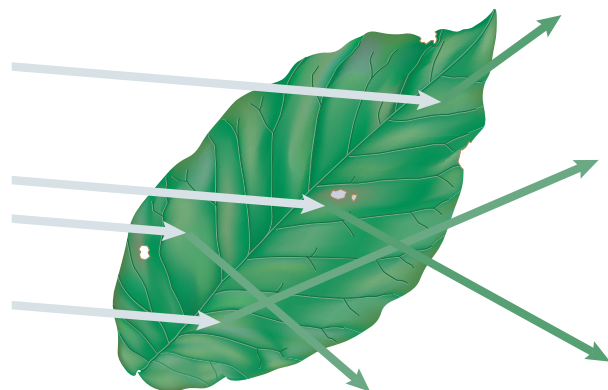


Figure 10 The color of this cooler seems to change under different lighting conditions.



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.



Reading Check

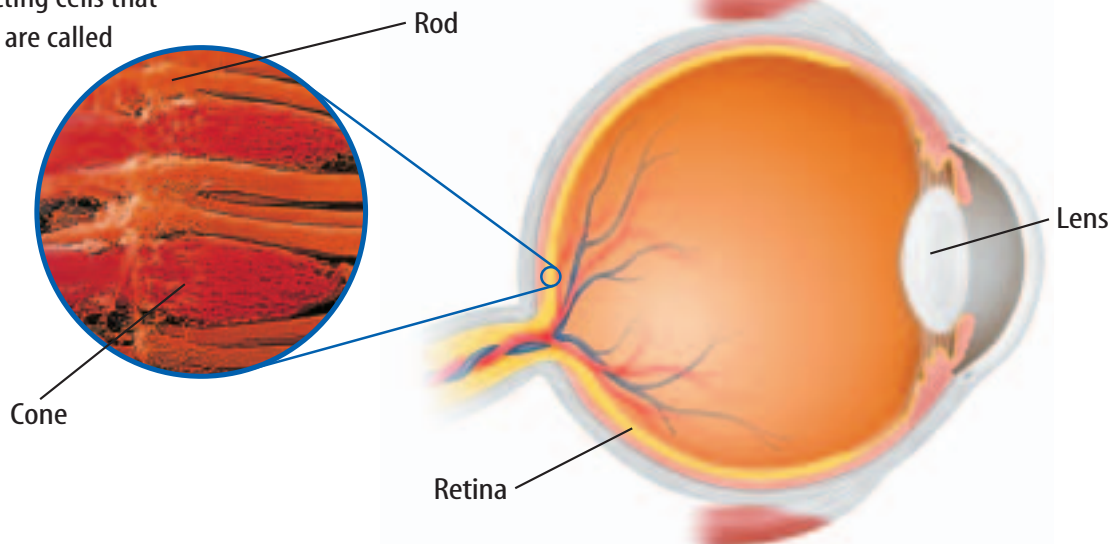
Why does the blue cooler appear black through a red filter?

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 day-time vision.

Figure 11 Light enters the eye and focuses on the retina. The two types of light-detecting cells that make up the retina are called rods and cones.



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.

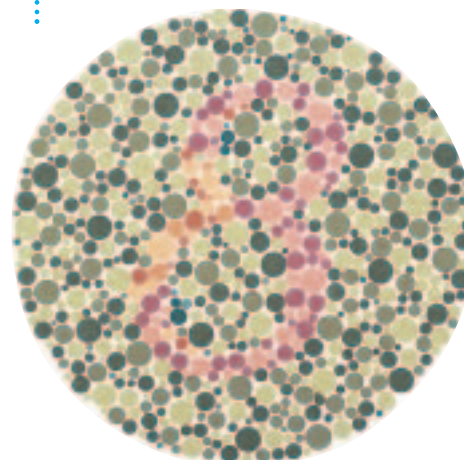


Interpreting Color Why does a banana look yellow? The light reflected by the banana causes the cone cells that are sensitive to red and green light to send signals to your brain. Your brain would get the same signal if a mixture of red light and green light reached your eye. Again, your red and green 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 page 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.

Identify what number you see in the dots.





Color for Photosynthesis

Plant pigments determine the wavelengths of light 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 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 is used to change the color of other substances. The color of a pigment results from the different wavelengths of light that the pigment reflects.

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 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.

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.

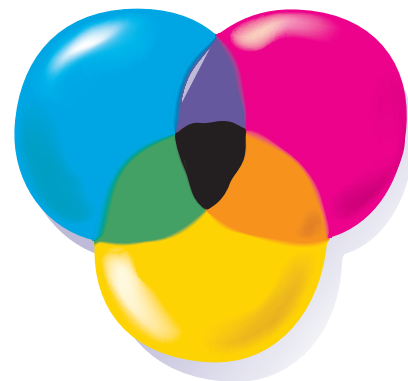


Figure 14 The three primary colors of pigment appear to be black when they are mixed.

section 2 review

Summary

Colors

- The color of an object is determined by the wavelengths of light it reflects.
- The color of a filter is the color of the light the filter transmits.

Seeing Color

- Rod and cone cells are light-sensitive cells found in the retina of the human eye.
- Rod cells are sensitive to dim light. Cone cells enable the human eye to see colors.
- There are three types of cone cells. One type responds to red light, another to green light, and another to blue light.

Mixing Colors

- Red, green and blue are the primary light colors. Any color can be created by mixing these primary light colors.
- Any pigment color can be formed by mixing the primary pigment colors—magenta, cyan, and yellow.

Self Check

1. **Identify** what colors are reflected and what colors are absorbed if a white light shines on a red shirt.
2. **Discuss** how the primary colors of light differ from the primary pigment colors.
3. **Explain** why a color-blind person can distinguish among some colors but not others.
4. **Determine** why a white fence appears to be white instead of multicolored if all colors are present in white light.
5. **Think Critically** Light reflected from an object passes through a green filter, then a red filter, and finally a blue filter. What color will the object seem to be?

Applying Math

6. **Use Percentages** In the human eye there are about 120,000,000 rods. If 90,000,000 rods trigger at once, what percentage of the total number of rods triggered?
7. **Convert Units** The wavelengths of a color are measured in nanometers (nm) which is 0.000001 mm. Find the wavelength in mm of a light wave that has a wavelength of 690 nm.

Producing Light

Reading Guide

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.

Why It's Important

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



Review Vocabulary

electron: negatively charged particle found in an atom

New Vocabulary

- incandescent light
- fluorescent light
- coherent light
- incoherent light

Incandescent Lights

Most of the lightbulbs in your house probably produce **incandescent light**, which is generated by heating a piece of metal until it glows. Inside an incandescent lightbulb is a small wire coil, called a filament, that usually is made of tungsten metal. When an electric current flows in the filament, the electric resistance of the metal causes the filament to become hot enough to give off light. However, about 90% of the energy given off by an incandescent bulb is in the form of thermal energy.



Reading Check

Why does an incandescent lightbulb get hot?

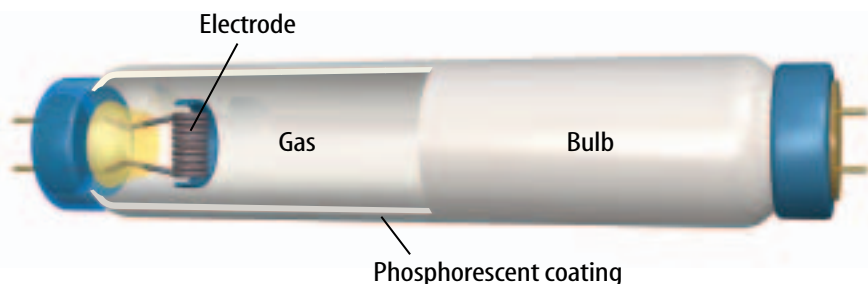
Fluorescent Lights

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.

Determine 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 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?*

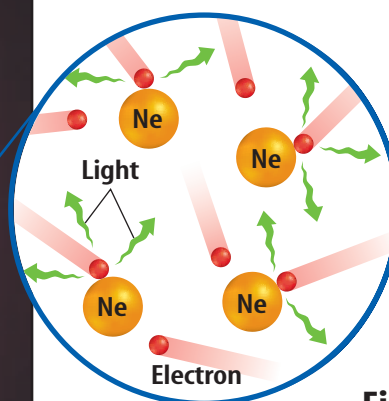


Figure 16 This neon light has vivid, glowing colors.

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

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**.

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.



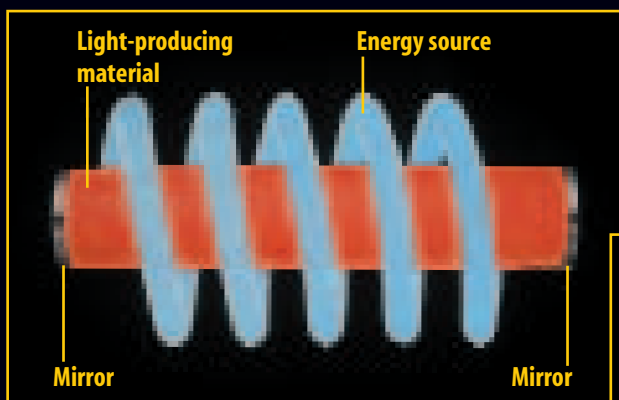
Topic: Light Pollution

Visit gpscience.com for Web links to information about sodium vapor lights and light pollution.

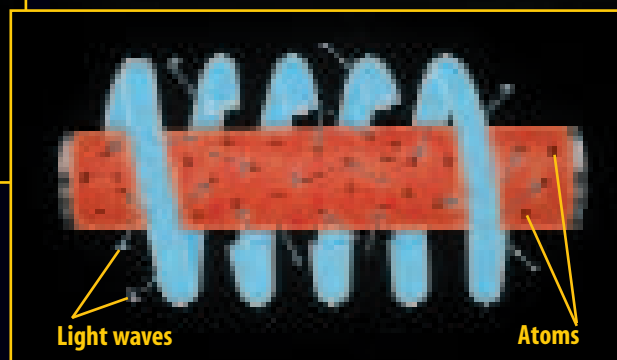
Activity Research light pollution and how it affects astronomers. Determine which types of outdoor lights create more and which create less light pollution.

Figure 18

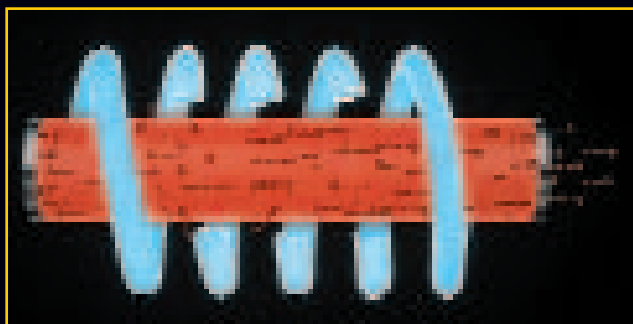
Lasers produce light waves that have the same wavelength. Almost all of these waves travel in the same direction and are in phase. As a result, beams of laser light can be made more intense than ordinary light. In modern eye surgery, shown at the right, lasers are often used instead of a traditional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



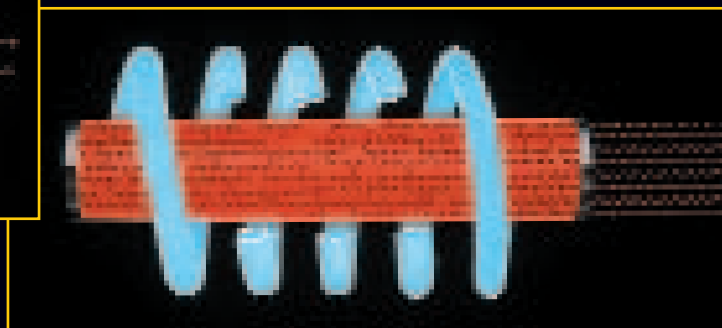
A The key parts of a laser include a material that can be stimulated to produce light, such as a ruby rod, and an energy source. In this example, the energy source is a lightbulb that spirals around the ruby rod and emits an intense light.



B When the lightbulb is turned on, 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.

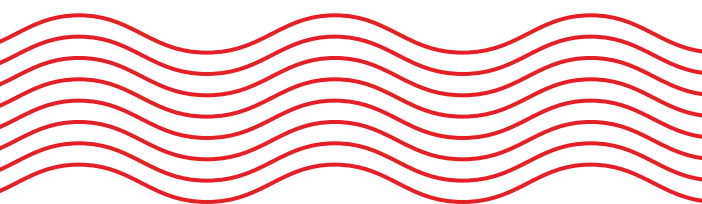


C Most of these waves are reflected between the mirrors located at each end of the laser. One of the mirrors, however, is only partially reflective, allowing one percent of the light waves to pass through it and form a beam.



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.

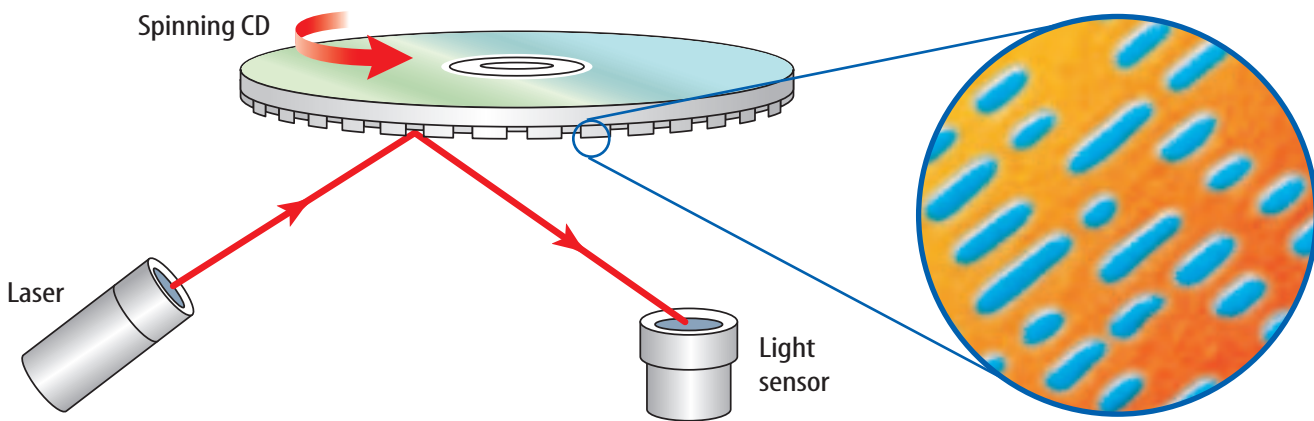
Coherent Light Lasers produce the narrow beams of light that zip across the stage and through the auditorium during some rock concerts. Beams of laser light do not spread out because laser light is coherent. **Coherent light** is light of only one wavelength that travels with its crests and troughs aligned. 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.



Compact Discs Compact discs 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. 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 that the speakers use to create sound.

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.

section 3 review

Summary

Incandescent and Fluorescent Lights

- In an incandescent bulb, an electric current heats a tungsten filament so that it glows.
- The phosphorescent coating on the inside of a fluorescent bulb absorbs ultraviolet light and emits visible light.

Other Light Sources

- In a neon tube, red light is produced when electrons collide with atoms of neon gas.
- In a sodium-vapor light, sodium metal is vaporized and emits a yellow-orange glow.
- A tungsten-halogen bulb is brighter and hotter than an ordinary incandescent bulb.

Lasers

- Laser light is produced when identical atoms are stimulated to emit coherent light.
- A laser beam does not spread, so energy carried by the beam can be concentrated in a small area.

Self Check

1. **Explain** how light is produced in an ordinary incandescent bulb.
2. **Discuss** 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.

Applying Math

5. **Calculate Efficiency** A 25-W fluorescent light emits 5.0 J of thermal energy each second. What is the efficiency of the fluorescent light?
6. **Use Percentages** If 90 percent of the energy emitted by an incandescent bulb is thermal energy, how much thermal energy is emitted by a 60-W bulb each second?

Using Light

Reading Guide

What You'll Learn

- **Distinguish** polarized light from unpolarized light.
- **Explain** how a hologram is made.
- **Determine** when total internal reflection occurs.
- **Describe** the uses of optical fibers.

Why It's Important

Light waves were used to transmit a TV program you watched today, or to send a telephone call to a friend.

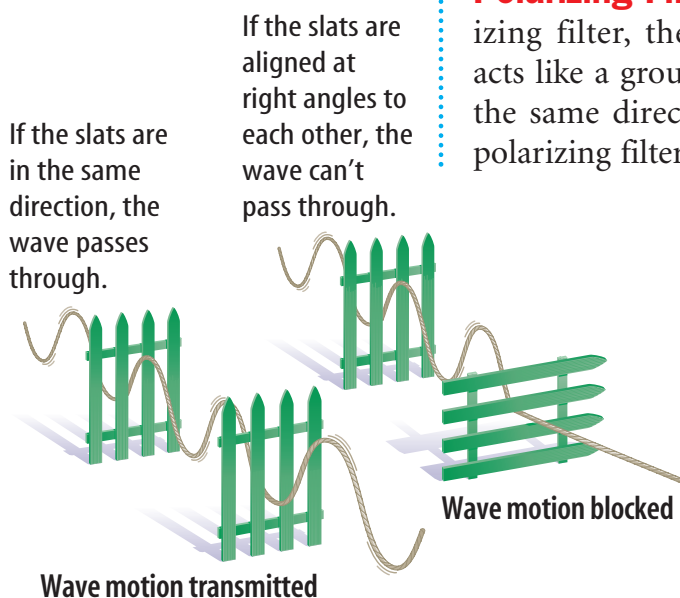
Review Vocabulary

interference: occurs when two or more waves overlap and form a new wave

New Vocabulary

- polarized light
- holography
- total internal reflection

Figure 21 Slats in a fence behave like a polarizing filter for a transverse wave on a rope.



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 vertical polarizing filters that block out the reflected light that has been polarized horizontally.

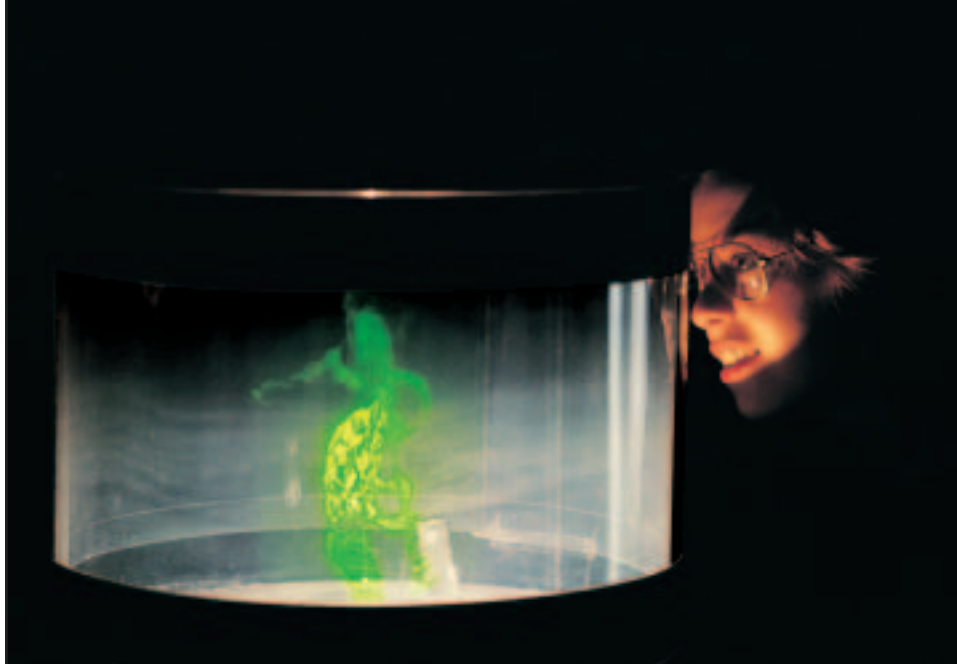


Figure 22 Lasers can be used to make holograms like this one.

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 viewed the real object. Three-dimensional images on credit cards are produced by holography. **Holography** is a technique that produces a hologram—a complete three-dimensional photographic image of an 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?



Topic: Holograms

Visit gpscience.com for Web links to information about holograms.

Activity Make an events-chain concept map of how a hologram is produced.

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?

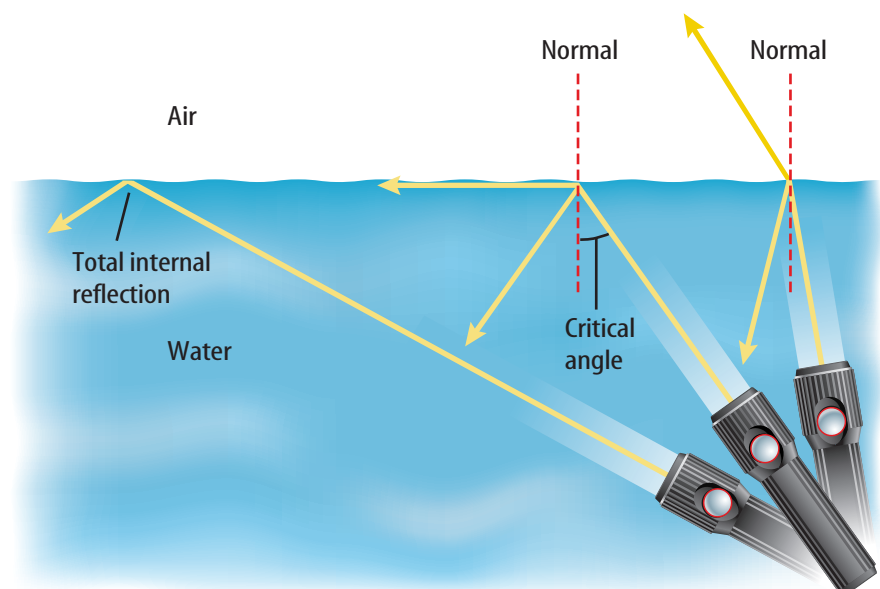
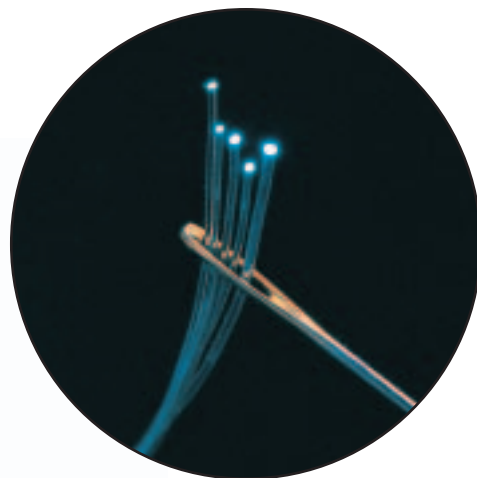
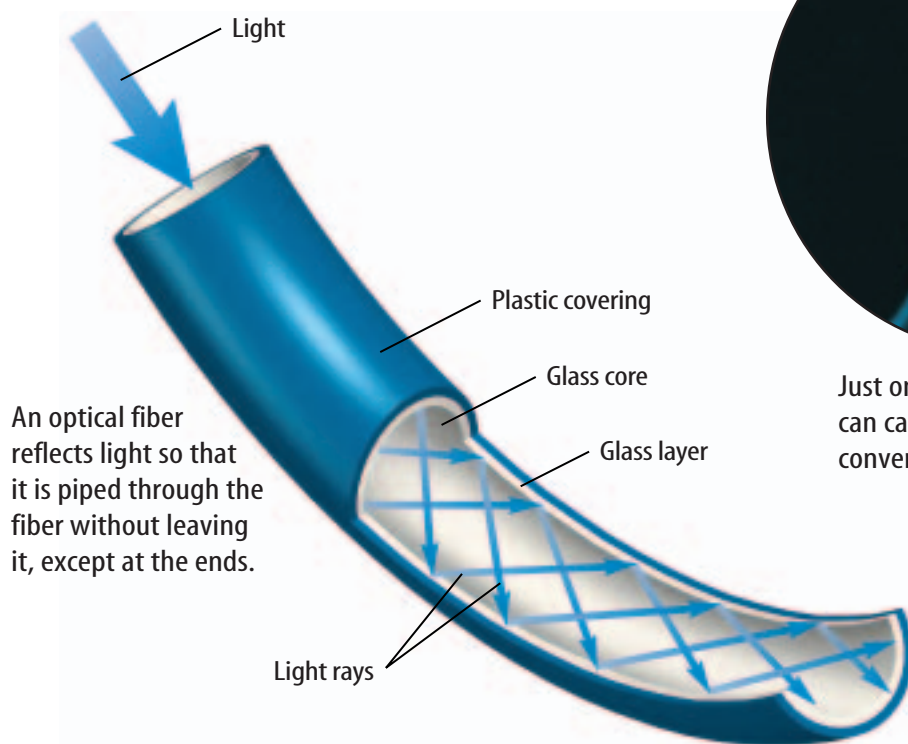


Figure 23 A light wave is bent away from the normal as it passes from water to air. At the critical angle, the refracted wave is traveling along the water surface. At angles greater than the critical angle, total internal reflection occurs.

Figure 24 Optical fibers make use of total internal reflection.



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 24**, 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 24** 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.



INTEGRATE History

Wire Communication

At one time telegraph and telephone communications were transmitted only through wire lines. Today, optical fibers sometimes are used instead of wires to transmit communications. Research the history of wire communication. Create a time line of what you learn.



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.

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 colors. The scanner converts the pattern to an electronic file that can be stored on a computer.

section 4 review

Summary

Polarized Light

- Polarized light has light waves that vibrate in only one direction.
- Polarizing filters block light waves that vibrate at right angles to the direction of the filter.

Holography

- A hologram is produced by interference between laser light reflected from an object and a second laser beam.

Optical Fibers

- Total internal reflection occurs when light is completely reflected at the boundary between two materials.
- Total internal reflection will occur when the angle between the light beam and the normal is equal to, or greater than, the critical angle.
- Optical fibers use total internal reflection to transmit light waves over long distances.

Self Check

1. **Explain** why polarized sunglasses can reduce the glare from light reflected from lakes and ponds.
2. **Describe** why a holographic image is considered to be three-dimensional.
3. **List** all the conditions that are necessary for total internal reflection to occur.
4. **Discuss** how optical fibers are used to transmit telephone conversations.
5. **Think Critically** On a sunny day you are looking at the surface of a lake through polarized sunglasses. How could you use your sunglasses to tell if the light reflected from the lake is polarized?

Applying Math

6. **Calculate Number of Fibers** An optical fiber has a diameter of 0.3 mm. How many fibers would be needed to form a cable with a square cross section, if the cross section was 1.5 cm on a side?

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.

Real-World Question

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

Goals

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

Materials

light source
unsharpened pencil
clear rectangular container
water
clay

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. **Discuss** how the image you see would 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.

Polarizing Filters

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



WARNING: *Never look directly at the Sun, even with a polarizing filter.*

Real-World Question

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?

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.

Test Your Hypothesis

Make a Plan

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.



Using Scientific Methods

3. Repeat step 2 but allow no light to shine through.
4. Make sure that your teacher approves your plan before you start.

Follow Your Plan

1. 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.
2. Test three orientations of the third filter for allowing the maximum amount of light to pass through. Record the results.
3. Repeat step 2 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 first two. How did the three orientations of the third filter change the amount of light that passed through? Explain.

Conclude and Apply

1. **Explain** why light did or did not shine through two polarizing filters in the various orientations.
2. **Evaluate** why or why not your hypothesis was supported.
3. **Infer** why light did or did not shine through various orientations of three polarizing filters.
4. **Analyze** whether or not your predictions were correct.
5. **Discuss** what you can conclude about the polarization of reflected light if a polarizing filter reduces the brightness of light reflected from the surface of a lake.

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



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 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. Why is imagination important in reading Haiku?

Respond to the Reading

1. How do the illustrations help the reader better understand the poems?
2. What do you think is meant by the word *lingering* in the Haiku about spring sunlight?
3. **Linking Science and Writing** Write one haiku about summer and another 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.



Integrate Physics Research has determined that there is a connection between color and mood. 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. Does the use of color change what you imagine when you read the haiku?

Reviewing Main Ideas

Section 1 The Behavior of Light

1. When light interacts with matter, some light can be absorbed, some can be transmitted, and some can be reflected.
2. When light waves are reflected, they obey the law of reflection—the angle of incidence equals the angle of reflection.



3. Light waves are refracted, or bent, when a light 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. Red, blue, and green are the three primary colors of light and can be mixed to form all other colors.
4. The color of a pigment is due to the wavelengths of the light reflected from the pigment. The primary pigment colors are magenta, cyan, and yellow.

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, have their crests and troughs aligned, and are moving in a single direction.

Section 4 Using Light

1. Polarized light consists of transverse waves that vibrate along only one plane.
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™**

Use the Foldable that you made at the beginning of this chapter to help you review light transmission.

Using Vocabulary

coherent light p.398	opaque p.384
fluorescent light p.395	pigment p.392
holography p.401	polarized light p.400
incandescent light p.394	total internal reflection p.402
incoherent light p.398	translucent p.384
index of refraction p.386	transparent p.384
mirage p.388	

Answer the following questions using complete sentences.

- What type of light does heating a filament until it glows produce?
- What process would you use to produce a complete three-dimensional image of an object?
- How would you describe an object that you can see through?
- What process makes it possible for optical fibers to transmit telephone conversations over long distances?
- What is a false image of a distant object?
- What type of light has light waves that vibrate in only one direction?
- 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
- 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
- What do the phosphors inside fluorescent bulbs absorb to create a glow?
A) incandescent light
B) ultraviolet radiation
C) halogens
D) argon
- What term describes objects that allow some light, but not all light to pass through them?
A) translucent C) transparent
B) reflective D) opaque
- Which light waves are bent most when passing through a prism?
A) red waves C) blue waves
B) yellow waves D) violet waves

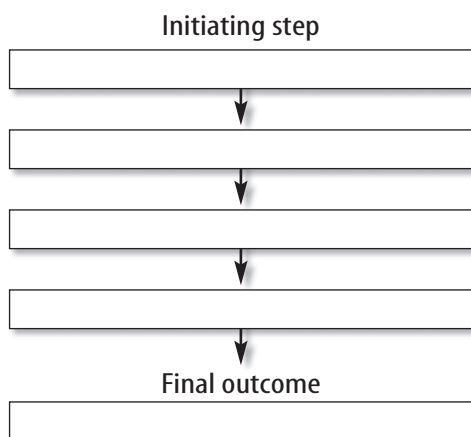
Checking Concepts

Choose the word or phrase that best answers the question.

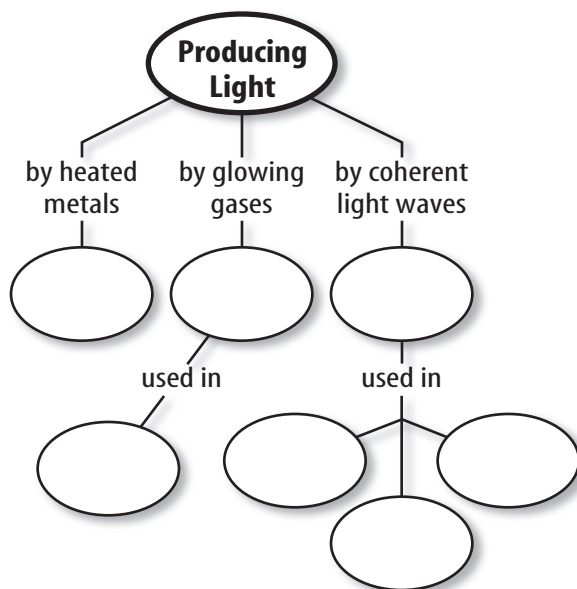
- Which word describes materials that absorb or reflect all light?
A) translucent C) ultraviolet
B) opaque D) diffuse
- What is the term for the property of a material that indicates how much light slows down when traveling in the material?
A) pigment C) index of refraction
B) filter D) mirage
- Which type of cells in your eyes allows you to see the color violet?
A) red cones C) blue cones
B) green cones D) rods
- 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
- Which of the following terms best describes laser light?
A) incoherent C) incandescent
B) coherent D) fluorescent

Interpreting Graphics

- 17. Concept Map** Copy and complete this concept map to show the steps in the production of fluorescent light.



- 18. Concept Map** Copy and complete the following concept map about producing light.



Thinking Critically

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

- 20. Compare and contrast** the reflection of light from a white wall with a rough surface with the reflection of light from a mirror.
- 21. Predict** what color a white shirt would appear to be if the light reflected from the shirt passed through a red filter and then through a green filter.
- 22. Identify** the color of light that changes speed the most as it passes through a prism. Explain your reasoning.
- 23. Infer** Most mammals, including dogs and cats, can't see colors. Infer how the retina of a cat's eye might be different from the retina of a human eye.
- 24. Compare** White light passes through a translucent pane of glass, and shines on a shirt. Both the translucent glass and the shirt appear green. Compare the colors of light that are absorbed and transmitted by the glass and the shirt.
- 25. Explain** The speed of light is greater in air than in glass. Explain whether or not internal reflection could occur when a light wave traveling in air strikes the glass.

Applying Math

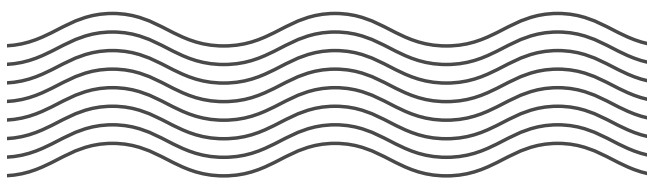
- 26. Calculate Angle of Incidence** A light ray is reflected from a mirror. If the angle between the incident ray and the reflected ray is 136 degrees, what is the angle of incidence?
- 27. Calculate Speed** The index of refraction of a material equals the speed of light in a vacuum, which is 300,000 km/s, divided by the speed of light in the material. What is the speed of light in water if the index of refraction for water is 1.33?

Part 1 Multiple Choice

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

1. Which word describes materials that transmit almost all of the light that strikes them?
- A. translucent C. opaque
B. transparent D. diffuse

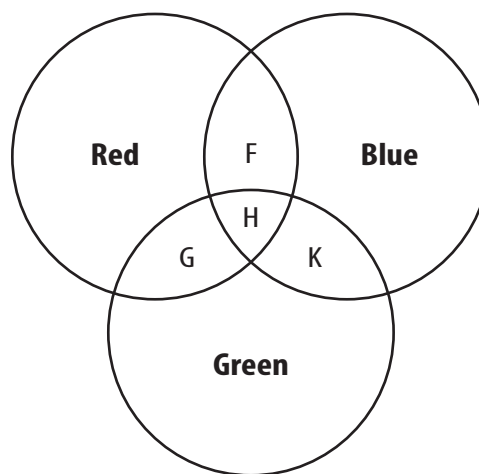
Use the diagram below to answer questions 2 and 3.



2. How are the light waves shown described?
- A. coherent C. opaque
B. incoherent D. translucent
3. What device produces these light waves?
- A. fluorescent light
B. sodium-vapor light
C. laser
D. incandescent light
4. What happens when light traveling at an angle passes from one material into another?
- A. The light is reflected.
B. The light is refracted.
C. The light always speeds up.
D. The light changes color.
5. Why does an apple look red?
- A. It reflects red light.
B. It absorbs red light.
C. It reflects all colors of light.
D. It reflects all colors of light except red.
6. Which of the following processes is used in optical fibers to transmit light?
- A. diffuse reflection
B. total internal reflection
C. polarization
D. incandescence

7. What part of the eye enables you see color in bright light?
- A. rods C. cones
B. retina D. lens
8. What do the phosphors inside a fluorescent bulb absorb to make the bulb emit visible light?
- A. infrared radiation
B. ultraviolet radiation
C. electrons
D. sodium vapor

Use the illustration below to answer questions 9–11.

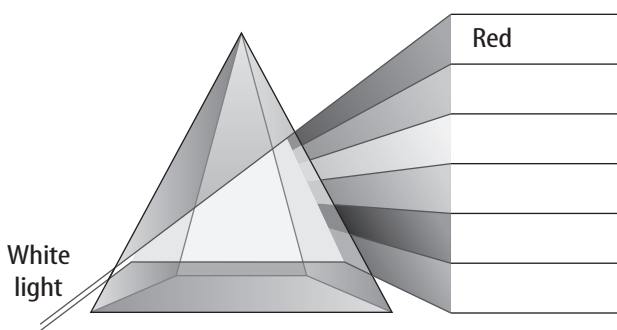


9. When the primary colors of light are added together, what color appears in area H?
- A. magenta C. cyan
B. yellow D. white
10. What color appears in area G?
- A. magenta C. cyan
B. yellow D. white
11. Which of the following light sources produces light by making a piece of metal hot enough to glow?
- A. fluorescent light C. neon light
B. incandescent light D. laser light

Part 2 Short Response/Grid In

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

Use the illustration below to answer questions 12 and 13.



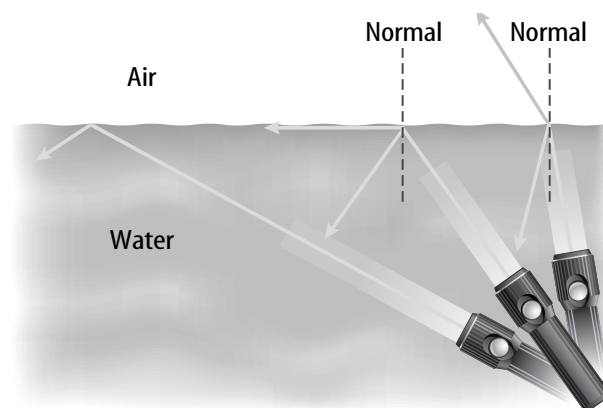
12. Identify the object shown in the figure and explain how it affects white light that passes through it.
13. Identify the colors that would be seen on the right side of the object, in order of decreasing wavelength.
14. Why would a green leaf appear to be black when you look at the leaf through a red filter?
15. Describe the effect that diffuse reflection would have on a beam of parallel light rays.
16. Describe the difference between an object that appears black and an object that appears white.
17. If green light shines on a black-and-white striped shirt, what colors will the stripes appear to be?
18. Why is an electric current needed to produce light in fluorescent lights and in neon lights?
19. For a regular reflection to occur, how must the roughness of a surface compare to the wavelengths of light it reflects?

Part 3 Open Ended

Record your answers on a sheet of paper.

20. Why can the human eye see colors better in bright light than in dim light?
21. Explain why, compared to the light from a lightbulb, a beam of laser light can deliver a large amount of energy to a small area.
22. Explain whether or not a large bottle made of green glass would be a suitable container in which to grow small plants.

Use the illustration below to answer questions 23 and 24.



23. When a light wave traveling in water reaches the water's surface, under what circumstances will total internal reflection occur?
24. If the flashlight were in air and the direction of the light beams shown in the figure were reversed. Under what circumstances would total internal reflection occur? Explain.

Test-Taking Tip

Answer All Parts Make sure each part of a question is answered when listing discussion points. For example, if the question asks you to compare and contrast, make sure you list similarities and differences

Question 17 Be sure to describe the change in color of both the black and the white stripes.