Chapter 18

Light

The BIG Idea

Transfer of Energy

How does light interact with matter?

Chapter Preview

❶ Light and Color
Discover How Do Colors Mix?
Skills Activity Developing Hypotheses
At-Home Activity Color Mix
Skills Lab Changing Colors

❷ Reflection and Mirrors
Discover How Does Your Reflection Wink?
Skills Activity Observing
Active Art Images in Mirrors

❸ Refraction and Lenses
Discover How Can You Make an Image Appear?
Analyzing Data Bending Light
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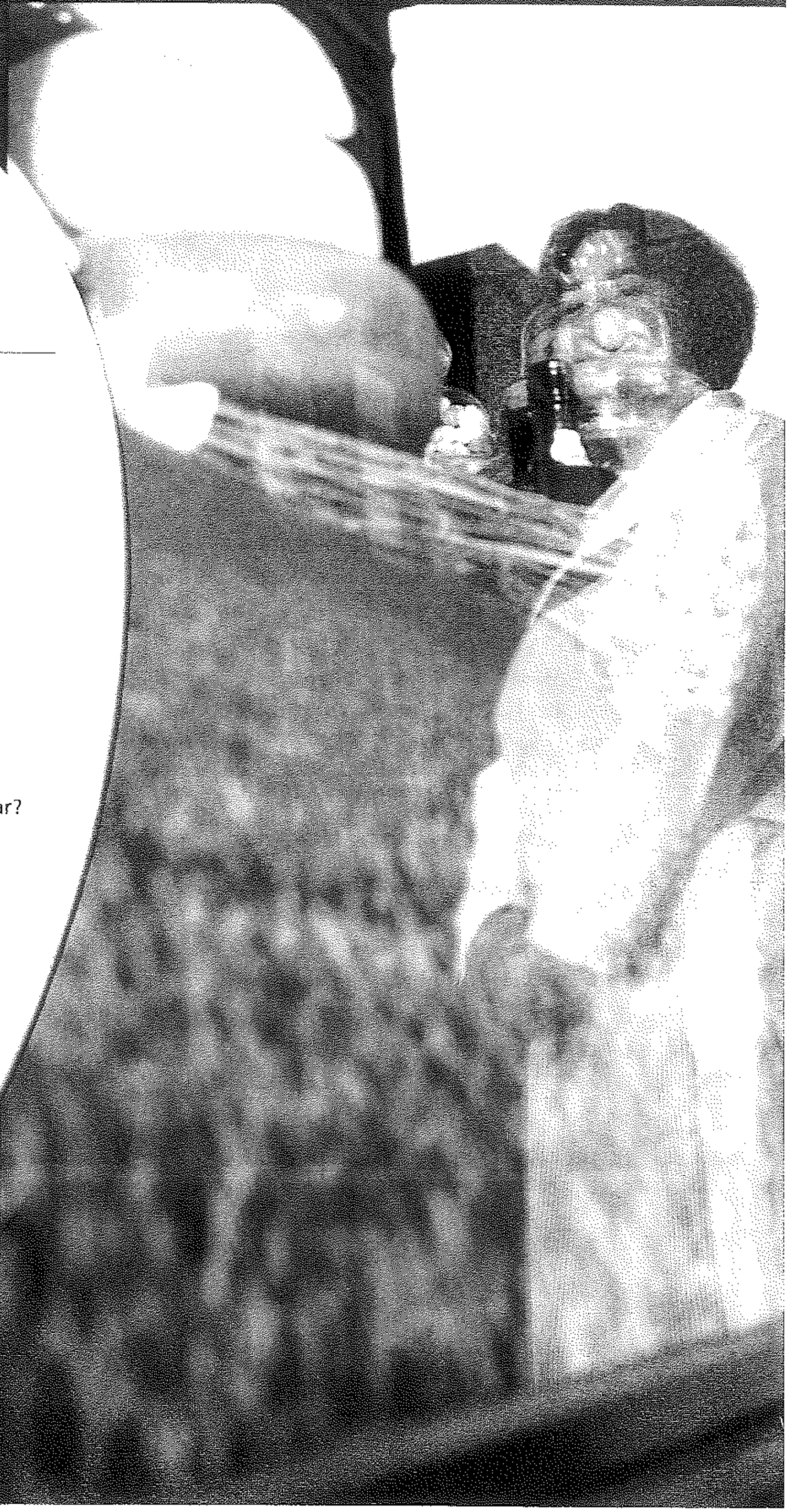
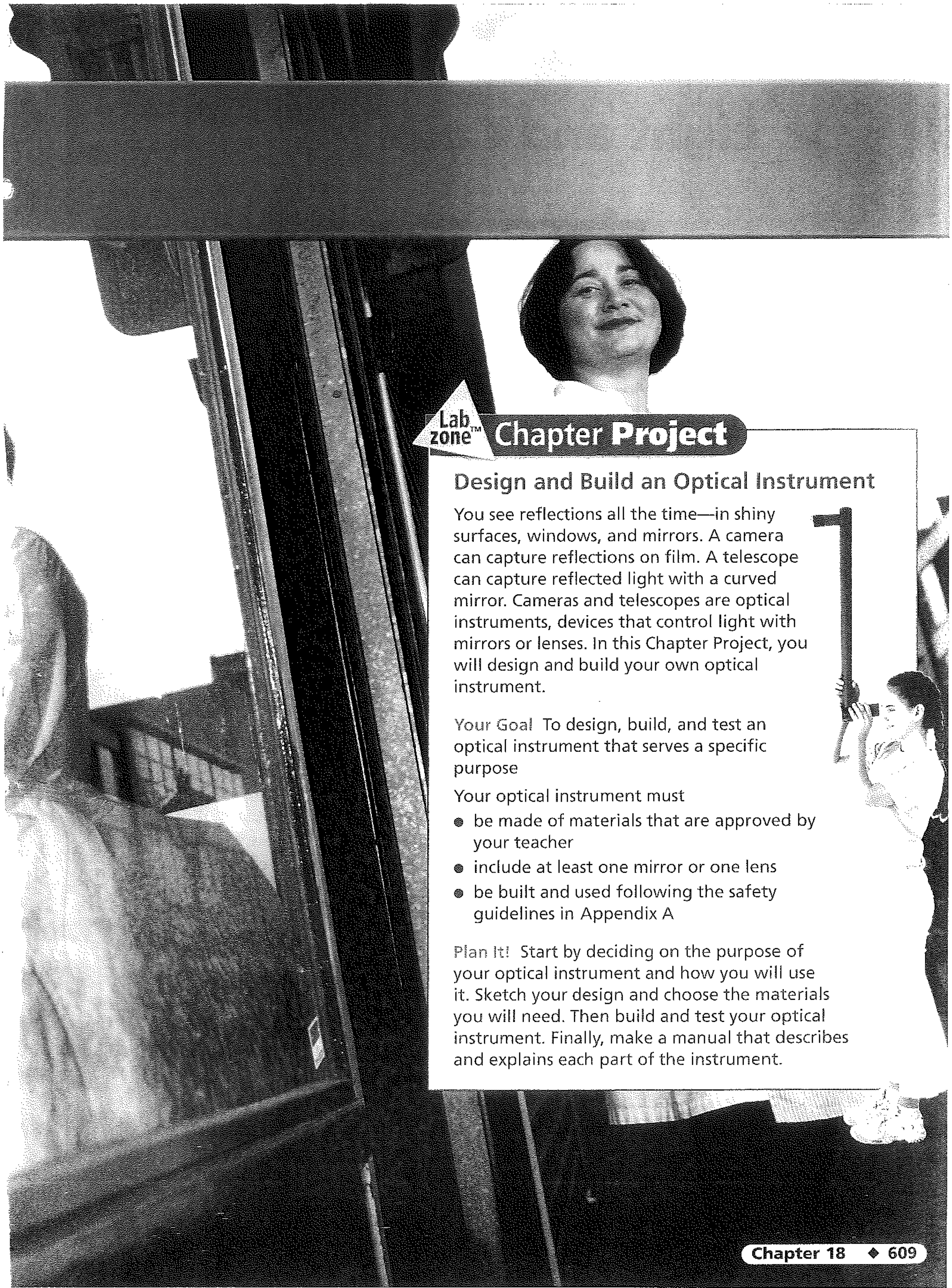
❹ Seeing Light
Discover Can You See Everything With One Eye?
Try This True Colors
At-Home Activity Optical Illusion

❺ Using Light
Discover How Does a Pinhole Viewer Work?
Try This What a View!
Tech & Design in History Instruments That Use Light



These windows reflect light, but they ▶ also let light pass straight through.



Lab zone™ Chapter **Project**

Design and Build an Optical Instrument

You see reflections all the time—in shiny surfaces, windows, and mirrors. A camera can capture reflections on film. A telescope can capture reflected light with a curved mirror. Cameras and telescopes are optical instruments, devices that control light with mirrors or lenses. In this Chapter Project, you will design and build your own optical instrument.

Your Goal To design, build, and test an optical instrument that serves a specific purpose

Your optical instrument must

- be made of materials that are approved by your teacher
- include at least one mirror or one lens
- be built and used following the safety guidelines in Appendix A

Plan It! Start by deciding on the purpose of your optical instrument and how you will use it. Sketch your design and choose the materials you will need. Then build and test your optical instrument. Finally, make a manual that describes and explains each part of the instrument.

Section 1

Light and Color

Reading Preview

Key Concepts

- What happens to the light that strikes an object?
- What determines the color of an opaque, transparent, or translucent object?
- How is mixing pigments different from mixing colors of light?

Key Terms

- transparent material
- translucent material
- opaque material
- primary colors
- secondary color
- complementary colors
- pigment

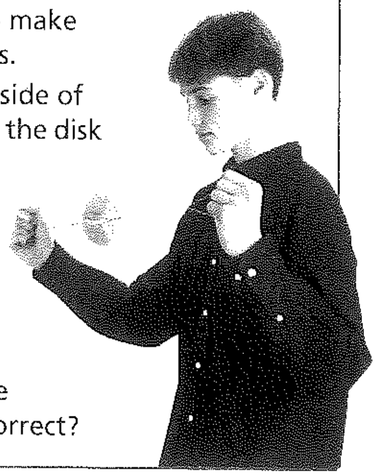
Target Reading Skill

Building Vocabulary Using a word in a sentence helps you think about how to best explain the word. As you read, carefully note the definition of each Key Term. Also note other details in the paragraph that contains the definition. Use all this information to write a sentence using the Key Term.

Lab zone Discover Activity

How Do Colors Mix?

1. Cut a disk with a diameter of 10 cm out of white cardboard. Divide the disk into three equal-sized segments. Color one segment red, the next green, and the third blue.
2. Carefully punch two holes, 2 cm apart, on opposite sides of the center of the disk.
3. Thread a 1-m long string through the holes. Tie the ends of the string together to make a loop that passes through both holes.
4. With equal lengths of string on each side of the disk, tape the string in place. Turn the disk to wind up the string. Predict what color(s) you will see if the disk spins fast.
5. Spin the disk by pulling the loops to unwind the string.



Think It Over

Observing What color do you see as the wheel spins fast? Was your prediction correct?

It was hard work, but you are finally finished. You stand back to admire your work. Color is everywhere! The bright green grass rolls right up to the flower garden you just weeded. In the bright sunlight, you see patches of yellow daffodils, purple hyacinths, and red tulips. The sun's light allows you to see each color. But sunlight is white light. What makes each flower appear to be a different color?

Flowers in sunlight ▼

When Light Strikes an Object

To understand why objects have different colors, you need to know how light can interact with an object. **When light strikes an object, the light can be reflected, transmitted, or absorbed.** Think about a pair of sunglasses. If you hold the sunglasses in your hand, you can see light that reflects off the lenses. If you put the sunglasses on, you see light that is transmitted by the lenses. The lenses also absorb some light. That is why objects appear darker when seen through the lenses.

Lenses, like all objects, are made of one or more materials. Most materials can be classified as transparent, translucent, or opaque based on what happens to light that strikes the material.

Transparent Materials A **transparent material** transmits most of the light that strikes it. The light passes right through without being scattered. This allows you to see clearly what is on the other side. Clear glass, water, and air all are transparent materials. In Figure 1, you can clearly see the straw through the glass on the left.

Translucent Materials A **translucent material** (trans LOO sunt) scatters light as it passes through. You can usually see something behind a translucent object, but the details are blurred. Wax paper and a frosted glass like the middle glass in Figure 1 are translucent materials.

Opaque Materials An **opaque material** (oh PAYK) reflects or absorbs all of the light that strikes it. You cannot see through opaque materials because light cannot pass through them. Wood, metal, and tightly woven fabric all are opaque materials. You cannot see the straw through the white glass in Figure 1 because the glass is opaque.

Reading Checkpoint **What happens when light strikes an opaque material?**

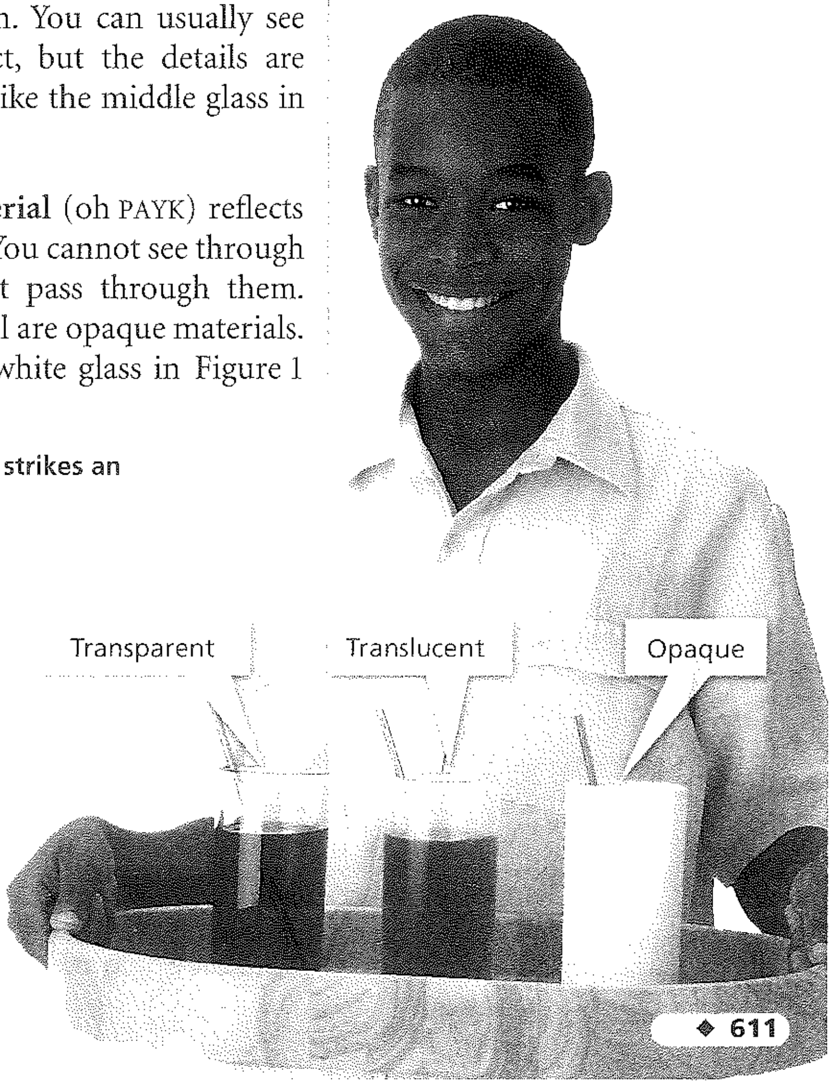
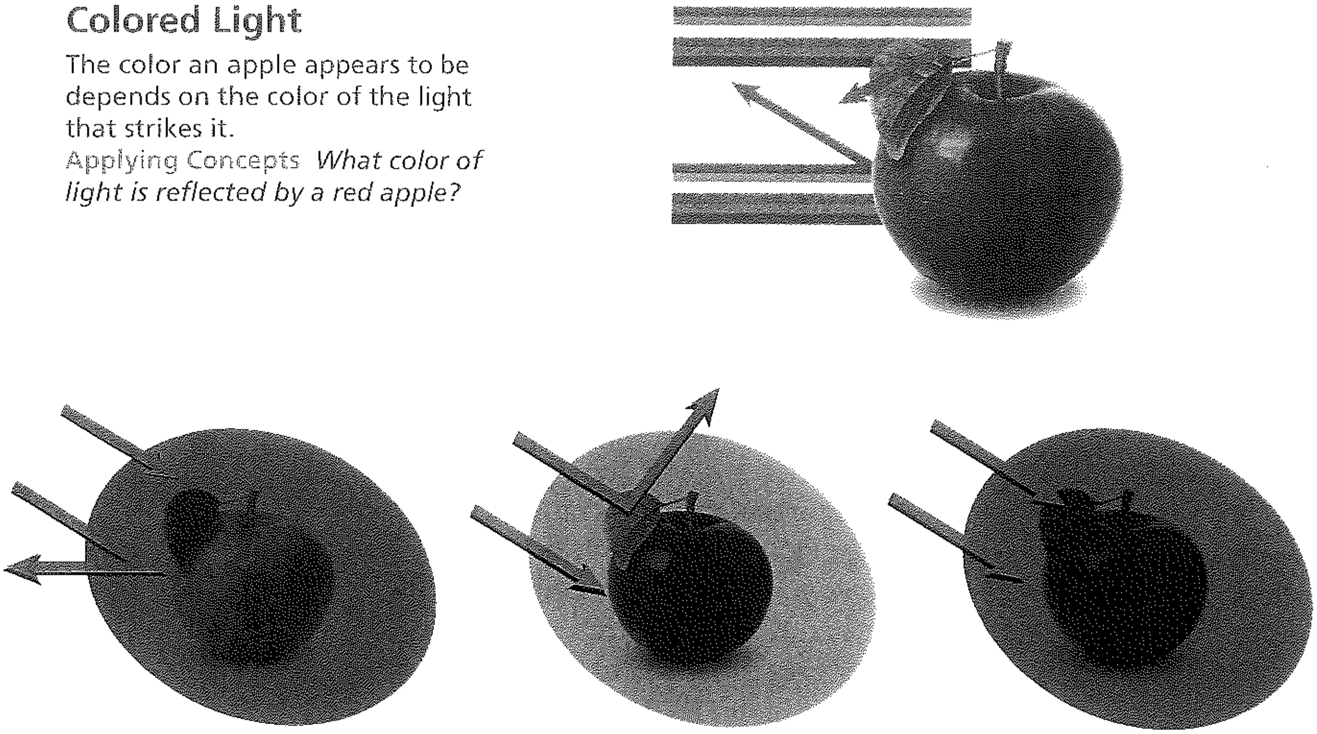


FIGURE 1
Types of Materials
Different types of materials reflect, transmit, and absorb different amounts of light.
Comparing and Contrasting
How does a straw seen through transparent glass compare with a straw seen through translucent glass?

FIGURE 2

Colored Light

The color an apple appears to be depends on the color of the light that strikes it.
Applying Concepts *What color of light is reflected by a red apple?*



In red light, the apple appears red because it reflects the red light. But the leaves look black.

In green light, the apple appears black because no red light strikes it. But the leaves look green.

In blue light, both the apple and the leaves appear black.

The Color of Objects

If you know how light interacts with objects, you can explain why objects such as flowers have different colors. The color of any object depends on the material the object is made of and the color of light striking the object.

Color of Opaque Objects The color of an opaque object depends on the wavelengths of light that the object reflects. Every opaque object absorbs some wavelengths of light and reflects others. **The color of an opaque object is the color of the light it reflects.** For example, look at the apple shown at the top of Figure 2. The apple appears red because it reflects red wavelengths of light. The apple absorbs the other colors of light. The leaf looks green because it reflects green light and absorbs the other colors.

Objects can appear to change color if you view them in a different color of light. In red light, the apple appears red because there is red light for it to reflect. But the leaf appears black because there is no green light to reflect. In green light, the leaf looks green but the apple looks black. And in blue light, both the apple and the leaf look black.

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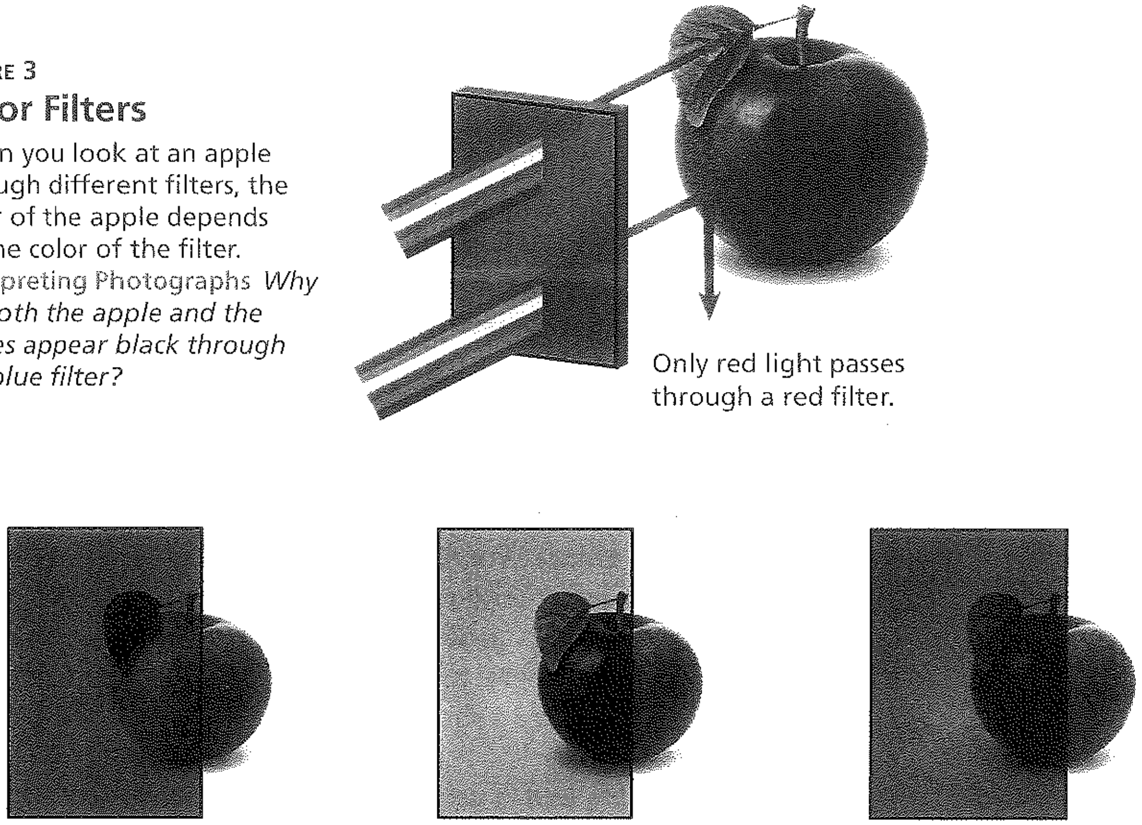
FIGURE 3

Color Filters

When you look at an apple through different filters, the color of the apple depends on the color of the filter. Interpreting Photographs *Why do both the apple and the leaves appear black through the blue filter?*



Only red light passes through a red filter.

The red filter transmits red light, so the apple looks red. But the leaf looks black.

The green filter transmits green light, so the leaf looks green. But the apple looks black.

The blue filter transmits blue light. Both the apple and the leaf look black.

Color of Transparent and Translucent Objects Materials that are transparent or translucent allow only certain colors of light to pass through them. They reflect or absorb the other colors. **The color of a transparent or translucent object is the color of the light it transmits.** For example, when white light shines through a transparent blue glass, the glass appears blue because it transmits blue light.

Transparent or translucent materials are used to make color filters. For example, a piece of glass or plastic that allows only red light to pass through is a red color filter. When you look at an object through a color filter, the color of the object may appear different than when you see the object in white light, as shown in Figure 3.

The lenses in sunglasses often are color filters. For example, lenses that are tinted yellow are yellow filters. Lenses that are tinted green are green filters. When you put on these tinted sunglasses, some objects appear to change color. The color you see depends on the color of the filter and on the color that the object appears in white light.

Reading Checkpoint **What is a color filter?**

Lab zone **Skills Activity**

Developing Hypotheses

1. Predict what colors you will see if you view a red, white, and blue flag through a red filter. Write a hypothesis of what the outcome will be. Write your hypothesis as an "If ... then ..." statement.
2. View an American flag using a red filter. What do you see? Is your hypothesis confirmed?
3. Repeat Steps 1 and 2 using a yellow filter.

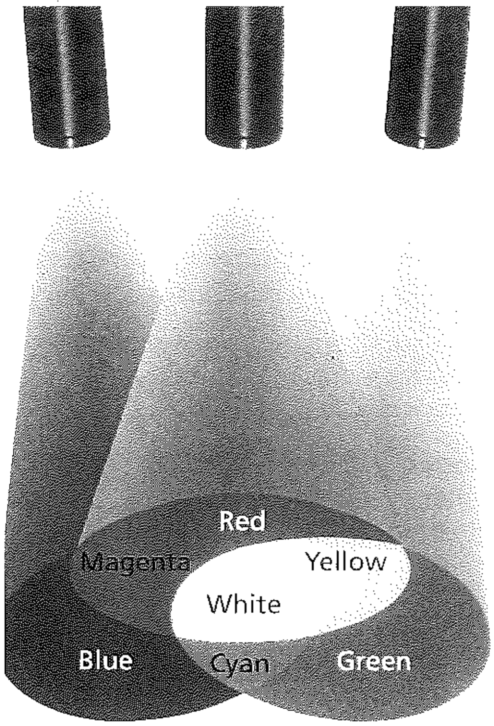


FIGURE 4
Primary Colors of Light
The primary colors of light combine in equal amounts to form white light.

Combining Colors

Color is used in painting, photography, theater lighting, and printing. People who work with color must learn how to produce a wide range of colors using just a few basic colors. Three colors that can combine to make any other color are called **primary colors.** Two primary colors combine in equal amounts to produce a **secondary color.**

Mixing Colors of Light The primary colors of light are red, green, and blue. **When combined in equal amounts, the three primary colors of light produce white light.** If they are combined in different amounts, the primary colors can produce other colors. For example, red and green combine to form yellow light. Yellow is a secondary color of light because two primary colors produce it. The secondary colors of light are yellow (red + green), cyan (green + blue), and magenta (red + blue). Figure 4 shows the primary and secondary colors of light.

A primary and a secondary color can combine to make white light. Any two colors that combine to form white light are called **complementary colors.** Yellow and blue are complementary colors, as are cyan and red, and magenta and green.

A color television produces many colors using only the primary colors of light—red, green, and blue. Figure 5 shows a magnified view of a color television screen. The picture in the screen is made up of little groups of red, green, and blue light. By varying the brightness of each colored bar, the television can produce thousands of different colors.

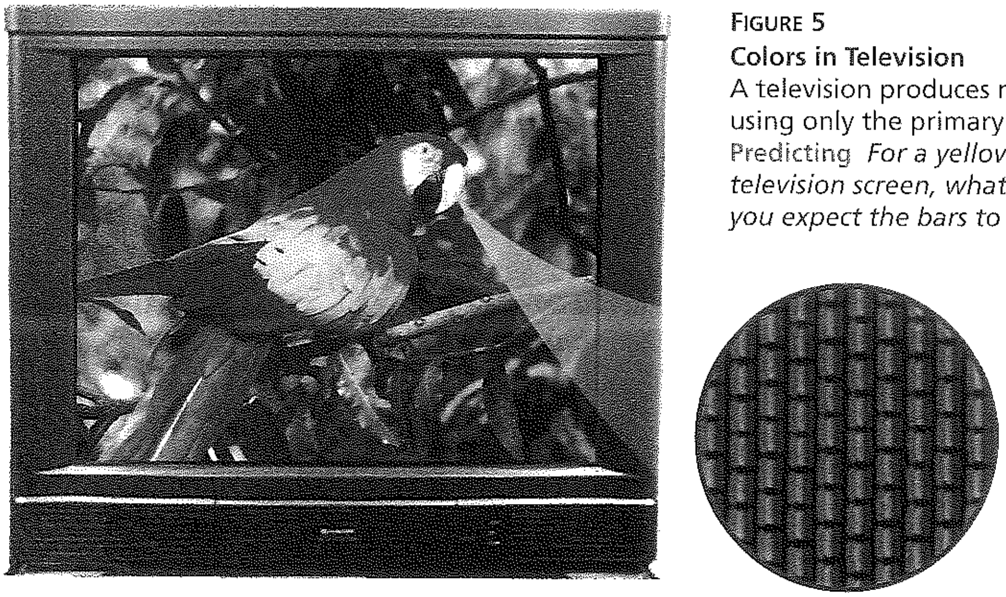


FIGURE 5
Colors in Television
A television produces many colors using only the primary colors of light.
Predicting *For a yellow area on a television screen, what color would you expect the bars to be?*

Mixing Pigments How does a printer produce the many shades of colors you see in this textbook? Inks, paints, and dyes contain **pigments,** or colored substances that are used to color other materials. Pigments absorb some colors and reflect others. The color you see is the result of the colors that particular pigment reflects.

Mixing colors of pigments is different from mixing colors of light. **As pigments are added together, fewer colors of light are reflected and more are absorbed.** The more pigments that are combined, the darker the mixture looks.

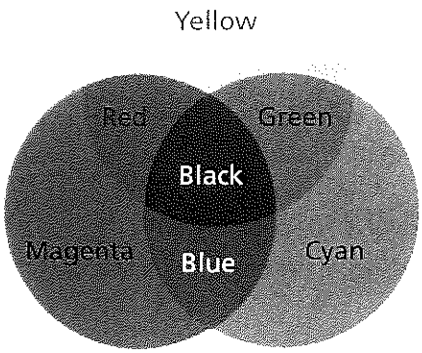
Cyan, yellow, and magenta are the primary colors of pigments. These colors combine in equal amounts to produce black. By combining pigments in varying amounts, you can produce many other colors. If you combine two primary colors of pigments, you get a secondary color, as shown in Figure 6. The secondary colors of pigments are red, green, and blue.

Look at the pictures in this book with a magnifying glass. You can see tiny dots of different colors of ink. The colors used are cyan, yellow, and magenta. Black ink is also used, so the printing process is called four-color printing.

FIGURE 6

Primary Colors of Pigments

The primary colors of pigments combine in equal amounts to form black.



Reading Checkpoint **What are pigments?**

Section 1 Assessment

Target Reading Skill Building Vocabulary Use your definitions to help answer the questions.

Reviewing Key Concepts

1. a. Identifying What three things may happen to the light that strikes an object?
   - b. Applying Concepts What happens to light that strikes the following materials: clear plastic, aluminum foil, and tissue paper?
   - c. Problem Solving Room-darkening window shades are used to keep sunlight out of a theater. What type of material should the shades be made of? Explain.
2. a. Reviewing What determines the color of an opaque object? Of a transparent or translucent object?
   - b. Drawing Conclusions An actor's red shirt and blue pants both appear black. What color is the stage light shining on the actor?
3. a. Describing What are the primary colors of light? The primary colors of pigments?
   - b. Comparing and Contrasting How does the result of mixing the primary colors of pigments compare to the result of mixing the primary colors of light?
   - c. Interpreting Diagrams In Figure 6, which pairs of colors combine to make black?

Lab zone At-Home Activity

Color Mix See how many different shades of green you can make by mixing blue and yellow paint in different proportions. On white paper, paint a "spectrum" from yellow to green to blue. Show the results to your family. Then explain how magazine photos reproduce thousands of colors.

Lab zone **Skills Lab**

Changing Colors

Problem

How do color filters affect the appearance of objects in white light?

Skills Focus

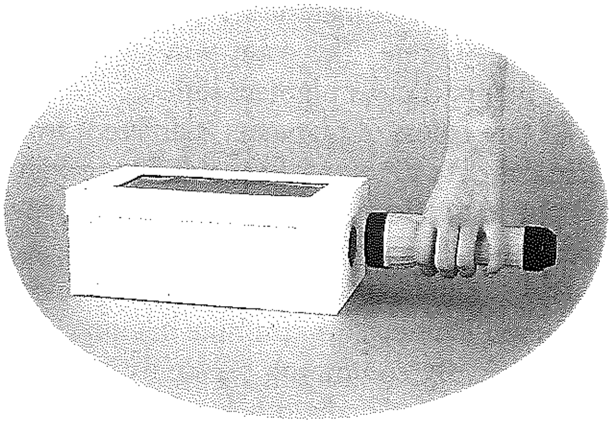
observing, inferring, predicting

Materials

- shoe box
- scissors
- flashlight
- removable tape
- red object (such as a ripe tomato)
- yellow object (such as a ripe lemon)
- blue object (such as blue construction paper)
- red, green, and blue cellophane, enough to cover the top of the shoe box

Procedure

1. Carefully cut a large rectangular hole in the lid of the shoe box.
2. Carefully cut a small, round hole in the center of one of the ends of the shoe box.
3. Tape the red cellophane under the lid of the shoe box, covering the hole in the lid.
4. Place the objects in the box and put the lid on.
5. In a darkened room, shine the flashlight into the shoe box through the side hole. Note the apparent color of each object in the box.
6. Repeat Steps 3–5 using the other colors of cellophane.



Analyze and Conclude

1. Observing What did you see when you looked through the red cellophane? Explain why each object appeared as it did.
2. Observing What did you see when you looked through the blue cellophane? Explain.
3. Inferring What color(s) of light does each piece of cellophane allow through?
4. Predicting Predict what you would see under each piece of cellophane if you put a white object in the box. Test your prediction.
5. Predicting What do you think would happen if you viewed a red object through yellow cellophane? Draw a diagram to support your prediction. Then test your prediction.
6. Communicating Summarize your conclusions by drawing diagrams to show how each color filter affects white light. Write captions to explain your diagrams.

Design an Experiment

Do color filters work like pigments or like colors of light? Design an experiment to find out what happens if you shine a light through both a red and a green filter. *Obtain your teacher's permission before carrying out your investigation.*

Section 2

Reflection and Mirrors

Reading Preview

Key Concepts

- What are the kinds of reflection?
- What types of images are produced by plane, concave, and convex mirrors?

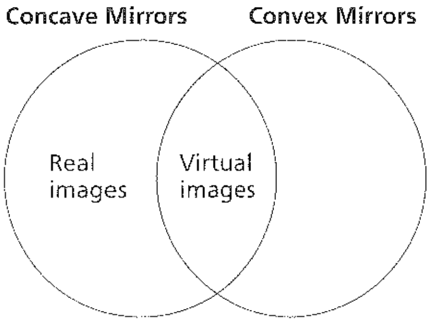
Key Terms

- ray
- regular reflection
- diffuse reflection
- plane mirror
- image
- virtual image
- concave mirror
- optical axis
- focal point
- real image
- convex mirror

Target Reading Skill

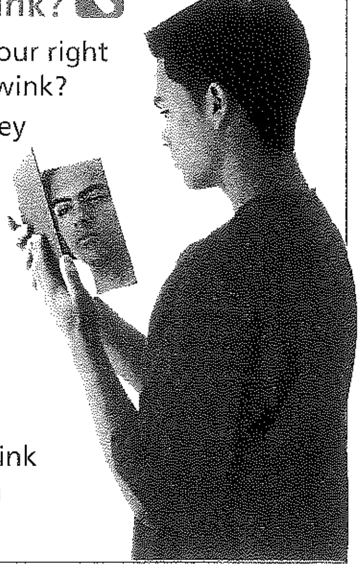
Comparing and Contrasting

As you read, compare and contrast concave and convex mirrors in a Venn diagram like the one below. Write the similarities in the space where the circles overlap and the differences on the left and right sides.



Lab zone Discover Activity

How Does Your Reflection Wink?



1. Look at your face in a mirror. Wink your right eye. Which eye does your reflection wink?
2. Tape two mirrors together so that they open and close like a book. Open them so they form a 90-degree angle with each other. **CAUTION:** *Be careful of any sharp edges.*
3. Looking into both mirrors at once, wink at your reflection again. Which eye does your reflection wink now?

Think It Over

Observing How does your reflection wink at you? How does the second reflection compare with the first reflection?

You laugh as you and a friend move toward the curved mirror. First your reflections look tall and skinny. Then they become short and wide. At one point, your reflections disappear even though you are still in front of the mirror. Imagine what it would be like if this happened every time you tried to comb your hair in front of a mirror!

Funhouse mirror ▶

Reflection of Light Rays

The reflection you see in a mirror depends on how the surface reflects light. To show how light reflects, you can represent light waves as straight lines called **rays**. You may recall that light rays obey the law of reflection—the angle of reflection equals the angle of incidence.

Figure 7 shows two kinds of reflection. In the choppy water, you do not see a clear reflection of the oars in the boat. But in the smooth water, you see a sharp reflection. **The two ways in which a surface can reflect light are regular reflection and diffuse reflection.**

Regular Reflection When parallel rays of light hit a smooth surface, **regular reflection** occurs. All of the light rays are reflected at the same angle because of the smooth surface. So, you see a sharp reflection.

Diffuse Reflection When parallel rays of light hit a bumpy or uneven surface, **diffuse reflection** occurs. Each light ray obeys the law of reflection but hits the surface at a different angle because the surface is uneven. Therefore, each ray reflects at a different angle, and you don't see a clear reflection.

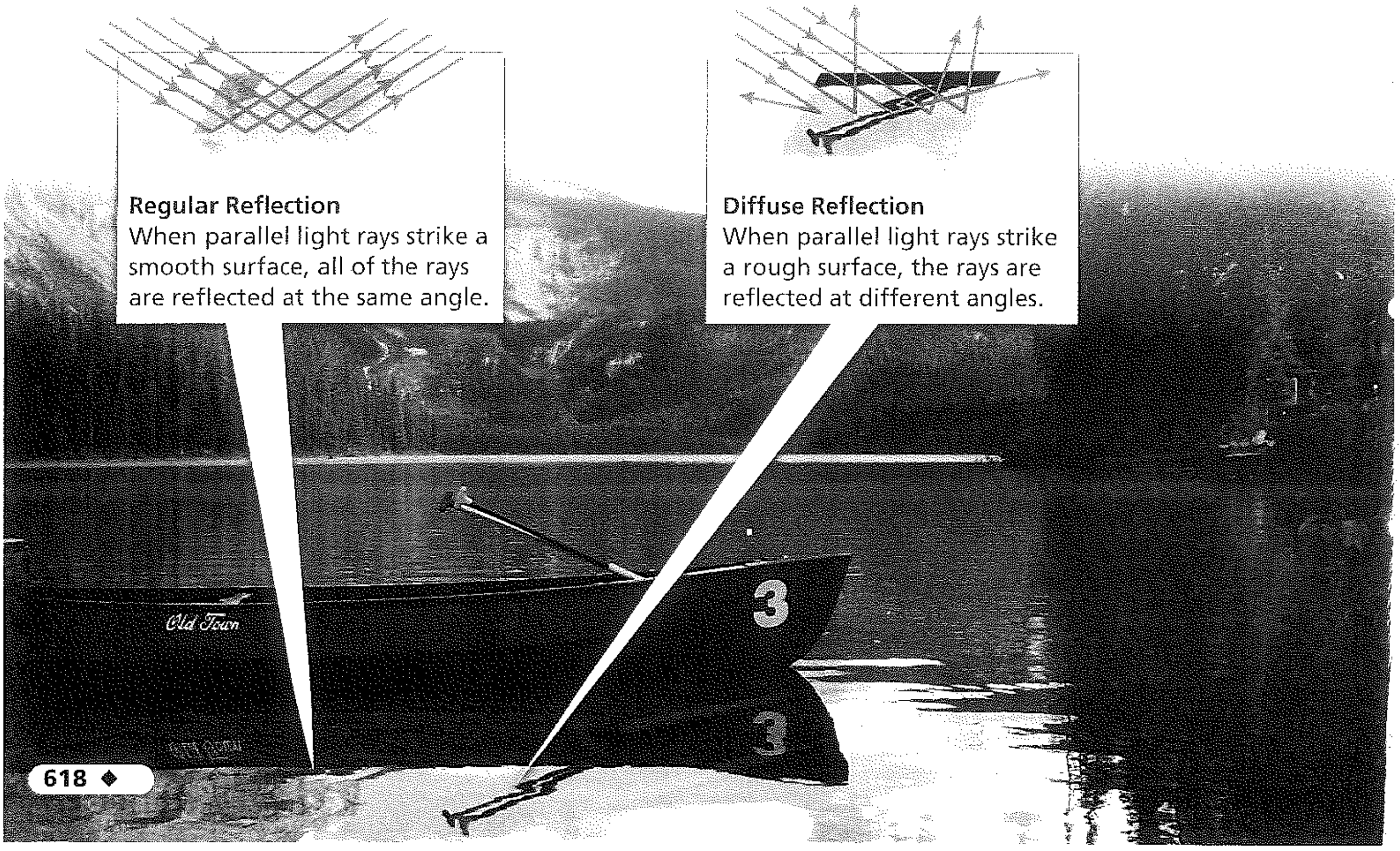
Reading Checkpoint **What kind of surface results in diffuse reflection?**

Lab zone Skills Activity

Observing

In a dark room, hold a flashlight next to a table. **CAUTION:** *Do not look directly into the flashlight.* Point its beam straight up so no light shines on the tabletop. Then hold a metal can upright 5 cm above the flashlight. Tilt the can so its flat bottom reflects light onto the table. Try this again using a white paper cup. How does the light reflected by the can compare with the light reflected by the cup?

FIGURE 7
Diffuse and Regular Reflection
The type of reflection that occurs at a surface depends on whether the surface is rough or smooth.



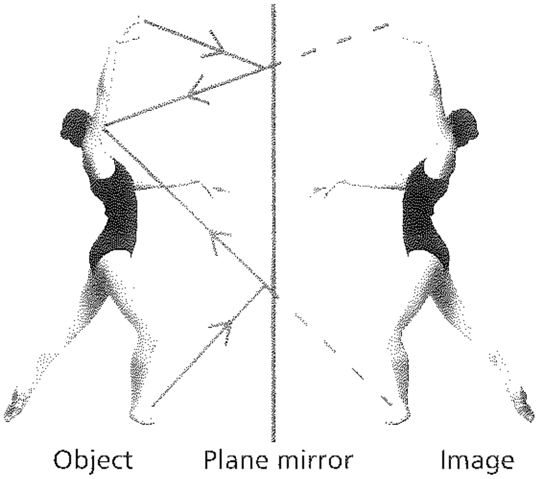
Regular Reflection
When parallel light rays strike a smooth surface, all of the rays are reflected at the same angle.

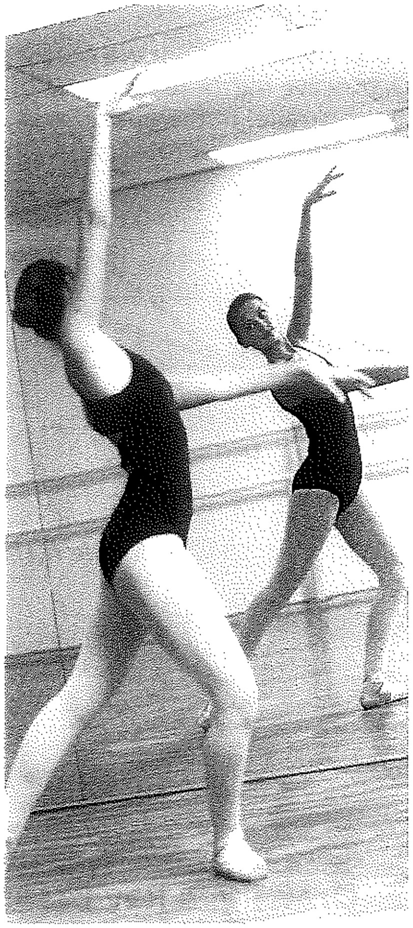
Diffuse Reflection
When parallel light rays strike a rough surface, the rays are reflected at different angles.

FIGURE 8

Image in a Plane Mirror

A plane mirror forms a virtual image. The reflected light rays appear to come from behind the mirror, where the image forms. Observing *Is the raised hand in the image a left hand or a right hand?*





Plane Mirrors

Did you look into a mirror this morning to comb your hair or brush your teeth? If you did, you probably used a plane mirror. A **plane mirror** is a flat sheet of glass that has a smooth, silver-colored coating on one side. Often the coating is on the back of the mirror to protect it from damage. When light strikes a mirror, the coating reflects the light. Because the coating is smooth, regular reflection occurs and a clear image forms. An **image** is a copy of an object formed by reflected or refracted rays of light.

What Kind of Image Forms The image you see in a plane mirror is a **virtual image**—an upright image that forms where light seems to come from. "Virtual" describes something that does not really exist. Your image appears to be behind the mirror, but you can't reach behind the mirror and touch it.

A plane mirror produces a virtual image that is upright and the same size as the object. But the image is not quite the same as the object. The left and right of the image are reversed. For example, when you look in a mirror, your right hand appears to be a left hand in the image.

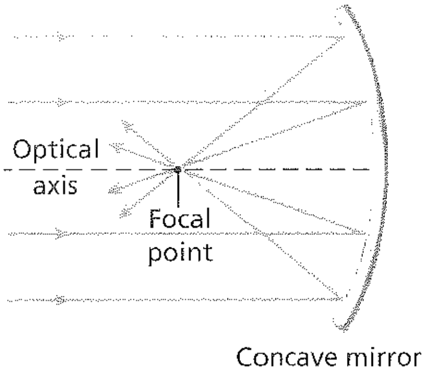
How Images Form Figure 8 shows how a plane mirror forms an image. In the photo, some light rays from the dancer strike the mirror and reflect toward her. Even though the rays are reflected, the dancer's brain treats them as if they had come from behind the mirror. The dashed lines in the illustration show where the light rays appear to come from. Because the light appears to come from behind the mirror, this is where the dancer's image appears to be located.

✓ Reading Checkpoint **Where does an image in a plane mirror appear to be located?**

FIGURE 9

Focal Point of a Concave Mirror

A concave mirror reflects rays of light parallel to the optical axis back through the focal point.



Concave Mirrors

A mirror with a surface that curves inward like the inside of a bowl is a **concave mirror.** Figure 9 shows how a concave mirror can reflect parallel rays of light so that they meet at a point. Notice that the rays of light shown are parallel to the optical axis. The **optical axis** is an imaginary line that divides a mirror in half, much like the Equator that divides Earth into northern and southern halves. The point at which rays parallel to the optical axis meet is called the **focal point.** The location of the focal point depends on the shape of the mirror. The more curved the mirror is, the closer the focal point is to the mirror.

Representing How Images Form Ray diagrams are used to show where a focused image forms in a concave mirror. A ray diagram shows rays of light coming from points on the object. Two rays coming from one point on the object meet or appear to meet at the corresponding point on the image. Figure 10 shows how a ray diagram is drawn.

FIGURE 10

Drawing a Ray Diagram

Ray diagrams show where an image forms and the size of the image. The steps below show how to draw a ray diagram.

① Draw a red ray from a point on the object (point **A**) to the mirror. Make this ray parallel to the optical axis. Then draw the reflected ray, which passes through the focal point.

② Draw the green ray from the same point on the object to the mirror. Draw this ray as if it comes from the focal point. Then draw the reflected ray, which is parallel to the optical axis.

③ Draw dashed lines behind the mirror to show where the reflected rays appear to come from. The corresponding point on the image is located where the dashed lines cross.

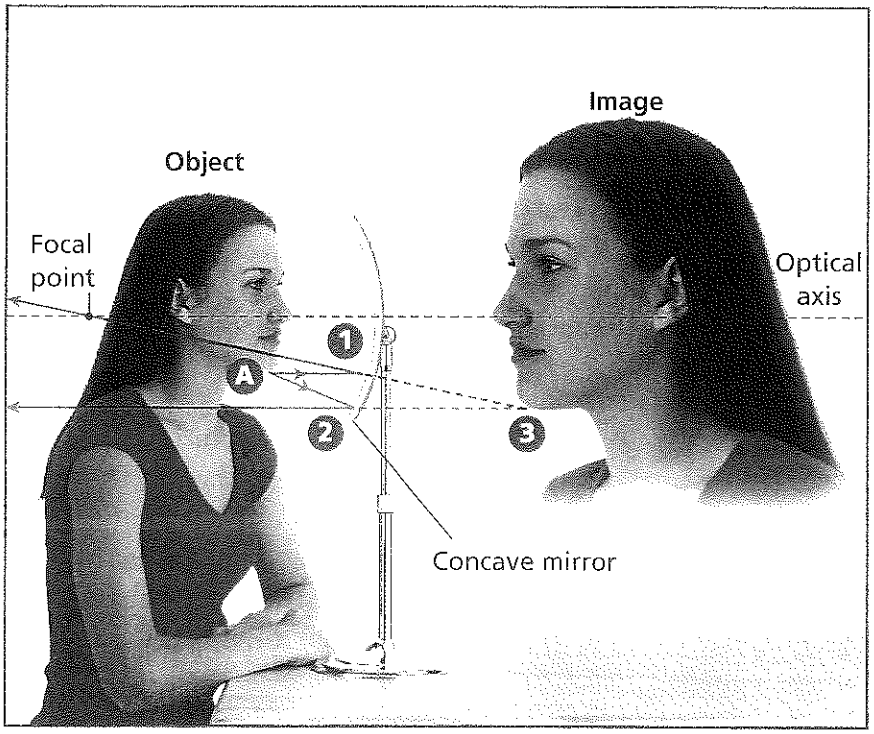
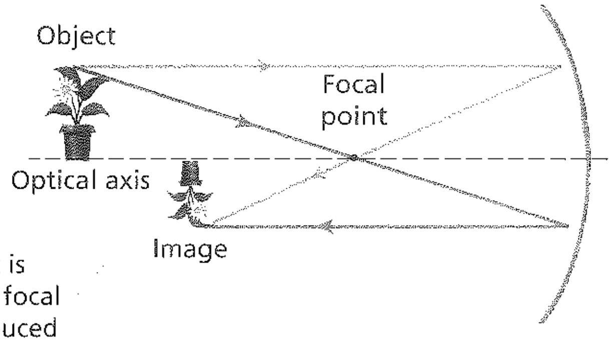
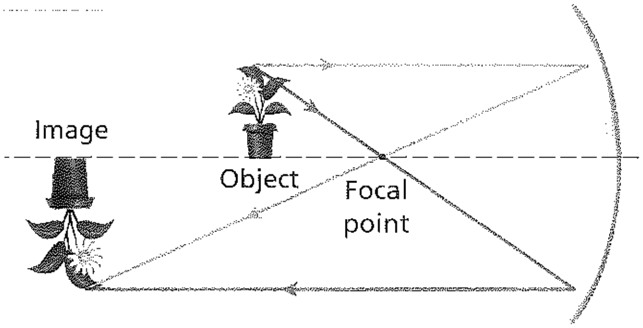


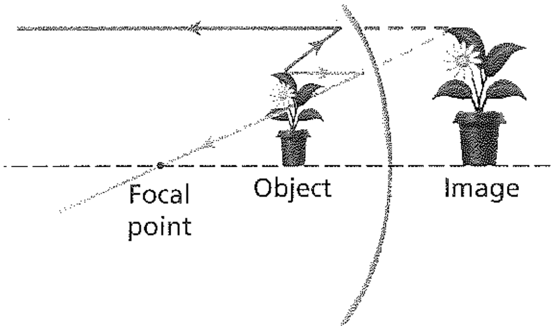
Figure 11
Images in Concave Mirrors
The type of image formed depends on the location of the object.
Interpreting Diagrams *When light rays actually meet, what kind of image is formed?*



When the object is well beyond the focal point, a real, reduced image forms.

When the object is beyond the focal point but near it, a real, enlarged image forms.





When the object is closer than the focal point, a virtual, enlarged image forms.

Determining the Type of Image The type of image that is formed by a concave mirror depends on the location of the object. **Concave mirrors can form either virtual images or real images.** If the object is farther away from the mirror than the focal point, the reflected rays form a real image as shown in Figure 11. A **real image** forms when rays actually meet. Real images are upside down. A real image may be larger or smaller than the object.

If the object is between the mirror and the focal point, the reflected rays form a virtual image. The image appears to be behind the mirror and is upright. Virtual images formed by a concave mirror are always larger than the object. Concave mirrors produce the magnified images you see in a makeup mirror.

If an object is placed at the focal point, no image forms. But if a light source is placed at the focal point, the mirror can project parallel rays of light. A car headlight, for example, has a light bulb at the focal point of a concave mirror. Light hits the mirror, forming a beam of light that shines on the road ahead.

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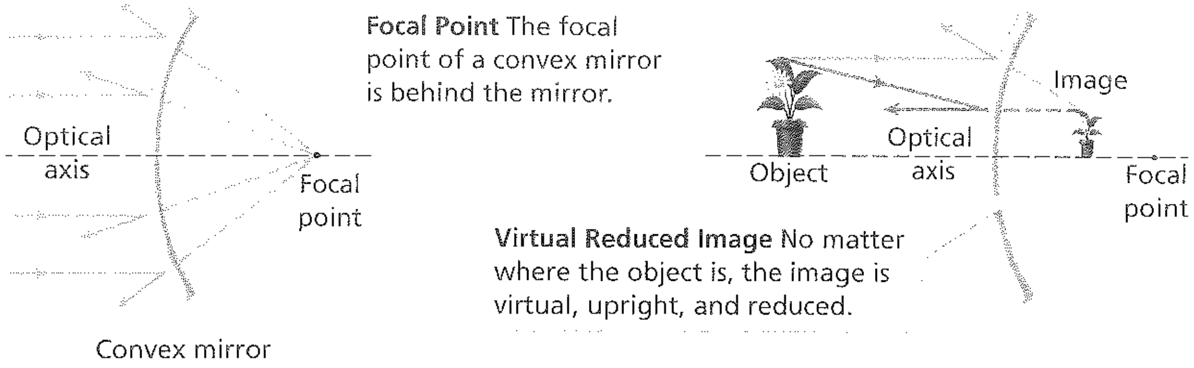
✓ Reading Checkpoint **What is a real image?**



Focal Point The focal point of a convex mirror is behind the mirror.

Virtual Reduced Image No matter where the object is, the image is virtual, upright, and reduced.

FIGURE 12
Convex Mirrors
Light rays parallel to the optical axis reflect as if they came from the focal point behind the mirror. The image formed by a convex mirror is always virtual.
Making Generalizations *Describe the directions of the parallel rays reflected by a convex mirror.*

Convex Mirrors

A mirror with a surface that curves outward is called a **convex mirror.** Figure 12 shows how convex mirrors reflect parallel rays of light. The rays spread out but appear to come from a focal point behind the mirror. The focal point of a convex mirror is the point from which the rays appear to come. **Because the rays never meet, images formed by convex mirrors are always virtual and smaller than the object.**

Perhaps you have seen this warning on a car mirror: "Objects in mirror are closer than they appear." Convex mirrors are used in cars as passenger-side mirrors. The advantage of a convex mirror is that it allows you to see a larger area than you can with a plane mirror. The disadvantage is that the image is reduced in size, so it appears to be farther away than it actually is.

✓ Reading Checkpoint **Where are convex mirrors typically used?**

Section 2 Assessment

Target Reading Skill

Comparing and Contrasting Use your Venn diagram about mirrors to help you answer Question 2 below.

Reviewing Key Concepts

1. a. Reviewing What are two kinds of reflection?
   b. Explaining Explain how both kinds of reflection obey the law of reflection.
   c. Inferring Why is an image clear in a shiny spoon but fuzzy in a tarnished spoon?
2. a. Defining What is an image?
   b. Classifying Which mirrors can form real images? Which can form virtual images?
   c. Comparing and Contrasting How are images in concave mirrors like images in convex mirrors? How are they different?

Writing in Science

Dialogue At a funhouse mirror, your younger brother notices he can make his image disappear as he walks toward the mirror. He asks you to explain, but your answer leads to more questions. Write the dialogue that might take place between you and your brother.

Section 3

Refraction and Lenses

Reading Preview

Key Concepts

- Why do light rays bend when they enter a medium at an angle?
- What determines the types of images formed by convex and concave lenses?

Key Terms

- index of refraction
- mirage
- lens
- convex lens
- concave lens

Target Reading Skill

Asking Questions Before you read, preview the red headings. In a graphic organizer like the one below, ask a *what, when, where* or *how* question for each heading. As you read, write the answers to your questions.

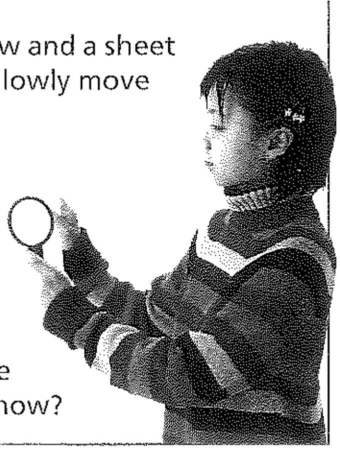
Refraction and Lenses

Question	Answer
When does refraction occur?	Refraction occurs . . .

Lab zone Discover Activity

How Can You Make an Image Appear?

1. Stand about 2 meters from a window. Hold a hand lens up to your eye and look through it. What do you see? **CAUTION:** *Do not look at the sun.*
2. Move the lens farther away from your eye. What changes do you notice?
3. Now hold the lens between the window and a sheet of paper, but very close to the paper. Slowly move the lens away from the paper and toward the window. Keep watching the paper. What do you see? What happens as you move the lens?



Think It Over

Observing How is an image formed on a sheet of paper? Describe the image. Is it real or virtual? How do you know?

A fish tank can play tricks on you. If you look through the side of a fish tank, a fish seems closer than if you look over the top. If you look through the corner, you may see the same fish twice. You see one image of the fish through the front of the tank and another through the side. The two images appear in different places! How can this happen?

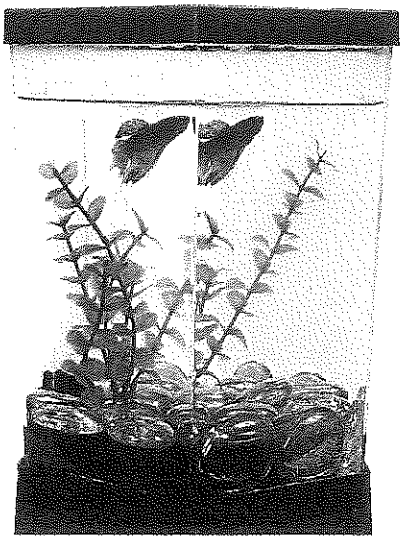


FIGURE 13
Optical Illusion in a Fish Tank
There is only one fish in this tank, but refraction makes it look as though there are two.

Math Analyzing Data

Bending Light

The index of refraction of a medium is a measure of how much light bends as it travels from air into the medium. The table shows the index of refraction of some common mediums.

1. Interpreting Data Which medium causes the greatest change in the direction of a light ray?
2. Interpreting Data According to the table, which tends to bend light more: solids or liquids?
3. Predicting Would you expect light to bend if it entered corn oil at an angle after traveling through glycerol? Explain.

Index of Refraction

Medium	Index of Refraction
Air (gas)	1.00
Water (liquid)	1.33
Ethyl alcohol (liquid)	1.36
Quartz (solid)	1.46
Corn oil (liquid)	1.47
Glycerol (liquid)	1.47
Glass, crown (solid)	1.52
Sodium chloride (solid)	1.54
Zircon (solid)	1.92
Diamond (solid)	2.42

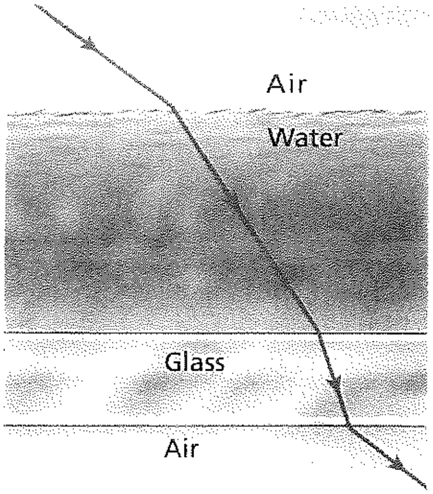
Refraction of Light

Refraction can cause you to see something that may not actually be there. As you look at a fish in a tank, the light coming from the fish to your eye bends as it passes through three different mediums. The mediums are water, the glass of the tank, and air. As the light passes from one medium to the next, it refracts. **When light rays enter a medium at an angle, the change in speed causes the rays to bend, or change direction.**

Refraction in Different Mediums Some mediums cause light to bend more than others, as shown in Figure 14. When light passes from air into water, the light slows down. Light slows down even more when it passes from water into glass. When light passes from glass back into air, the light speeds up. Light travels fastest in air, a little slower in water, and slower still in glass. Notice that the ray that leaves the glass is traveling in the same direction as it was before it entered the water.

Glass causes light to bend more than either air or water. Another way to say this is that glass has a higher index of refraction than either air or water. A material's **index of refraction** is a measure of how much a ray of light bends when it enters that material. The higher the index of refraction of a medium, the more it bends light. The index of refraction of water is 1.33, and the index of refraction of glass is about 1.5. So light is bent more by glass than by water.

FIGURE 14
Refraction of Light
As light passes from a less dense medium into a more dense medium, it slows down and is refracted.



Prisms and Rainbows Recall that when white light enters a prism, each wavelength is refracted by a different amount. The longer the wavelength, the less the wave is bent by a prism. Red, with the longest wavelength, is refracted the least. Violet, with the shortest wavelength, is refracted the most. This difference in refraction causes white light to spread out into the colors of the spectrum—red, orange, yellow, green, blue, and violet.

The same process occurs in water droplets suspended in the air. When white light from the sun shines through the droplets, a rainbow may appear. The water droplets act like tiny prisms, refracting and reflecting the light and separating the colors.

Mirages You're traveling in a car on a hot day, and you notice that the road ahead looks wet. Yet when you get there, the road is dry. Did the puddles dry up? No, the puddles were never there! You saw a **mirage** (mih RAHJ)—an image of a distant object caused by refraction of light. The puddles on the road are light rays from the sky that are refracted to your eyes.

Figure 16 shows a mirage. Notice the white areas on the road. The air just above the road is hotter than the air higher up. Light travels faster in hot air. So, light rays that travel toward the road are bent upward by the hot air. Your brain assumes that the rays traveled in a straight line. So the rays look as if they have reflected off a smooth surface. What you see is a mirage.

✓ Reading Checkpoint **What causes a mirage?**

FIGURE 15
Rainbows
A rainbow forms when sunlight is refracted and reflected by tiny water droplets. Observing *What is the order of colors in a rainbow?*

FIGURE 16
Mirages
The puddles and white reflections on the road are mirages. Light refracts as it goes from hot air to cool air. The refracted light appears to come from the ground.

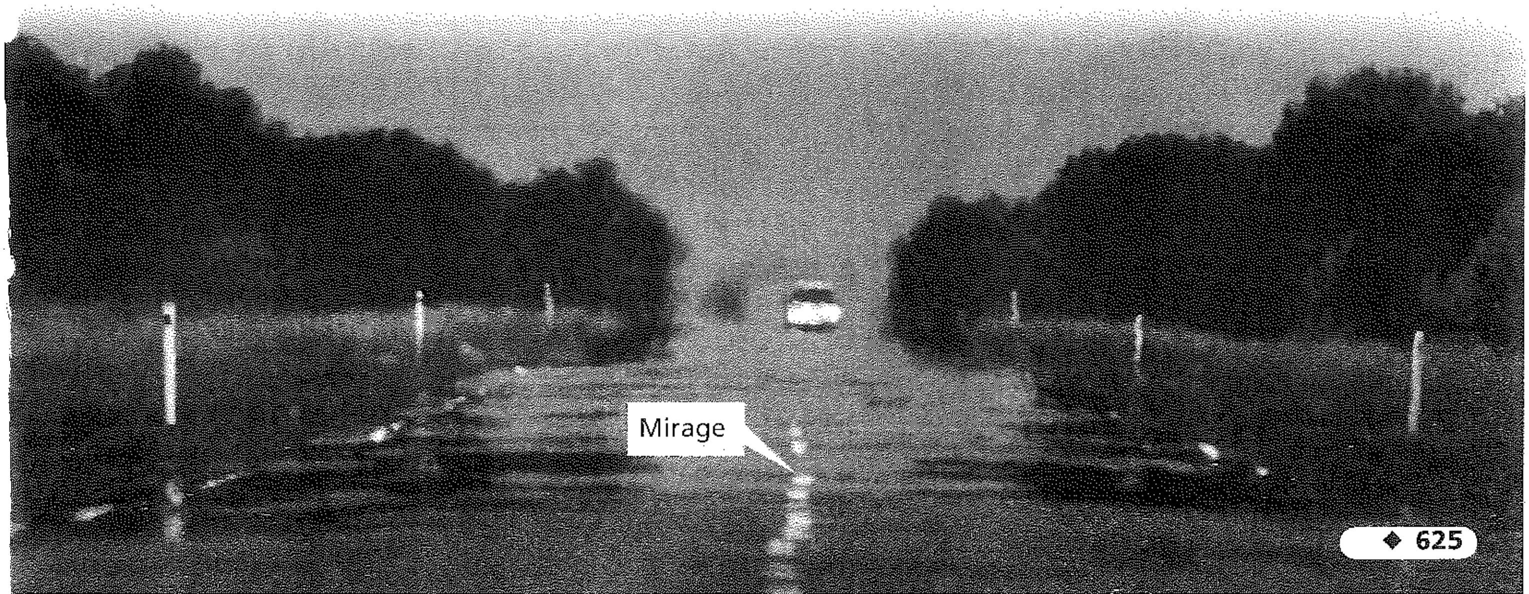
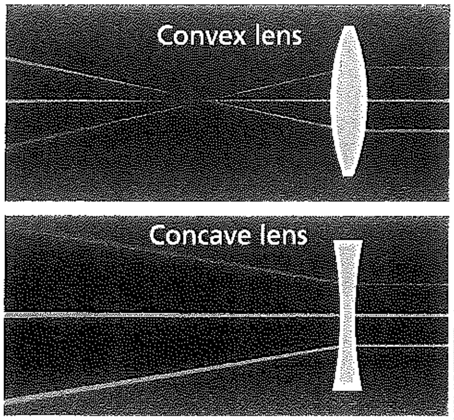


Figure 17
Convex and Concave Lenses
A convex lens can focus parallel rays at a focal point. A concave lens causes parallel rays to spread apart.



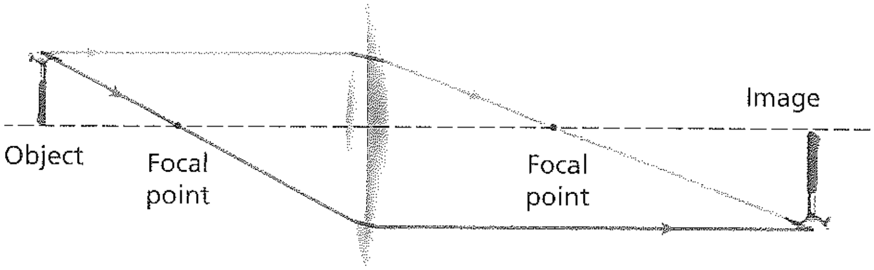
Lenses

Anytime you look through binoculars, a camera, or eyeglasses, you are using lenses to bend light. A **lens** is a curved piece of glass or other transparent material that is used to refract light. A lens forms an image by refracting light rays that pass through it. Like mirrors, lenses can have different shapes. The type of image formed by a lens depends on the shape of the lens and the position of the object.

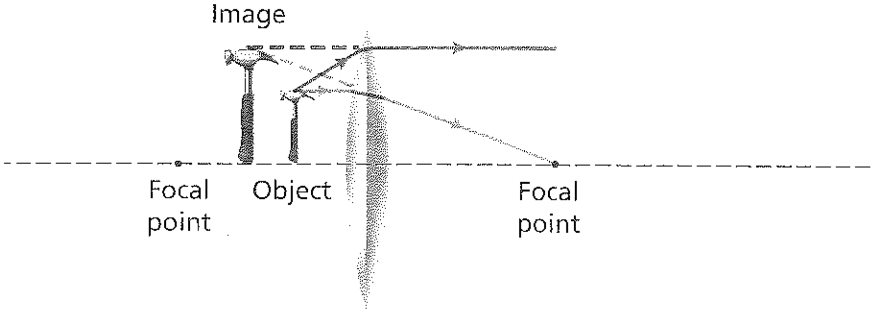
Convex Lenses A **convex lens** is thicker in the center than at the edges. As light rays parallel to the optical axis pass through a convex lens, they are bent toward the center of the lens. The rays meet at the focal point of the lens and continue to travel beyond. The more curved the lens, the more it refracts light. A convex lens acts somewhat like a concave mirror, because it focuses rays of light.

An object's position relative to the focal point determines whether a convex lens forms a real image or a virtual image. Figure 18 shows that if the object is farther away than the focal point, the refracted rays form a real image on the other side of the lens. If the object is between the lens and the focal point, a virtual image forms on the same side of the lens as the object.

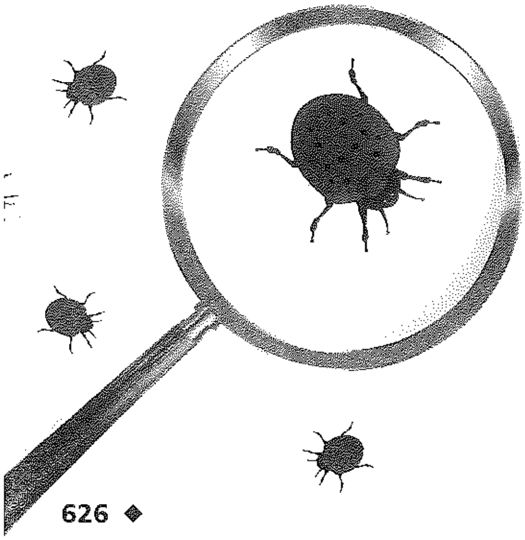
Figure 18
Images in Convex Lenses
The type of image formed by a convex lens depends on the object's position.

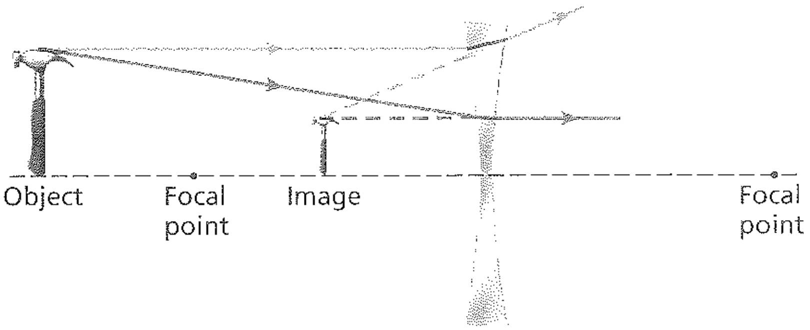


Real Image If the object is farther from the lens than the focal point, a real image forms.



Virtual Image If the object is closer to the lens than the focal point, a virtual image forms.





Virtual, Reduced Image Wherever the object is placed, a virtual image forms.

FIGURE 19
Images in Concave Lenses
A concave lens produces virtual images that are upright and smaller than the object.
Interpreting Diagrams *Why can a concave lens only form a virtual image?*

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Concave Lenses A **concave lens** is thinner in the center than at the edges. When light rays traveling parallel to the optical axis pass through a concave lens, they bend away from the optical axis and never meet. **A concave lens can produce only virtual images because parallel light rays passing through the lens never meet.**

Figure 19 shows how an image forms in a concave lens. The virtual image is located where the light rays appear to come from. The image is always upright and smaller than the object.

✓ Reading Checkpoint **What is the shape of a concave lens?**

Section 3 Assessment

Target Reading Skill Asking Questions Use the answers to the questions you wrote about the headings to help you answer the questions below.

Reviewing Key Concepts

1. a. Identifying What is a material's index of refraction?
   b. Relating Cause and Effect What causes light rays to bend when they enter a new medium at an angle?
   c. Predicting If a glass prism were placed in a medium such as water, would it separate white light into different colors? Explain.
2. a. Defining What is a lens?
   b. Comparing and Contrasting Describe the shapes of a concave lens and a convex lens.
   c. Interpreting Diagrams Use Figure 18 to explain how you can tell whether a convex lens will form a real or virtual image.

Lab zone At-Home Activity

Bent Pencil Here's how you can bend a pencil without touching it. Put a pencil in a glass of water so that it is half in and half out of the water. Have your family members look at the pencil from the side. Using your understanding of refraction, explain to your family why the pencil appears as it does.

Lab zone **Skills Lab**

Looking at Images

Problem

How does the distance between an object and a convex lens affect the image formed?

Skills Focus

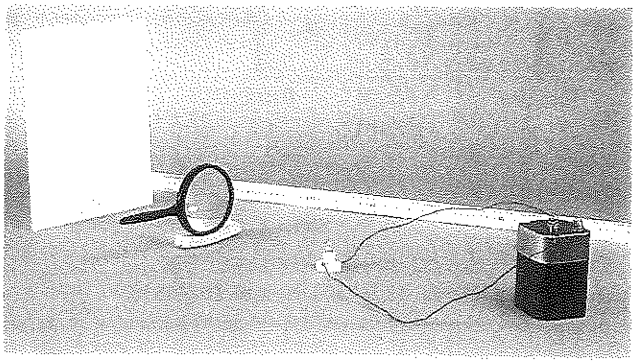
controlling variables, interpreting data

Materials

- tape
- convex lens
- cardboard stand
- blank sheet of paper
- light bulb and socket
- clay, for holding the lens
- battery and wires
- meter stick
- centimeter ruler

Procedure

1. Tape the paper onto the cardboard stand.
2. Place a lit bulb more than 2 m from the paper. Use the lens to focus light from the bulb onto the paper. Measure the distance from the lens to the paper. This is the approximate focal length of the lens you are using.
3. Copy the data table into your notebook.
4. Now place the bulb more than twice the focal length away from the lens. Adjust the cardboard until the image is focused. Record the size of the image on the paper and note the orientation of the image. Record the distance from the bulb to the lens and from the lens to the cardboard.
5. Now, move the bulb so that it is just over one focal length away from the lens. Record the position and size of the image.



Analyze and Conclude

1. **Controlling Variables** Make a list of the variables in this experiment. Which variables did you keep constant? Which was the manipulated variable? Which were the responding variables?
2. **Observing** What happened to the position of the image as the bulb moved toward the lens?
3. **Interpreting Data** Was the image formed by the convex lens always enlarged? If not, under what conditions was the image reduced?
4. **Predicting** What would happen if you look through the lens at the bulb when it is closer to the lens than the focal point? Explain your prediction.
5. **Communicating** Write a paragraph explaining how the distance between an object and a convex lens affects the image formed. Use ray diagrams to help you summarize your results.

Design an Experiment

Design an experiment to study images formed by convex lenses with different thicknesses. How does the lens thickness affect the position and size of the images? *Obtain your teacher's permission before carrying out your investigation.*

Data Table

Focal Length of Lens: ____ cm Height of Bulb: ____ cm

Distance From Bulb to Lens (cm)	Distance From Lens to Cardboard (cm)	Image Orientation (upright or upside down)	Image Size (height in cm)

Section 4

Integrating Life Science

Seeing Light

Reading Preview

Key Concepts

- How do you see objects?
- What types of lenses are used to correct vision problems?

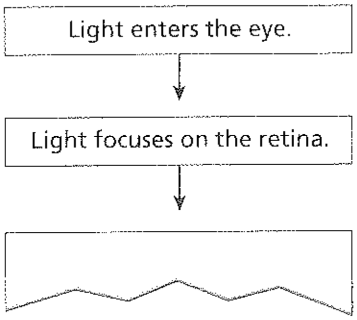
Key Terms

- cornea
- pupil
- iris
- retina
- rods
- cones
- optic nerve
- nearsighted
- farsighted

Target Reading Skill

Sequencing A sequence is the order in which the steps in a process occur. As you read, make a flowchart that shows how you see objects. Put the steps of the process in separate boxes in the flowchart in the order in which they occur.

How You See Objects



Lab zone Discover Activity

Can You See Everything With One Eye?

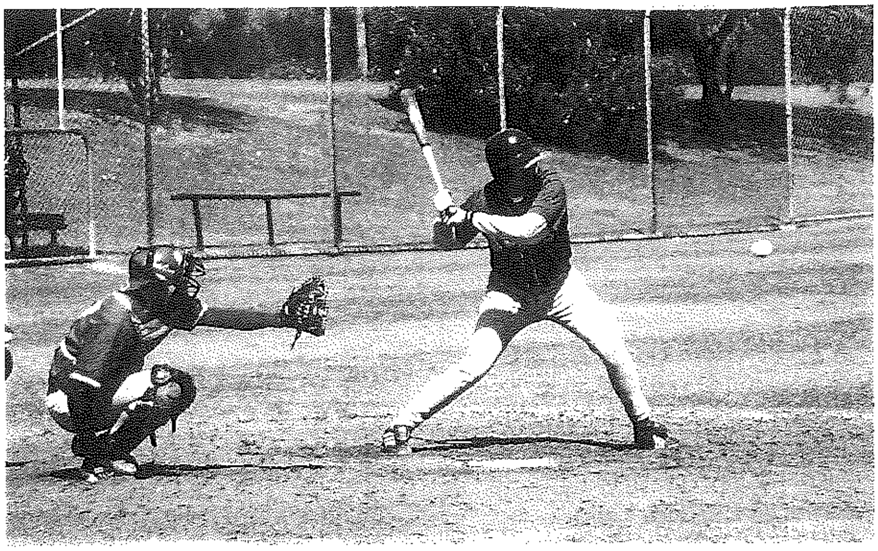
1. Write an X and an O on a sheet of paper. The O should be about 5 cm to the right of the X.
2. Hold the sheet of paper at arm's length.
3. Close or cover your left eye. Stare at the X with your right eye.
4. Slowly move the paper toward your face while staring at the X. What do you notice?
5. Repeat the activity, keeping both eyes open. What difference do you notice?

Think It Over

Posing Questions Write two questions about vision that you could investigate using the X and the O.

The pitcher goes into her windup, keeping her eye on the strike zone. The batter watches the pitcher release the ball and then swings. Crack! She drops the bat and sprints toward first base. From your seat, you watch the ball travel toward the outfield. Will it be a base hit? The left fielder watches the ball speed toward her. It's over her head for a double!

Players and spectators alike followed the first rule of baseball: Keep your eye on the ball. As the ball moves near and far, your eyes must adjust continuously to keep it in focus. Fortunately, this change in focus happens automatically.



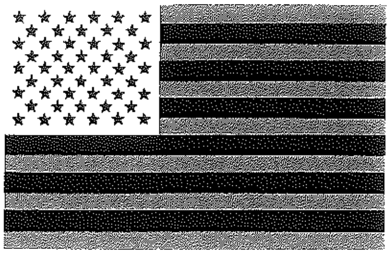
Keep your eye on the ball! ▶

Lab zone Try This Activity

True Colors

When you stare too long at a color, the cones in your eyes get tired.

1. Stare at the bottom right star of the flag for at least 60 seconds. Do not move your eyes or blink during that time.



2. Now stare at a sheet of blank white paper.

Observing What do you see when you look at the white paper? How are the colors you see related to the colors in the original flag?

The Human Eye

Your eyes allow you to sense light. The eye is a complex structure with many parts, as you can see in Figure 20. Each part plays a role in vision. **You see objects when a process occurs that involves both your eyes and your brain.**

Light Enters the Eye Light enters the eye through the transparent front surface called the **cornea** (KAWR nee uh). The cornea protects the eye. It also acts as a lens to help focus light rays.

After passing through the cornea, light enters the pupil, the part of the eye that looks black. The **pupil** is an opening through which light enters the inside of the eye. In dim light, the pupil becomes larger to allow in more light. In bright light, the pupil becomes smaller to allow in less light. The **iris** is a ring of muscle that contracts and expands to change the size of the pupil. The iris gives the eye its color. In most people the iris is brown; in others it is blue, green, or hazel.

An Image Forms After entering the pupil, the light passes through the lens. The lens is a convex lens that refracts light to form an image on the lining of your eyeball. Muscles, called ciliary muscles, hold the lens in place behind the pupil. When you focus on a distant object, the ciliary muscles relax, and the lens becomes longer and thinner. When you focus on a nearby object, the muscles contract, and the lens becomes shorter and fatter.

When the cornea and the lens refract light, an upside-down image is formed on the retina. The **retina** is a layer of cells that lines the inside of the eyeball. (Cells are the tiny structures that make up living things.)

The retina is made up of tiny, light-sensitive cells called rods and cones. **Rods** are cells that contain a pigment that responds to small amounts of light. The rods allow you to see in dim light. **Cones** are cells that respond to color. They may detect red light, green light, or blue light. Cones respond best in bright light. Both rods and cones help change images on the retina into signals that then travel to the brain.

A Signal Goes to the Brain The rods and cones send signals to the brain along a short, thick nerve called the **optic nerve.** The optic nerve begins at the blind spot, an area of the retina so called because it has no rods or cones. Your brain interprets the signals as an upright image. It also combines the images from each of your eyes into a single three-dimensional image.

Reading Checkpoint Where does an image form in the eye?

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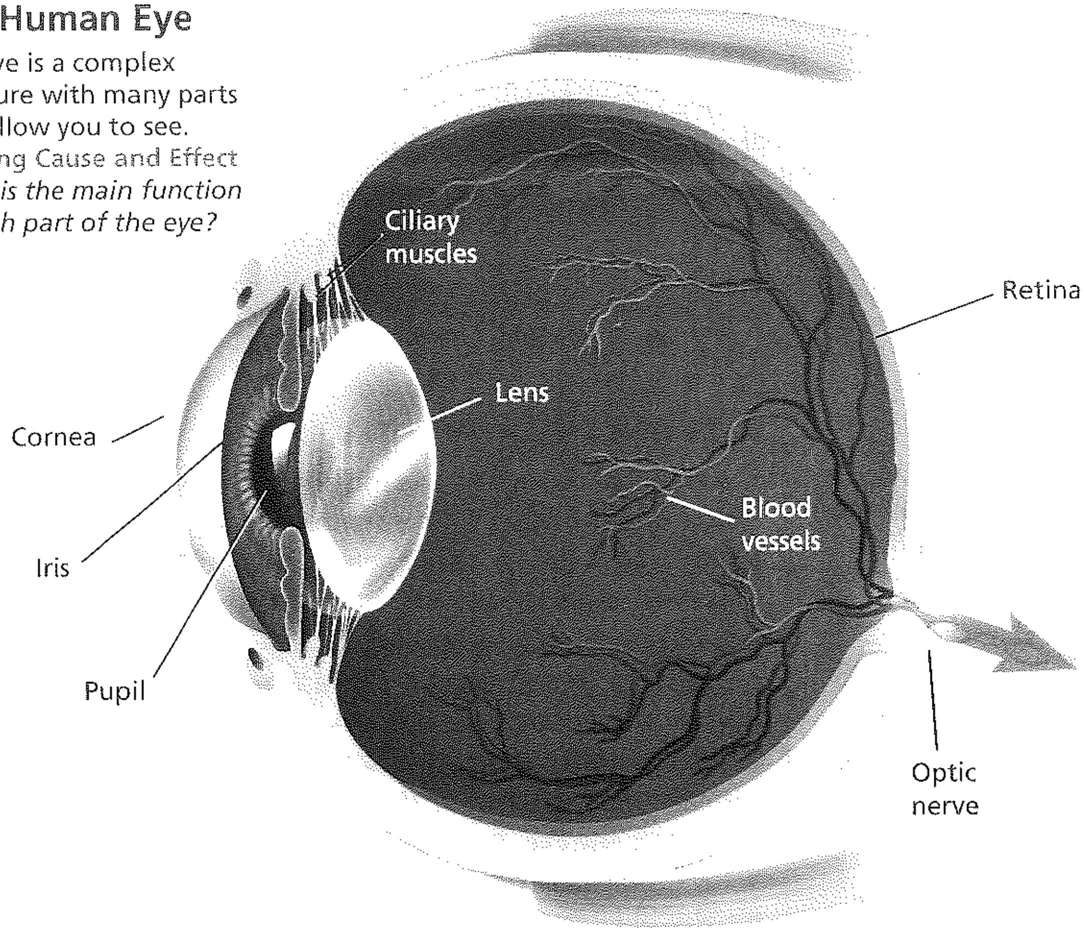
FIGURE 20

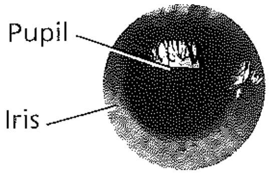
The Human Eye

The eye is a complex structure with many parts that allow you to see. Relating Cause and Effect *What is the main function of each part of the eye?*

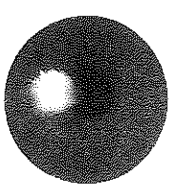


Pupil and Iris

The iris controls the size of the pupil, which determines how much light enters the eye.



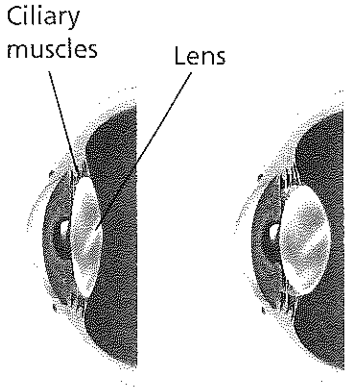
Dim Light The iris contracts, making the pupil large.



Bright Light The iris expands, making the pupil small.

Lens and Ciliary Muscles

The ciliary muscles change the shape of the lens.

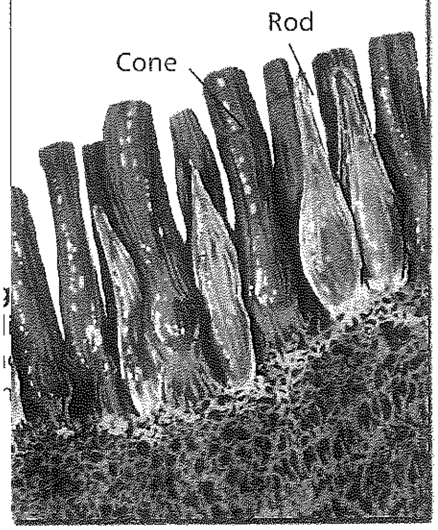


Seeing Far Away The ciliary muscles relax, making the lens thin.

Seeing Close Up The ciliary muscles contract, making the lens thick.

Retina

The retina has two kinds of cells that detect light. The rods respond to dim light. The cones respond to red, green, and blue light.



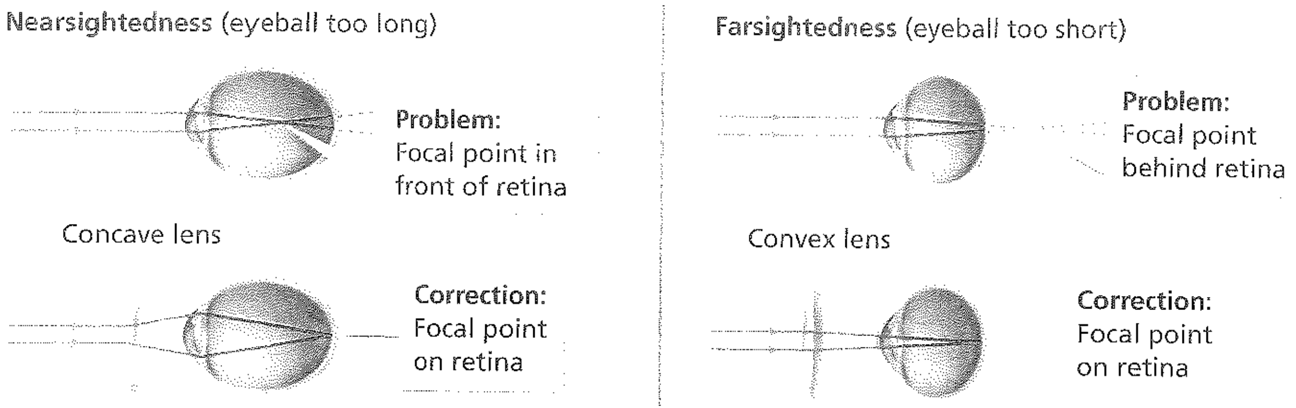


FIGURE 21
Vision Correction
Nearsightedness and farsightedness are caused when the eyeball is too long or too short. Both can be corrected with lenses.

Correcting Vision

If the eyeball is slightly too long or too short, the image on the retina is out of focus. Fortunately, wearing glasses or contact lenses can correct this type of vision problem. **Concave lenses are used to correct nearsightedness. Convex lenses are used to correct farsightedness.**

A **nearsighted** person can see nearby things clearly, but objects at a distance are blurred. The eyeball is too long, so the lens focuses the image in front of the retina. To correct this, a concave lens in front of the eye spreads out light rays before they enter the eye. As a result, the image forms on the retina.

A **farsighted** person can see distant objects clearly, but nearby objects appear blurry. The eyeball is too short, so the image that falls on the retina is out of focus. A convex lens corrects this by bending light rays toward each other before they enter the eye. An image then focuses on the retina.

Section 4 Assessment

Target Reading Skill Sequencing Refer to your flowchart about how you see as you answer Question 1.

Reviewing Key Concepts

1. a. Identifying Which parts of your body are involved in seeing objects?
   b. Explaining How is an image formed on the retina?
   c. Sequencing What happens to light after it strikes the retina?
2. a. Reviewing What types of lenses help correct vision problems?
   b. Describing Describe a nearsighted person's eye.
   c. Comparing and Contrasting With uncorrected vision, where does an image form in a nearsighted person's eye? In a farsighted person's eye?

Lab zone At-Home Activity

Optical Illusion Look through a cardboard tube with your right eye. Hold your left hand against the far end of the tube with the palm facing you. Keeping both eyes open, look at a distant object. Draw what you see. What do you think causes this illusion?

Section 5

Using Light

Reading Preview

Key Concepts

- How are lenses used in telescopes, microscopes, and cameras?
- What makes up laser light, and how is it used?
- Why can optical fibers carry laser beams a long distance?

Key Terms

- telescope
- refracting telescope
- objective
- eyepiece
- reflecting telescope
- microscope
- camera
- laser
- hologram
- optical fiber
- total internal reflection

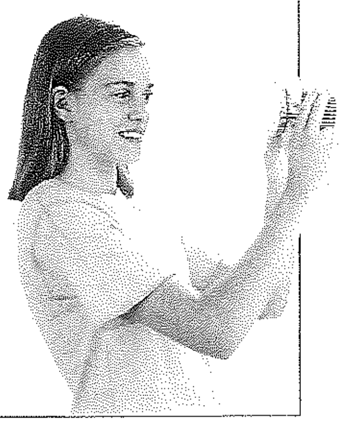
Target Reading Skill

Building Vocabulary A definition states the meaning of a word or a phrase by telling about its most important feature or function. Carefully read the definition of each Key Term and also read the neighboring sentences. Then write a definition of each Key Term in your own words.

Lab zone Discover Activity

How Does a Pinhole Viewer Work?

1. Carefully use a pin to make a tiny hole in the center of the bottom of a paper cup.
2. Place a piece of wax paper over the open end of the cup. Hold the paper in place with a rubber band.
3. Turn off the room lights. Point the end of the cup with the hole in it at a bright window. **CAUTION:** *Do not look directly at the sun.*
4. Look at the image on the wax paper.

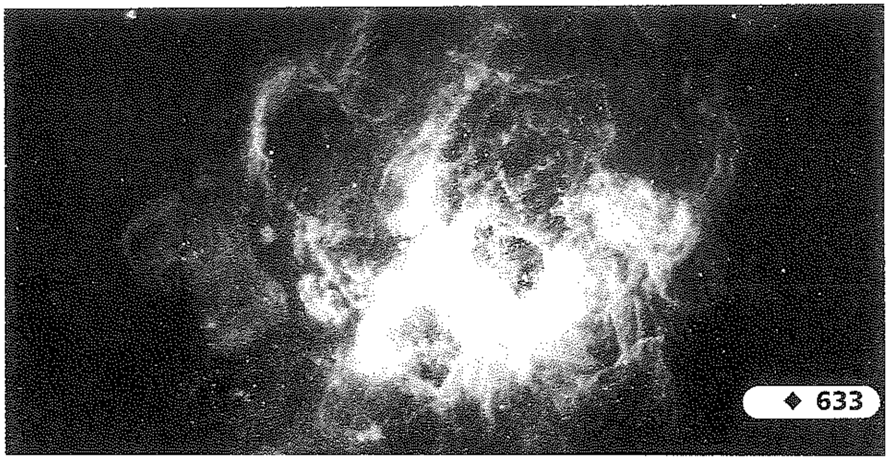


Think It Over

Classifying Describe the image you see. Is it upside down or right-side up? Is it smaller or larger than the actual object? What type of image is it?

Have you ever seen photos of the moons of Jupiter? Have you ever thought it would be exciting to fly close to the rings of Saturn? You know that traveling in space has been done for only a few decades. But you might be surprised to know that the moons of Jupiter and the rings of Saturn had not been seen before the year 1600. It was only about 1607 that a new invention, the telescope, made those objects visible to people.

Since the 1600s, astronomers have built more powerful telescopes that allow them to see objects in space that are very far from Earth. For example, the star-forming nebula, or cloud of gas and dust in space, shown below is located trillions of kilometers from Earth. It took about 3 million years for light from this nebula to travel to Earth.

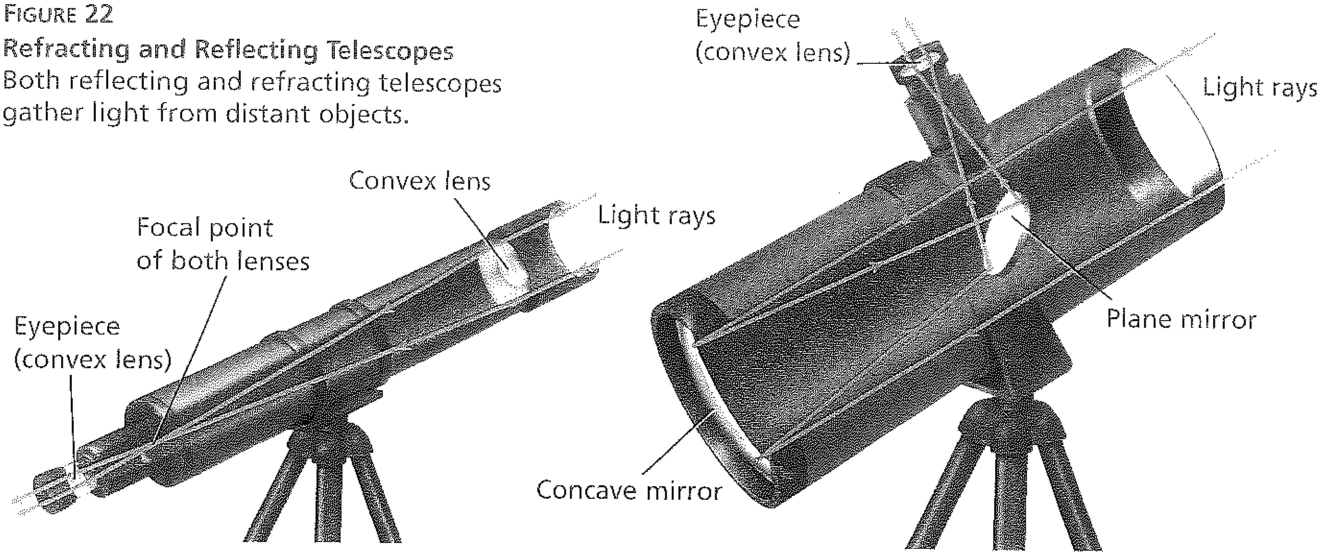


Nebula image from the Hubble Space Telescope ▶

FIGURE 22

Refracting and Reflecting Telescopes

Both reflecting and refracting telescopes gather light from distant objects.



Refracting Telescope

Reflecting Telescope

Optical Instruments

A telescope helps you see objects that are far away. But another type of optical instrument, a microscope, helps you see objects that are nearby. Three common types of optical instruments are telescopes, microscopes, and cameras.

Telescopes Distant objects are difficult to see because light from them has spread out by the time it reaches your eyes. Your eyes are too small to gather much light. A **telescope** forms enlarged images of distant objects. **Telescopes use lenses or mirrors to collect and focus light from distant objects.** The most common use of telescopes is to study objects in space.

Figure 22 shows the two main types of telescopes: refracting telescopes and reflecting telescopes. A **refracting telescope** consists of two convex lenses, one at each end of a tube. The larger lens is called the objective. The **objective** gathers the light coming from an object and focuses the rays to form a real image. The lens close to your eye is called the eyepiece. The **eyepiece** magnifies the image so you can see it clearly. The image seen through the refracting telescope in Figure 22 is upside down.

A **reflecting telescope** uses a large concave mirror to gather light. The mirror collects light from distant objects and focuses the rays to form a real image. A small mirror inside the telescope reflects the image to the eyepiece. The images you see through a reflecting telescope are upside down, just like the images seen through a refracting telescope.

Lab zone Try This Activity

What a View!

You can use two hand lenses of different strengths to form an image.

1. Hold the stronger lens close to your eye.
2. Hold the other lens at arm's length.
3. Use your lens combination to view a distant object. **CAUTION:** *Do not look at the sun.* Adjust the distance of the farther lens until the image is clear.

Classifying What type of image do you see? What type of telescope is similar to this lens combination?

Microscopes To look at small, nearby objects, you would use a microscope. A **microscope** is an optical instrument that forms enlarged images of tiny objects. **A microscope uses a combination of lenses to produce and magnify an image.** For example, the microscope shown in Figure 23 uses two convex lenses to magnify an object, or specimen. The specimen is placed near the objective. The objective forms a real, enlarged image of the specimen. Then the eyepiece enlarges the image even more.

Cameras A **camera** uses one or more lenses to focus light, and film to record an image. Figure 24 shows the structure of a camera. Light from an object travels to the camera and passes through the lens. **The lens of the camera focuses light to form a real, upside-down image on film in the back of the camera.** In many cameras, the lens automatically moves closer to or away from the film until the image is focused.

To take a photo, you press a button that briefly opens the shutter, a screen in front of the film. Opening the shutter allows light passing through the lens to hit the film. The diaphragm is a device with a hole that can be made smaller or larger. Changing the size of the hole controls how much light hits the film. This is similar to the way the pupil of your eye changes size.

✓ Reading Checkpoint **What part of a camera controls the amount of light that enters the camera?**

FIGURE 23
Microscope
This microscope uses a combination of lenses to form enlarged images of tiny objects.

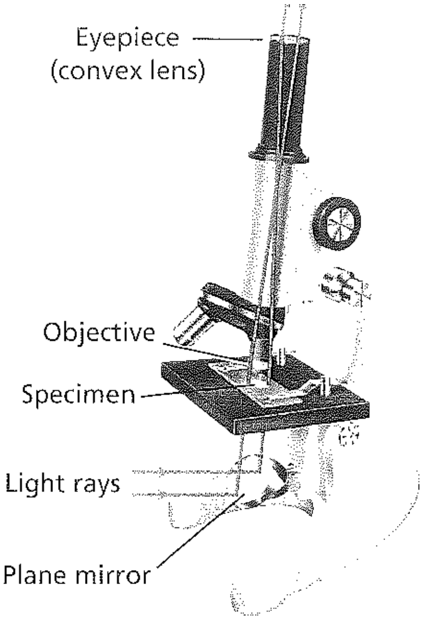


FIGURE 24
Camera
A camera uses a lens to project an image onto film. Interpreting Diagrams *What happens to each light ray as it passes through the lens?*

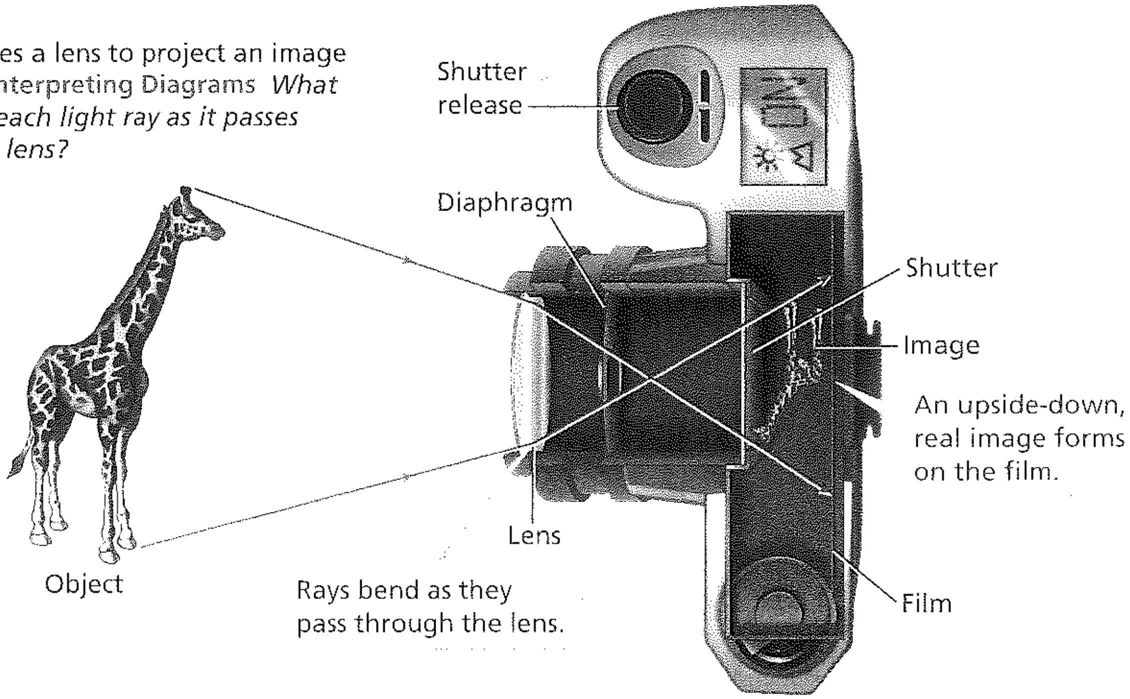
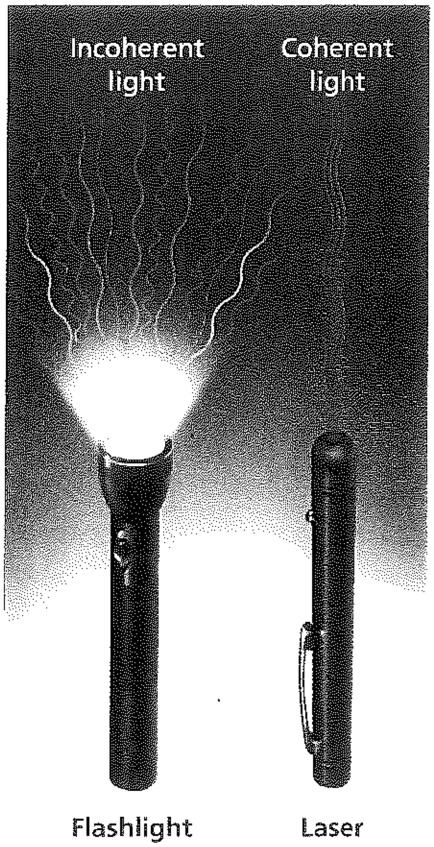


FIGURE 25
Coherent and Incoherent Light
White light is made up of many different wavelengths. Laser light waves all have the same wavelength. Inferring *What can you infer about the color of laser light?*



Lasers

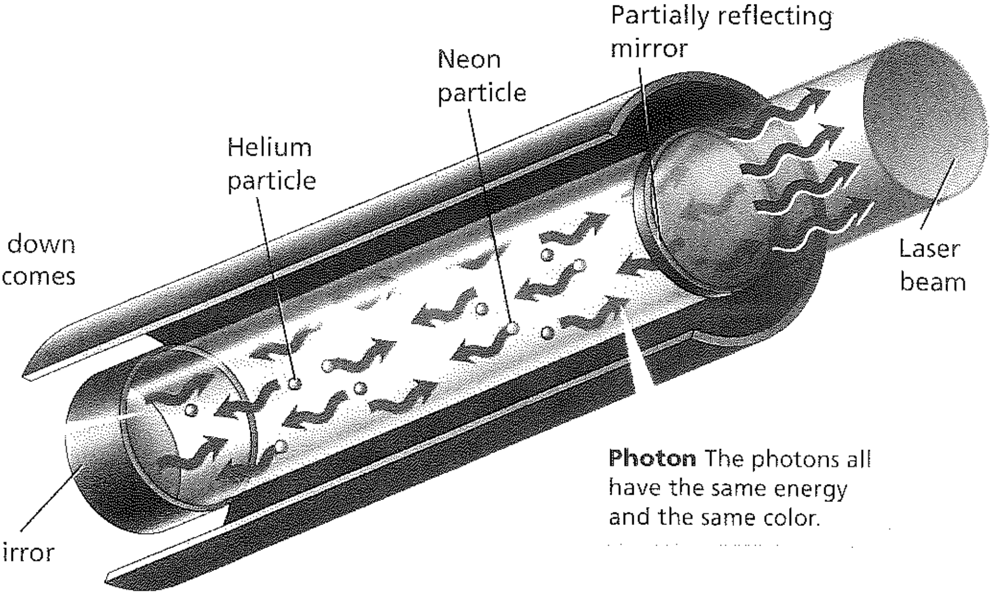
When you turn on a flashlight, the light spreads out as it travels. Ordinary light is made up of different colors and wavelengths. Laser light is different from ordinary light. **Laser light consists of light waves that all have the same wavelength, or color. The waves are coherent, or in step.** All of the crests of the waves align with one another, as shown in Figure 25.

What Is a Laser? A **laser** is a device that produces a narrow beam of coherent light. The word *laser* comes from a phrase that describes how it works: light amplification by stimulated emission of radiation. *Light amplification* means that the light is strengthened. *Stimulated emission* means that the atoms emit light when exposed to electromagnetic radiation.

Producing Laser Light A helium-neon laser is shown in Figure 26. The laser tube contains a mixture of helium and neon gases. An electric current causes this gas mixture to emit photons. You may recall that a photon is a packet of light energy. The mirrors at both ends of the tube reflect the photons back and forth. As a photon travels back and forth, it may bump into a neon particle. This causes the neon particle to emit a photon with the same energy as the one that caused the collision. Then the two photons travel together in step with one another. This process continues until there is a stream of in-step photons traveling up and down the tube. Some of the light "leaks" through the partially reflecting mirror. This light is the laser beam.

Reading Checkpoint **What is a laser?**

FIGURE 26
Helium-Neon Laser
Photons travel in step up and down the laser tube. The light that comes out of the tube is laser light.



Mirror The parallel mirrors reflect photons back and forth, so they all travel in parallel directions.

Photon The photons all have the same energy and the same color.

Uses of Lasers

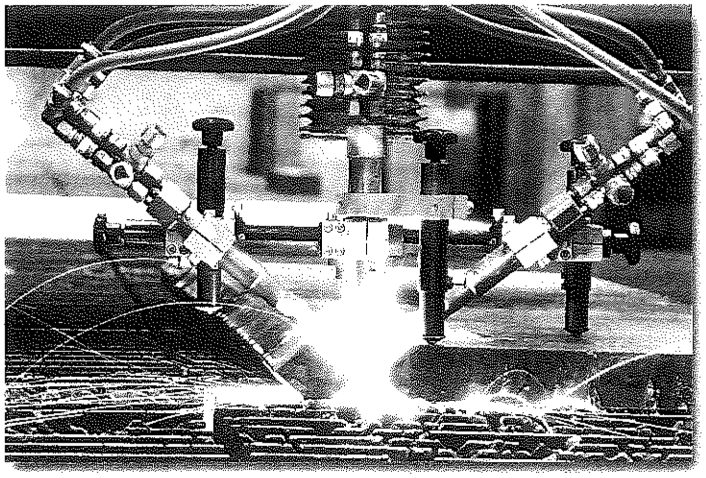
Lasers have many practical uses. Many stores use lasers to scan bar codes. The store's computer then displays the price of the item. Lasers are used in industry to cut through metal. Engineers use laser beams to make sure that surfaces are level and bridges or tunnels are properly aligned. **In addition to their use by stores, industry, and engineers, lasers are used to read information on compact discs, create holograms, and perform surgery.**

Go Online
SCILINKS NSTA

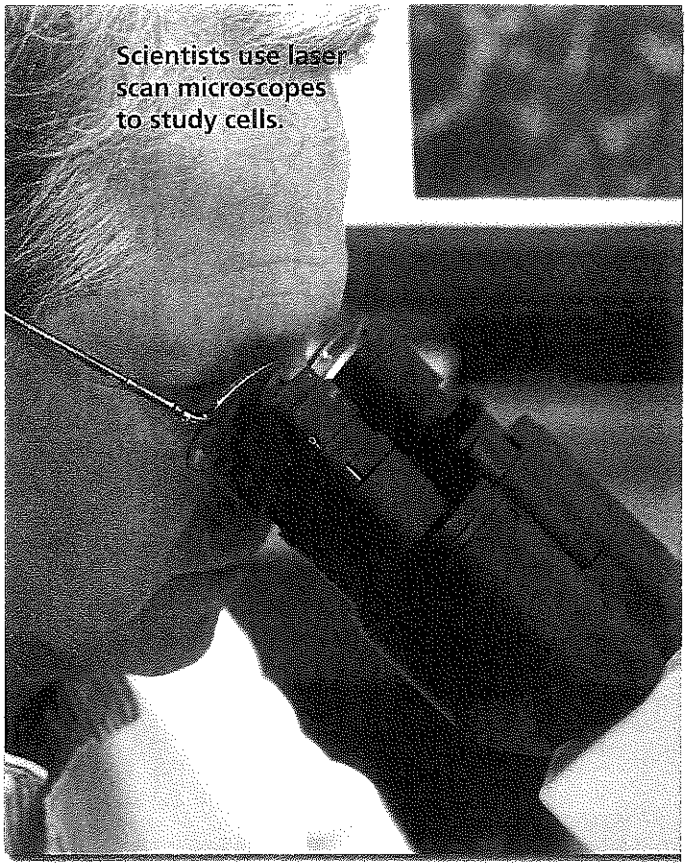
For: Links on lasers
Visit: www.SciLinks.org
Web Code: scn-1545

FIGURE 27
Using Lasers

Lasers have become commonplace in everyday living. They are found at home, in stores, and in industry.

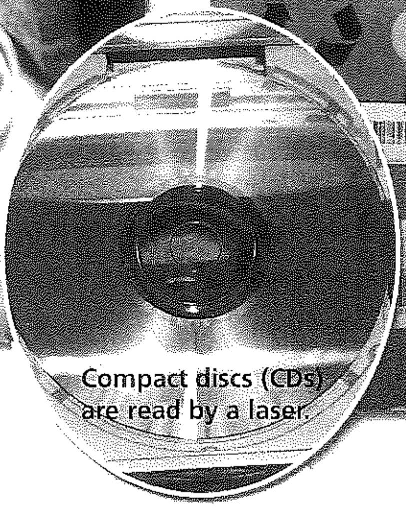


▲ Lasers are used for precision cutting in industry.



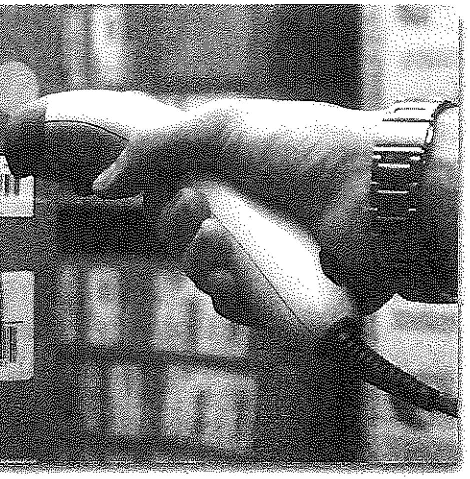
Scientists use laser scan microscopes to study cells.

▲ Lasers are used in surveying.



Compact discs (CDs) are read by a laser.

▼ Bar codes are scanned with lasers.



Compact Discs Lasers can be used to store and read information. A compact disc is produced by converting data into electrical signals. The electrical signals are used to control a laser beam, which cuts a pattern of pits on a blank disc. When you play a compact disc or read one with a computer, a laser beam shines on the surface and is reflected. The reflection patterns vary because of the pits. The compact disc player or disc drive changes these patterns into electrical signals. The signals are then converted into sound or computer data.

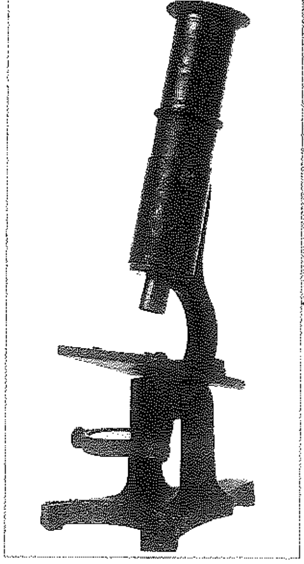
Holography Check out your local video store or newsstand. Some videos and magazines have pictures that appear to move as you walk by. These pictures are called holograms. A **hologram** is a three-dimensional photograph created by using the light from a laser. The process of making these photographs is called holography.

• Tech & Design in History •

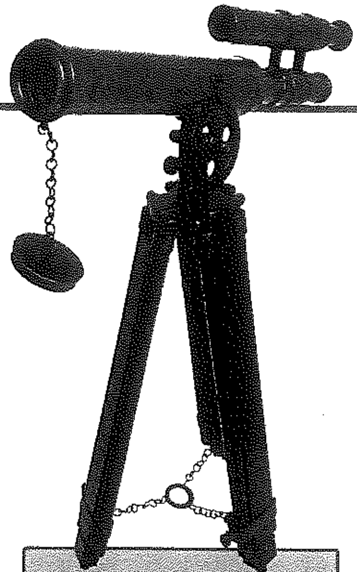
Instruments That Use Light

The development of technologies that use light has changed the way we look at the world and beyond. It has allowed major scientific discoveries.

1286 Spectacles
Italian craftsmen made small disks of glass that could be framed and worn in front of the eyes. Early spectacles consisted of convex lenses. They were used as reading glasses.



1595 Microscope
The first useful microscope is thought to have been constructed in the Netherlands by Zacharias Jansen or his father, Hans. The Jansen microscope could magnify images up to nine times the size of the object. By the mid-1600s, microscopes looked like the one shown here.



1608 Telescope
The first telescope was made of two convex lenses. From this simple invention the Italian scientist Galileo developed his more powerful telescopes.

1300

1400

1500

1600

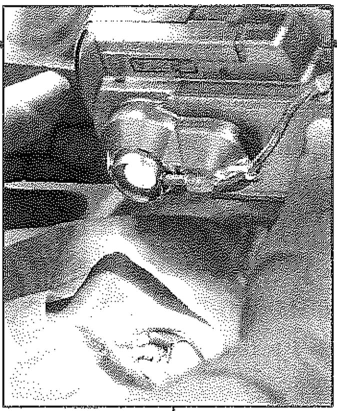
Laser Surgery A beam of laser light can be powerful enough to replace a sharp knife. For example, doctors may use lasers instead of scalpels to cut into a person's body. As the laser cuts, it seals the blood vessels. This reduces the amount of blood a patient loses. Wounds from laser surgery usually heal faster than wounds from surgery done with a scalpel.

A common use of laser surgery is to correct vision by reshaping the cornea of the eye. Doctors can also use lasers to repair detached retinas. If the retina falls away from the inside of the eye, the rods and cones can no longer send signals to the brain. This can lead to total or partial blindness. The doctor can use a laser to "weld" or burn the retina back onto the eyeball. Lasers can also be used to destroy or remove skin blemishes and cancerous growths.

✓ Reading Checkpoint **What are three types of surgery done with lasers?**

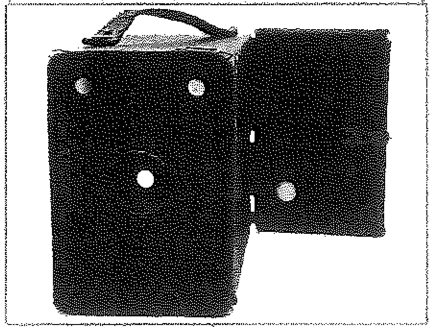
Writing in Science

Research and Write Find out more about early photography. Then imagine you are a newspaper reporter in 1855 asked to interview a photographer. Write a newspaper article about the photographic processes and the possible uses it might have in the future.



1826 Camera

The earliest camera, the pinhole camera, was adapted to form and record permanent images by Joseph Nicéphore Niépce and Louis-Jacques-Mandé Daguerre of France.

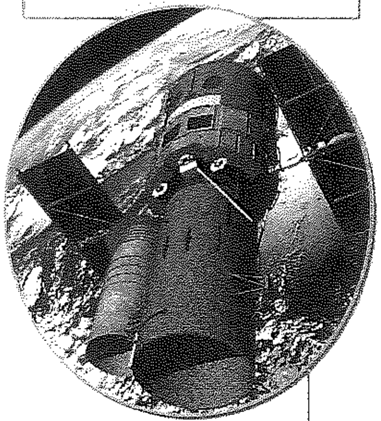


1960 Laser

The first laser, built by American Theodore Maiman, used a rod of ruby to produce light. Since then, lasers have been used in numerous ways, including in engineering, medicine, and communications.

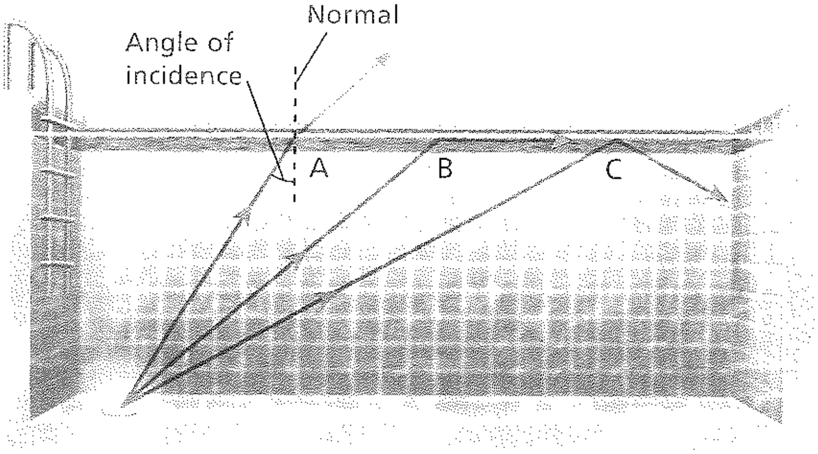
1990 Hubble Space Telescope

This large reflecting telescope was launched by the crew of the space shuttle *Discovery*. It can detect infrared, visible, and ultraviolet rays in space and send pictures back to Earth.



1700 1800 1900 2000

FIGURE 28
Total Internal Reflection
The floodlight in the swimming pool gives off light rays that travel to the surface. If the angle of incidence is great enough, a light ray is completely reflected back into the water.



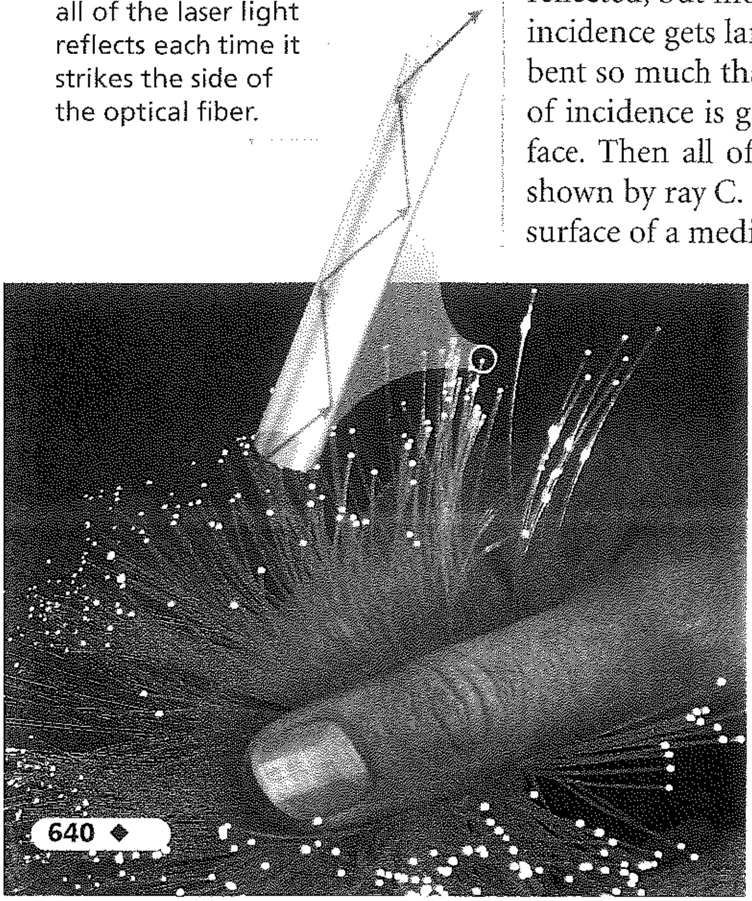
Optical Fibers

Laser beams, like radio waves, can carry signals from one place to another. But, laser beams are not usually sent through the air. Instead, they are sent through optical fibers. **Optical fibers** are long, thin strands of glass or plastic that can carry light for long distances without allowing the light to escape.

Optical fibers can carry a laser beam for long distances because the beam stays totally inside the fiber as it travels. Figure 28 shows how light rays can stay inside a medium and not pass through the surface to the outside. The angle of incidence determines whether or not light passes through the surface.

When ray A strikes the water's surface, some light is reflected, but most passes through and is bent. As the angle of incidence gets larger, the light is bent more and more. Ray B is bent so much that it travels parallel to the surface. If the angle of incidence is great enough, no light passes through the surface. Then all of the light is reflected back into the water, as shown by ray C. This complete reflection of light by the inside surface of a medium is called **total internal reflection.**

Figure 29 shows how total internal reflection allows light to travel a long distance in an optical fiber. Each time the light ray strikes the side of the optical fiber, the angle of incidence is large. Because the angle is large, the light ray is always completely reflected. So, no light can escape through the sides of the optical fiber.



Because the angle of incidence is large, all of the laser light reflects each time it strikes the side of the optical fiber.

FIGURE 29
Optical Fibers
Light travels long distances through optical fibers. Drawing Conclusions *Why doesn't light exit through the sides of the optical fiber?*

Medicine Optical fibers are commonly used in medical instruments. Doctors can insert a thin optical fiber inside various parts of the body, such as the heart or the stomach. The optical fiber can be attached to a microscope or a camera. In this way, doctors can examine internal organs without having to perform major surgery.

Doctors often use optical fibers to repair damage to joints. In knee surgery, for example, doctors make small cuts to insert optical fibers and tiny surgical tools. Because the surgery does less damage to the knee, the recovery is easier.

Communications To send signals through optical fibers, the electrical signals that start out over copper wires are changed into pulses of light by tiny lasers. Then the signals can travel over long distances in the optical fiber. Optical fibers have led to great improvements in telephone service, computer networks, and cable television systems. Signals sent over optical fibers are usually faster and clearer than those sent over copper wire. One tiny optical fiber can carry thousands of phone conversations at the same time. Optical fibers are so much thinner than copper wire that many more fibers can be bundled together in the same space.

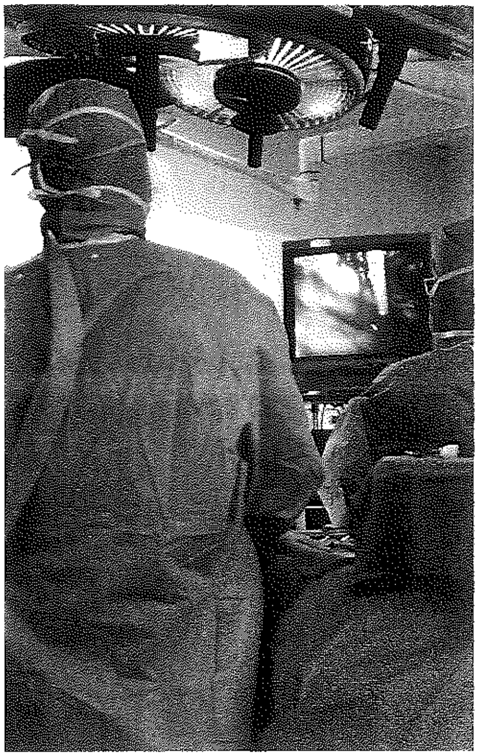


FIGURE 30
Optical-Fiber Surgery
Using optical fibers, surgeons can avoid damaging nearby healthy parts of the body.

✓ Reading Checkpoint **How do optical fibers carry signals?**

Section 5 Assessment

Target Reading Skill Building Vocabulary
Use your definitions to help you answer the questions below.

Reviewing Key Concepts

1. a. Reviewing How are lenses used in telescopes, microscopes, and cameras?
   b. Comparing and Contrasting Compare and contrast how images form in a refracting telescope, a reflecting telescope, and a microscope.
   c. Classifying A pair of binoculars has two lenses in each tube. Which type of optical instrument are the binoculars most similar to?
2. a. Identifying What is laser light?
   b. Summarizing How can laser light be used?
   c. Sequencing How does a laser produce laser light?
3. a. Defining What are optical fibers?
   b. Describing What are three uses of optical fibers?
   c. Relating Cause and Effect Why can optical fibers carry laser beams long distances?

Writing in Science

Advertisement A company has asked you to write an advertisement for its new, easy-to-use camera. In the ad, the company wants you to describe the camera's features so that buyers will understand how the camera works. Be sure to mention the shutter, lens, and diaphragm.

Chapter 18 Study Guide

The BIG Idea

Transfer of Energy When light energy strikes an object, it can be reflected, transmitted, or absorbed. When light energy enters a new medium at an angle, it can be refracted.

1 Light and Color

Key Concepts

- When light strikes an object, the light can be reflected, transmitted, or absorbed.
- An opaque object is the color of the light it reflects. A transparent or translucent object is the color of the light it transmits.
- When combined in equal amounts, the three primary colors of light produce white light. As pigments are added together, fewer colors of light are reflected and more are absorbed.

Key Terms

transparent material
translucent material
opaque material
primary colors
secondary color
complementary colors
pigment

2 Reflection and Mirrors

Key Concepts

- There are two types of reflection—regular reflection and diffuse reflection.
- A plane mirror produces a virtual image that is upright and the same size as the object. Concave mirrors form virtual or real images. Convex mirrors form only virtual images.

Key Terms

ray
regular reflection
diffuse reflection
plane mirror
image
virtual image
concave mirror
optical axis
focal point
real image
convex mirror

3 Refraction and Lenses

Key Concepts

- A convex lens can form virtual or real images. A concave lens can produce only virtual images.

Key Terms

• index of refraction • mirage • lens
• convex lens • concave lens

4 Seeing Light

Key Concepts

- You see objects when a process occurs that involves both your eyes and your brain.
- Convex lenses correct near-sightedness. Concave lenses correct farsightedness.

Key Terms

• cornea • pupil • iris • retina • rods
• cones • optic nerve • nearsighted
• farsighted

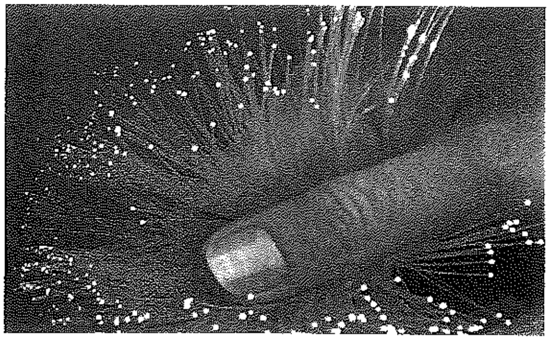
5 Using Light

Key Concepts

- Telescopes use lenses or mirrors to collect and focus light from distant objects. A microscope uses a combination of lenses to magnify an image. The lens of a camera focuses light to form a real image on film.
- Laser light consists of light waves that all have the same wavelength, or color. The waves are coherent, or in step.
- In addition to their use by stores, industry, and engineers, lasers are used to read information on compact discs, create holograms, and perform surgery.
- Optical fibers can carry a laser beam for long distances because the beam stays totally inside the fiber as it travels.

Key Terms

telescope
refracting telescope
objective
eyepiece
reflecting telescope
microscope
camera
laser
hologram
optical fiber
total internal reflection



Review and Assessment

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Organizing Information

Comparing and Contrasting Copy the graphic organizer about mirrors and lenses onto a separate sheet of paper. Then complete it and add a title. (For more on Comparing and Contrasting, see the Skills Handbook.)

Mirrors and Lenses

Type of Mirror	Effect on Light Rays	Type of Image
Plane	Regular reflection	a. ___?___
b. ___?___	c. ___?___	Real or virtual
Convex	Spread out	d. ___?___

Type of Lens	Effect on Light Rays	Type of Image
Convex	e. ___?___	f. ___?___
g. ___?___	h. ___?___	Virtual

Reviewing Key Terms

Choose the letter of the best answer.

1. A material that reflects or absorbs all of the light that strikes it is a(n)
   - a. translucent material.
   - b. opaque material.
   - c. transparent material.
   - d. polarizing filter.
2. When light bounces off an uneven surface, the result is called
   - a. regular reflection.
   - b. refraction.
   - c. diffuse reflection.
   - d. internal reflection.
3. A curved piece of glass or other transparent material that is used to refract light is a
   - a. prism.
   - b. lens.
   - c. mirage.
   - d. mirror.
4. A ring of muscle that changes the size of the eye's pupil is the
   - a. retina.
   - b. cornea.
   - c. iris.
   - d. ciliary muscle.
5. A device that produces coherent light is a(n)
   - a. telescope.
   - b. microscope.
   - c. laser.
   - d. optical fiber.

If the statement is true, write *true*. If it is false, change the underlined word or words to make the statement true.

6. <u>Primary colors</u> combine to make any color.
7. Lines that represent light waves are called <u>rays</u>.
8. An upright image that forms where light seems to come from is a <u>virtual</u> image.
9. For a <u>nearsighted</u> person, nearby objects appear blurry.
10. <u>Holograms</u> are long, thin strands of glass or plastic that can carry light for long distances.

Writing in Science

Persuasive Letter Write a short letter to your representative in Congress asking him or her to continue supporting telescopes in space. Include at least two advantages of space telescopes in your letter.

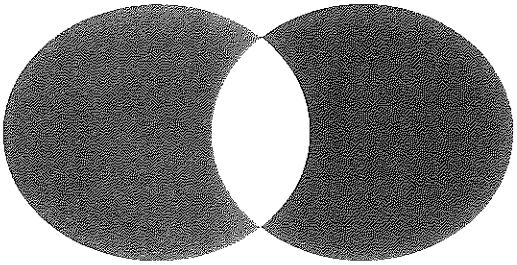
Review and Assessment

Checking Concepts

11. Describe transparent, translucent, and opaque materials. Give an example of each.
12. Why do you see the petals of a rose as red and the leaves as green?
13. What colors can be formed by combining complementary colors?
14. Sketch the optical axis and focal point(s) of a concave mirror and a convex mirror.
15. Describe real and virtual images. How can each type of image be formed by mirrors?
16. How is the index of refraction of a substance related to the speed of light in the substance?
17. Explain why you see a mirage on a hot road.
18. Which parts of the eye help to focus light? Which part carries a signal to the brain?
19. Explain how your eyes are able to clearly see both near and distant objects.
20. How does total internal reflection depend on the angle of incidence of light rays?

Thinking Critically

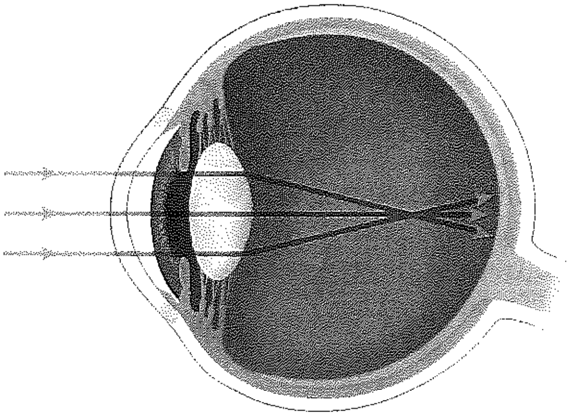
21. Classifying Do the colors shown below represent pigments or colors of light? Explain.



22. Applying Concepts Can a plane mirror produce a real image? Explain.
23. Comparing and Contrasting How are convex and concave mirrors alike? How are they different?
24. Inferring You shine a light through a convex lens so it forms a spot on an index card. Where should the lens and card be located to make the spot as small as possible?
25. Relating Cause and Effect Explain why your eyes can only see shades of gray in dim light.
26. Problem Solving A telescope produces an upside-down image. How could you modify the telescope so the image is upright?
27. Comparing and Contrasting How is a microscope similar to a convex lens used as a magnifying lens? How is it different?
28. Making Generalizations Why is laser light never white?

Applying Skills

Use the diagram to answer Questions 29–31.



29. Classifying Which type of vision problem does this eye have?
30. Problem Solving What type of lens can correct this vision problem?
31. Communicating Copy the diagram above on a separate sheet of paper. Add a correcting lens to your diagram and show how the lens makes the three rays focus on the retina.

Lab zone Chapter Project

Performance Assessment Demonstrate your optical instrument to your class. Explain how your instrument works and how it can be used. Use diagrams that show how the mirrors or lenses in your instrument reflect or refract light.

Standardized Test Prep

Test-Taking Tip

Reading All the Answer Choices

It is important that you read all of the answer choices in a multiple-choice question before selecting the one you think is correct. More than one answer choice may be correct, but one choice may be clearly better than the others. "All of the above" may also be a choice and is usually listed last. If you don't read all of the choices, you may miss the best answer.

Sample Question

The compound microscope has at least two convex lenses: an objective and an eyepiece. The objective forms an enlarged real image of the specimen. The eyepiece enlarges the first image, producing the virtual image you see when you look through the microscope.

Compound microscopes

A have two or more convex lenses.
B produce a virtual image.
C have both an eyepiece and an objective.
D all of the above

Answer

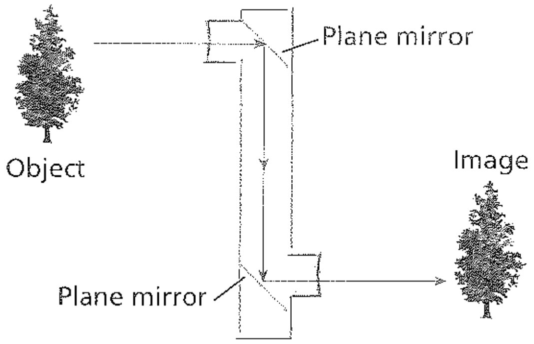
The best answer is **D** because choices **A**, **B**, and **C** are all correct statements.

Choose the letter of the best answer.

1. The index of refraction for water is 1.33 and for glass is 1.5. When light moves from glass into water, the speed of light
   A increases.
   B decreases.
   C remains the same.
   D depends on the angle of incidence.

2. A convex lens can produce a real or a virtual image. Which type of mirror is most similar to a convex lens?
   F plane mirror
   G convex mirror
   H concave mirror
   J none of the above

Periscope



Use the diagram above and your knowledge of science to answer Question 3.

3. If you want to build a periscope, what measurement is most important?
   A the angle between the two mirrors
   B the distance between the mirrors
   C the width of the mirrors
   D the width of the tube

4. A friend hypothesizes that a periscope produces an upright image that reverses left and right. How could you test this hypothesis?
   F Test A: Draw a ray diagram to determine the type of image that is produced.
   G Test B: Look at your friend through the periscope to see if her image is upright.
   H Test C: Look at your friend through the periscope and ask her to move her right hand. Observe which hand (left or right) is moving in the image.
   J Conduct both Test B and Test C.

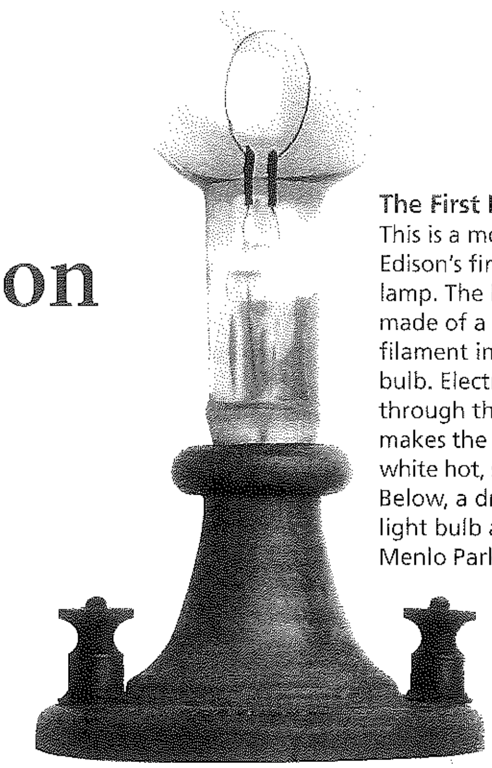
5. You view an American flag through sunglasses that are tinted green. What colors do you see?
   A green
   B black
   C green and black
   D red and blue

Constructed Response

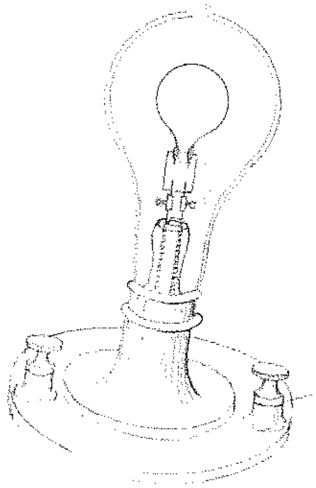
6. How is a camera like a human eye? Give the function of each part of a camera and identify the part of the eye that has the same function. Use the following terms in your answer: *lens, diaphragm, film, cornea, pupil,* and *retina.*

Edison—Genius of Invention

What inventor gave us
- sound recording?
- motion pictures?
- electric lighting?



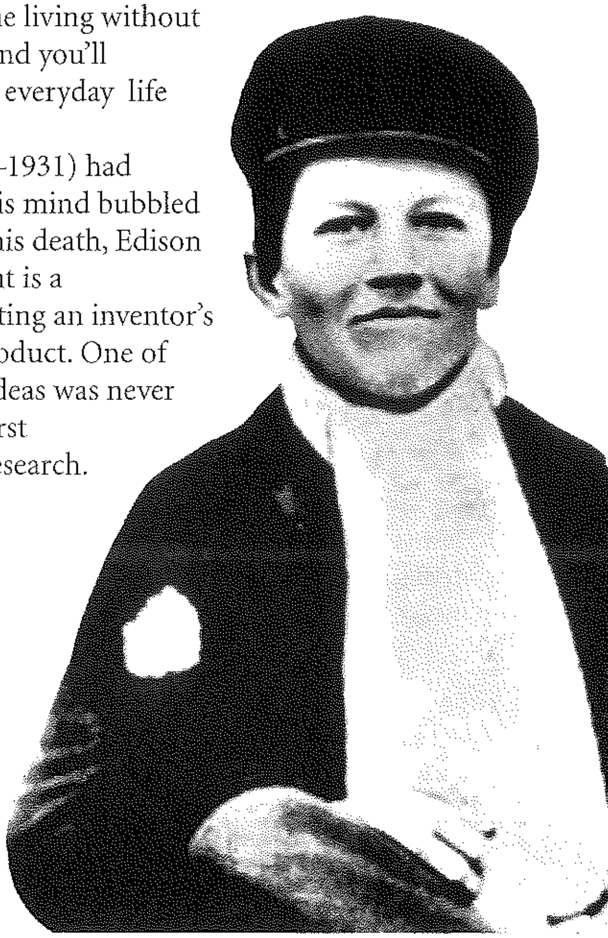
The First Light Bulb
This is a model of Edison's first successful lamp. The light bulb is made of a carbon filament inside a glass bulb. Electricity flowing through the filament makes the filament white hot, so that it glows. Below, a drawing of the light bulb appears in a Menlo Park notebook.



In 1881, the electric light was a novelty. City streets and some homes were lit with gas. Most homes used oil lamps or candles. Thomas Edison was still developing his system of indoor electric lighting.

Electric lights brought with them a system of power distribution, which made other uses of electricity possible. Imagine living without any electrical appliances, and you'll understand the changes in everyday life that Edison started.

Thomas Edison (1847–1931) had almost no schooling. Yet his mind bubbled with ideas. At the time of his death, Edison held 1,093 patents. A patent is a government license protecting an inventor's right to make and sell a product. One of Edison's most important ideas was never patented. He created the first laboratory for industrial research.



Thomas Edison at 14
Edison worked as a telegrapher for about six years.

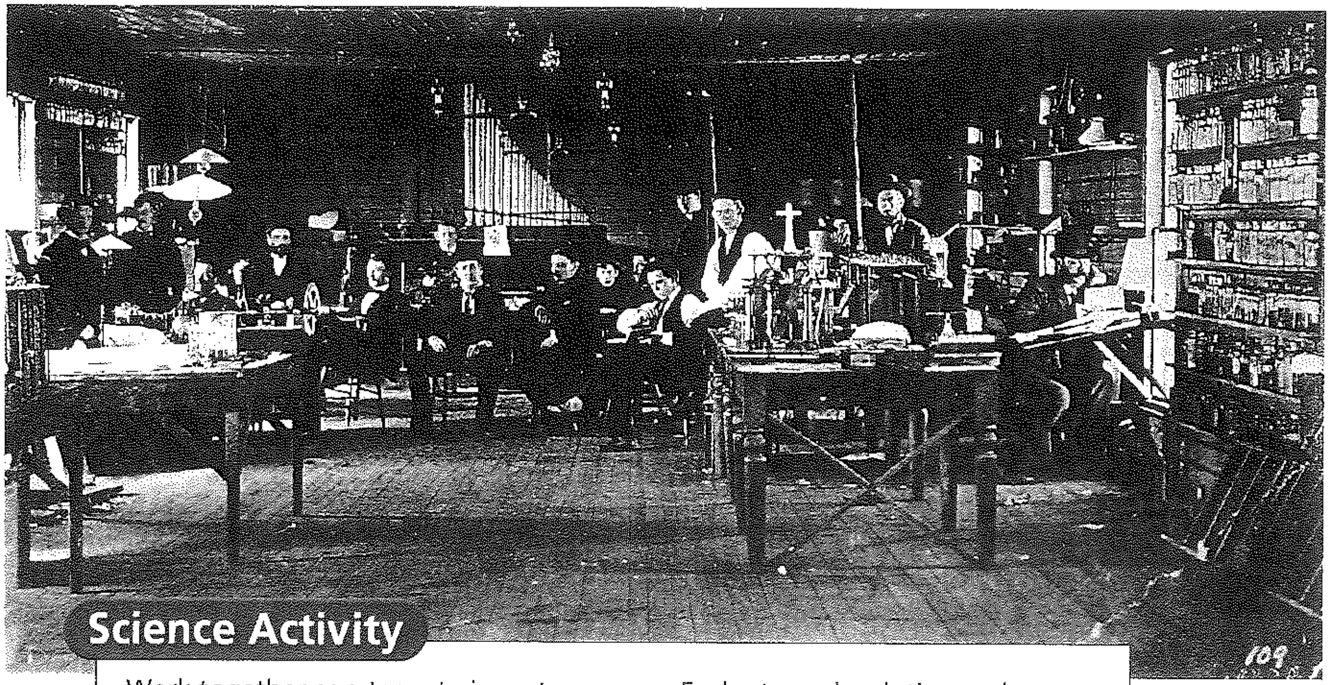
The Wizard of Menlo Park

Before 1900, most inventors worked alone. Edison, in contrast, depended on a strong team of research co-workers to carry out his ideas. Edison had an unusual ability to inspire those who worked for him. Some of his original team stayed with him for years. A very hard worker himself, Edison demanded that everyone on his team also work long hours.

By 1876, Edison had enough money to set up an "invention factory." He chose the small town of Menlo Park, New Jersey. His Menlo Park laboratory became the world's first industrial research laboratory.

Edison's team often made improvements on other people's inventions. The light bulb is an example. Other scientists had invented electric lamps, but their light bulbs burned rapidly. The problem was to find a material for the filament that would not overheat or burn out quickly.

The Menlo Park team spent months testing hundreds of materials. First, they rolled each material into a long, thin strand. Then, they carbonized it, which meant baking it until it turned to charcoal. Finally, they tested it in a vacuum, or in the absence of air. Most materials failed in only a few minutes or a few hours. The breakthrough came in 1879. The first successful filament was a length of ordinary cotton thread, carefully carbonized. The newspapers carried the headlines "Success in a Cotton Thread" and "It Makes a Light, Without Gas or Flame."



Edison's Lab
Edison set up his research laboratory in Menlo Park.

Science Activity

Work together as a team to invent a new electrical device.

- What could a new electrical device help you do? How could it make your life easier?
- Brainstorm for possible products that would help you in some way. Write down all possible ideas.
- Evaluate each solution and agree on the best one.
- Plan your design and make a labeled drawing. List the supplies you will need. Note any new skills you should learn.
- Write down the steps you will use to build your device.

Lighting Manhattan

Edison recognized the value of publicity. Besides being a productive inventor, he knew how to promote himself. He made glowing predictions about his new electric system. Electricity would soon be so cheap, he said, that "only the rich would be able to afford candles."

When he built his first neighborhood generating station, Edison made a shrewd choice of location. The Pearl Street power station brought light and power to about 2.6 square kilometers of downtown Manhattan. It supplied businesses and factories, as well as private homes. The circuits could light 400 light bulbs. Some of those lights were in the offices of J. P. Morgan, the leading banker and financier of the time. Other lights were located in the offices of *The New York Times.* Here is how a reporter might have written about the event.

New York City
This photo shows Broadway in 1904.

SEPTEMBER 5, 1882—Yesterday at three o'clock in the afternoon, Thomas Edison stood in the downtown Manhattan offices of J.P. Morgan and turned on his Edison incandescent light bulb. Instantly, a soft, steady light filled the room. Other Edison bulbs glowed throughout a small section of lower Manhattan yesterday evening, including some in the nearby offices of The *New York Times.*

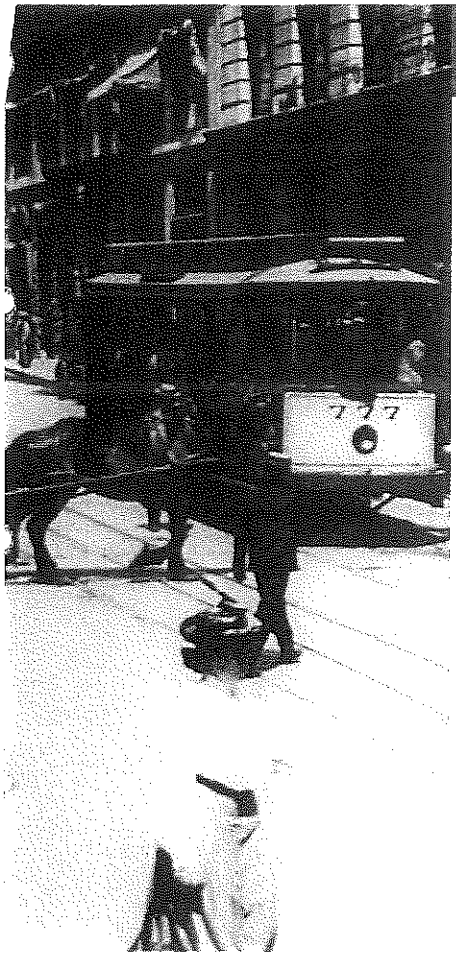
Unlike gaslights, electric lights do not flicker, so they are easier on the eyes. Edison boasts that his bulbs are also cooler than gaslights. Electric lights give off only about one fifteenth of the heat of a gas lamp, he says.

A *New York Times* reporter described using the electric bulbs after dark. He said the light was "soft, mellow, and grateful to the eye, and it seemed almost like writing by daylight to have a light without a particle of flicker and with scarcely any heat to make the head ache."

The power that lights the Edison bulbs originates in Edison's new Pearl Street Power Plant, located a few blocks from the J.P. Morgan office. There, a generator works to provide light on demand. The light comes to the office buildings by way of a multitude of underground wires and tubes.

Language Arts Activity

A reporter must observe details carefully and use them to write about an event. The reporter may quote other people's opinions. Look back at the story. Now write about the event as Edison would have told it to convince people to buy light bulbs and install electric generating systems. You could make an advertisement. Inform your readers about the product and persuade them to buy it.



Solving Practical Problems

As he grew older, Edison worried that American students were not learning mathematics well enough. To motivate students, he suggested using problems that related to real-life situations. In 1925, when he was 78, he proposed these problems below as recorded in his notebooks. Note that light bulbs were called lamps. Tungsten is a metal used in light bulbs.

Edison Lamp
This 1908 advertisement promotes the use of an electric lamp.

Problem 1

American electric plants now serve 9,500,000 homes. The estimated number of homes in the United States is 21,000,000. What percentage receives electrical energy?

Problem 2

It needs about 280,000,000 tungsten lamps [bulbs] each year to supply the market today. And yet the first lamp factory in the world—the Edison Lamp Works. . .—was not started until 1880, and I was told it would never pay. The output for our first year was about 25,000 globes [bulbs]. How many times that figure would be required for the present market?

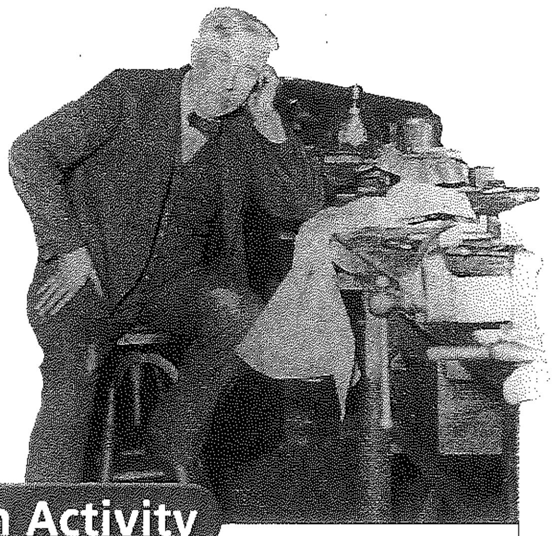
Problem 3

A household using 21 lamps requires about 7 new lamps each year. What percentage is this?

Problem 4

If these lamps had been bought at the retail prices of the first year of the lamp factory, they would have cost $1.25 each. How much would the family save by the decreased prices of today?

Inventor Thomas Edison
Edison at work in 1905.



Math Activity

Solve the four math problems that Edison wrote. To solve Problem 4, use 1925 prices. That year, incandescent light bulbs (or lamps) cost $.30 each.

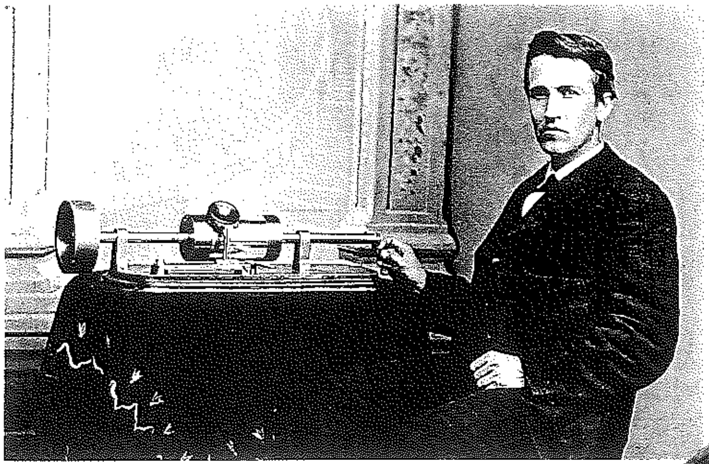
Daily Life Transformed

Edison's inventions in the late 1800s helped spark a technological and social revolution. Some of these inventions forever transformed the way people live, play, and work.

Edison's light bulb made indoor lighting practical. Along with the light bulb, he developed the idea of a central power system to distribute electricity to homes and businesses. That system included generators, underground cables, junction boxes, and meters. Other inventors improved on Edison's ideas for lights and electricity.

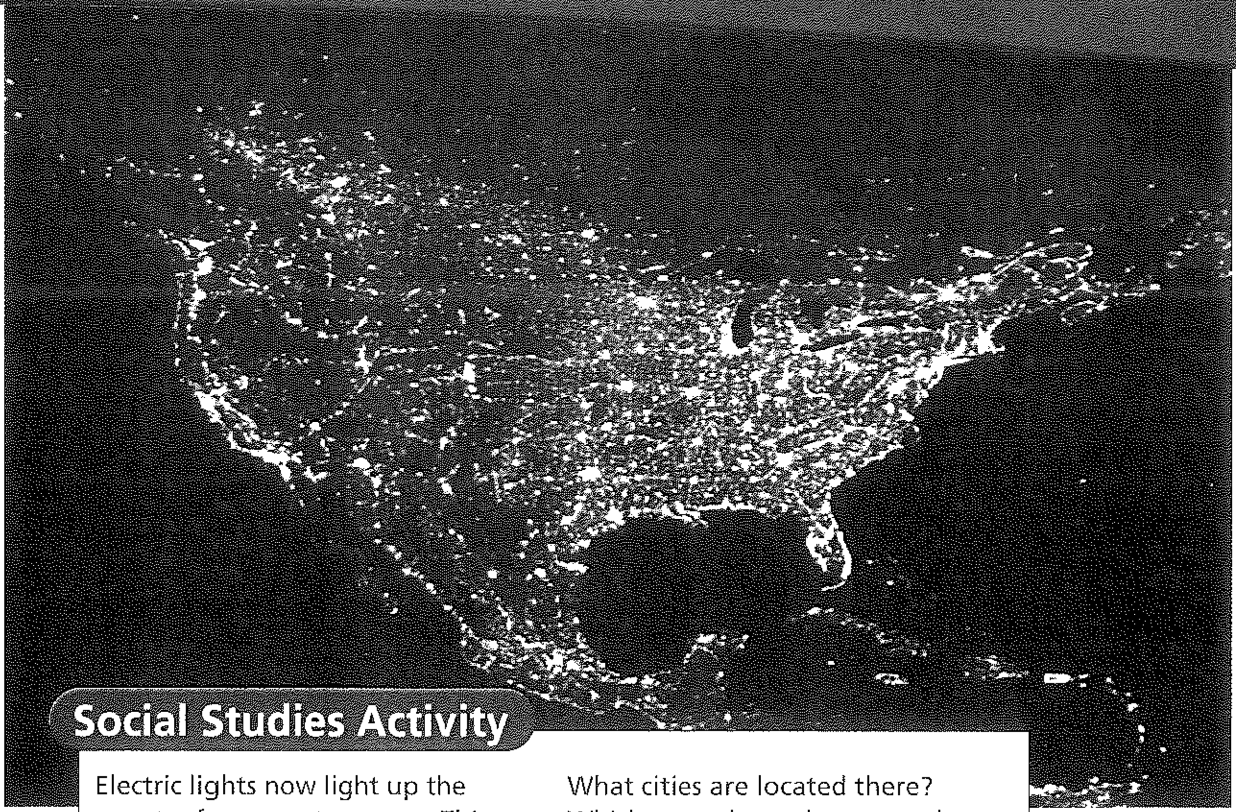
Other Edison inventions influenced ways that people entertain themselves. Edison created the phonograph, a rotating disk that could record and play back sounds. About that same time, Edison invented the first movie camera, a device that could store pictures. These inventions spurred the development of the recording and film industries.

Edison Movie
This photograph consists of 45 frames for an 1894 Edison movie showing a man sneezing.



Phonograph
In 1878, Edison demonstrated his phonograph, which recorded sound on a rotating cylinder. A needle attached to a thin metal disk played the sound.

Improved Phonograph
A later version of Edison's phonograph included a horn to project the sound.



Social Studies Activity

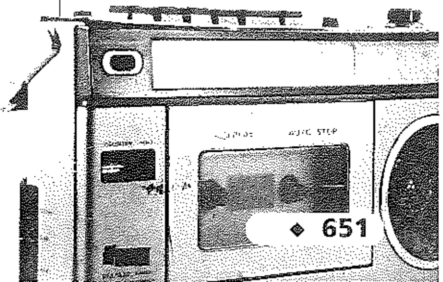
Electric lights now light up the country from coast to coast. This map, based on population data, shows what the United States might look like from space at night. Using a map of the United States, identify the regions that are the brightest. What cities are located there? Which states have the most urban areas? Which have the least? Use an almanac to find out the population of five of the largest cities. Compare these data with the total United States population.

Tie It Together

Modern Times

Many of the inventions that came out of Menlo Park still affect things we do today. Work in pairs to research one of Edison's inventions. Or research another scientist's inventions. Find out how the device changed and improved in the 1900s. Write up your research and present it to the class. If the device is no longer used, explain what has replaced it. Here are a few inventions from which to choose. (Not all of them were Edison's.)

- stock ticker
- telegraph
- phonograph
- disk record
- voting machine
- electric pen and press
- radio transmitter
- linotype
- typewriter
- telephone
- automobile
- vacuum tube
- mechanical music



Cassette Player
Is this device related to Edison's invention?