


# Light, Mirrors, and Lenses

## chapter preview

### sections

- 1 Properties of Light
  - 2 Reflection and Mirrors  
*Lab Reflection from a Plane Mirror*
  - 3 Refraction and Lenses
  - 4 Using Mirrors and Lenses  
*Lab Image Formation by a Convex Lens*
-  **Virtual Lab** How are lenses used to correct vision?

## Seeing the Light

This lighthouse at Pigeon Point, California, produces beams of light that can be seen for many miles. These intense light beams are formed in the same way as a flashlight beam. The key ingredient is a curved mirror that reflects the light from a bright source.

**Science Journal** Describe how you use mirrors and lenses during a typical day.

# Start-Up Activities



## Bending Light

Everything you see results from light waves entering your eyes. These light waves are either given off by objects, such as the Sun and lightbulbs, or reflected by objects, such as trees, books, and people. Lenses and mirrors can cause light to change direction and make objects seem larger or smaller.

1. Place two paper cups next to each other and put a penny in the bottom of each cup.
2. Fill one of the cups with water and observe how the penny looks.
3. Looking straight down at the cups, slide the cup with no water away from you just until you can no longer see the penny.
4. Pour water into this cup and observe what seems to happen to the penny.
5. **Think Critically** In your Science Journal, record your observations. Did adding water make the cup look deeper or shallower?



Preview this chapter's content and activities at [ips.msscience.com](http://ips.msscience.com)

## FOLDABLES™ Study Organizer

### Light, Mirrors, and Lenses

Make the following Foldable to help you understand the properties of and the relationship between light, mirrors, and lenses.

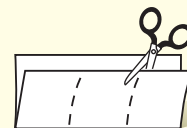
- STEP 1** **Fold** a sheet of paper in half lengthwise. Make the back edge about 5 cm longer than the front edge.



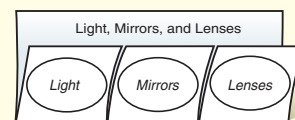
- STEP 2** **Turn** the paper so the fold is on the bottom. Then **fold** it into thirds.



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



- STEP 4** **Label** the Foldable as shown.



**Summarize in a Table** As you read the chapter, summarize the information you find about light, mirrors, lenses.

# Properties of Light

## as you read

### What You'll Learn

- **Describe** the wave nature of light.
- **Explain** how light interacts with materials.
- **Determine** why objects appear to have color.

### Why It's Important

Everything you see comes from information carried by light waves.

### Review Vocabulary

**electromagnetic waves:** waves created by vibrating electric charges that can travel through space or through matter

### New Vocabulary

- light ray
- medium

## What is light?

Drop a rock on the smooth surface of a pond and you'll see ripples spread outward from the spot where the rock struck. The rock produced a wave much like the one in **Figure 1**. A wave is a disturbance that carries energy through matter or space. The matter in this case is the water, and the energy originally comes from the impact of the rock. As the ripples spread out, they carry some of that energy.

Light is another type of wave that carries energy. A source of light such as the Sun or a lightbulb gives off light waves into space, just as the rock hitting the pond causes waves to form in the water. But while the water waves spread out only on the surface of the pond, light waves spread out in all directions from the light source. **Figure 1** shows how light waves travel.

Sometimes, however, it is easier to think of light in a different way. A **light ray** is a narrow beam of light that travels in a straight line. You can think of a source of light as giving off, or emitting, a countless number of light rays that are traveling away from the source in all directions.

**Figure 1** Light moves away in all directions from a light source, just as ripples spread out on the surface of water.



A source of light, such as a lightbulb, gives off light rays that travel away from the light source in all directions.



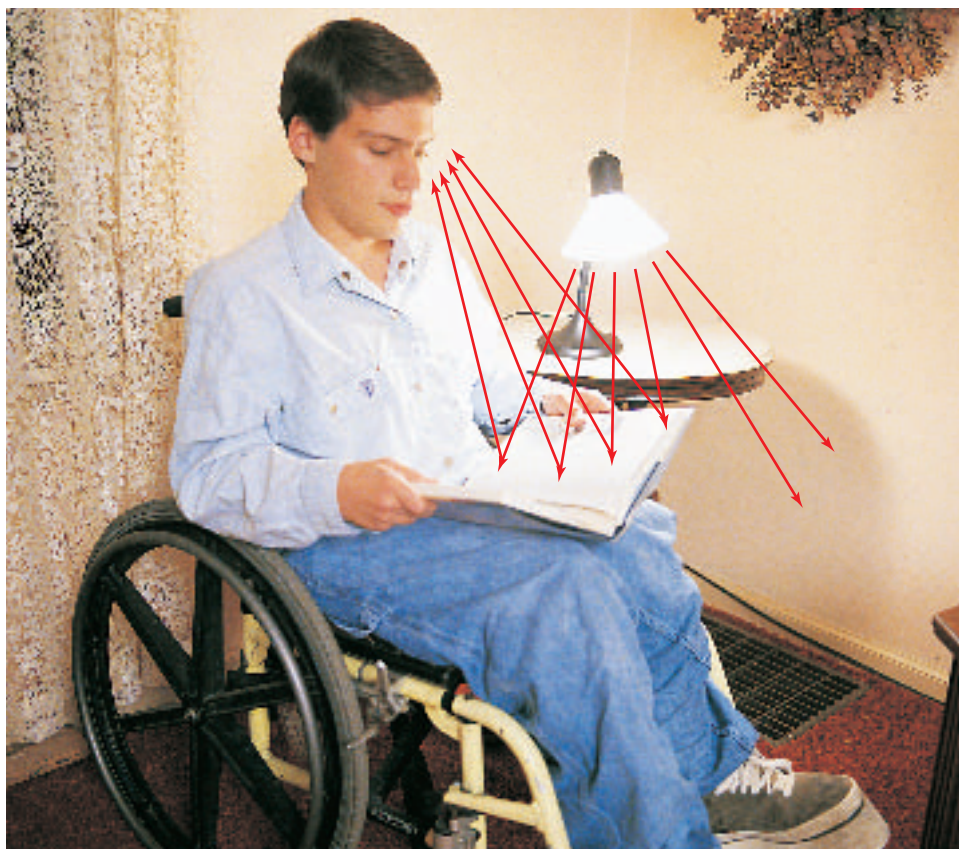
Ripples on the surface of a pond are produced by an object hitting the water. The ripples spread out from the point of impact.

**Light Travels Through Space** There is, however, one important difference between light waves and the water wave ripples on a pond. If the pond dried up and had no water, ripples could not form. Waves on a pond need a material—water—in which to travel. The material through which a wave travels is called a **medium**. Light is an electromagnetic wave and doesn't need a medium in which to travel. Electromagnetic waves can travel in a vacuum, as well as through materials such as air, water, and glass.

## Light and Matter

What can you see when you are in a closed room with no windows and the lights out? You can see nothing until you turn on a light or open a door to let in light from outside the room. Most objects around you do not give off light on their own. They can be seen only if light waves from another source bounce off them and into your eyes, as shown in **Figure 2**. The process of light striking an object and bouncing off is called reflection. Right now, you can see these words because light emitted by a source of light is reflecting from the page and into your eyes. Not all the light rays reflected from the page strike your eyes. Light rays striking the page are reflected in many directions, and only some of these rays enter your eyes.

 **Reading Check** *What must happen for you to see most objects?*



**Figure 2** Light waves are given off by the lightbulb. Some of these light waves hit the page and are reflected. The student sees the page when some of these reflected waves enter the student's eyes.

## Mini LAB

### Observing Colors in the Dark

#### Procedure

1. Get six pieces of **paper** that are different colors and about 10 cm × 10 cm.
2. Darken a room and wait 10 min for your eyes to adjust to the darkness.
3. Write on each paper what color you think the paper is.
4. Turn on the lights and see if your night vision correctly detected the colors.

#### Analysis

1. If the room were perfectly dark, what would you see? Explain.
2. Your eyes contain rod cells and cone cells. Rod cells enable you to see in dim light, but don't detect color. Cone cells enable you to see color, but do not work in dim light. Which type of cell was working in the darkened room? Explain.





An opaque object allows no light to pass through it.



A translucent object allows some light to pass through it.



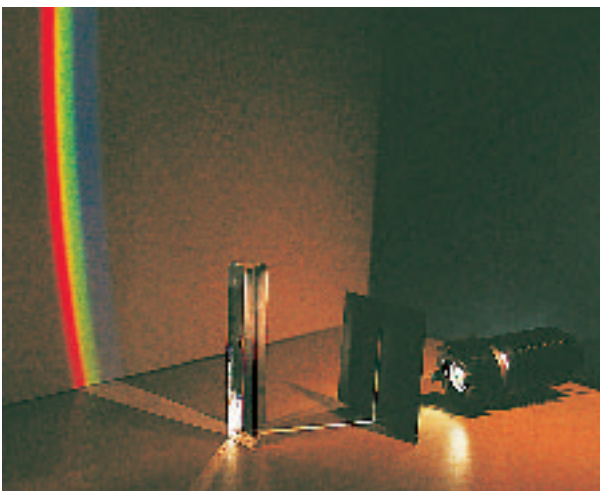
A transparent object allows almost all light to pass through it.

**Figure 3** Materials are opaque, translucent, or transparent, depending on how much light passes through them.

**Infer** which type of material reflects the least amount of light.

**Figure 4** A beam of white light passing through a prism is separated into many colors.

**Describe** the colors you see emerging from the prism.



**Opaque, Translucent, and Transparent** When light waves strike an object, some of the waves are absorbed by the object, some are reflected by it, and some might pass through it. What happens to light when it strikes the object depends on the material that the object is made of.

All objects reflect and absorb some light waves. Materials that let no light pass through them are opaque (oh PAYK). You cannot see other objects through opaque materials. On the other hand, you clearly can see other objects through materials such as glass and clear plastic that allow nearly all the light that strikes them to pass through. These materials are transparent. A third type of material allows only some light to pass through. Although objects behind these materials are visible, they are not clear. These materials, such as waxed paper and frosted glass, are translucent (trans LEW sent). Examples of opaque, translucent, and transparent objects are shown in **Figure 3**.

## Color

The light from the Sun might look white, but it is a mixture of colors. Each different color of light is a light wave with a different wavelength. Red light waves have the longest wavelengths and violet light waves have the shortest wavelengths. As shown in **Figure 4**, white light is separated into different colors when it passes through a prism. The colors in white light range from red to violet. When light waves from all these colors enter the eye at the same time, the brain interprets the mixture as being white.



A pair of gym shoes and socks as seen under white light.



The same shoes and socks photographed through a red filter.

**Why do objects have color?** Why does grass look green or a rose look red? When a mixture of light waves strikes an object that is not transparent, the object absorbs some of the light waves. Some of the light waves that are not absorbed are reflected. If an object reflects red waves and absorbs all the other waves, it looks red. Similarly, if an object looks blue, it reflects only blue light waves and absorbs all the others. An object that reflects all the light waves that strike it looks white, while one that reflects none of the light waves that strike it looks black. **Figure 5** shows gym shoes and socks as seen under white light and as seen when viewed through a red filter that allows only red light to pass through it.

**Primary Light Colors** How many colors exist? People often say white light is made up of red, orange, yellow, green, blue, and violet light. This isn't completely true, though. Many more colors than this exist. In reality, most humans can distinguish thousands of colors, including some such as brown, pink, and purple, that are not found among the colors of the rainbow.

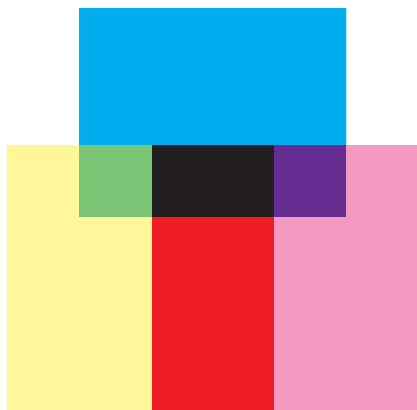
Light of almost any color can be made by mixing different amounts of red, green, and blue light. Red, green, and blue are known as the primary colors. Look at **Figure 6**. White light is produced where beams of red, green, and blue light overlap. Yellow light is produced where red and green light overlap. You see the color yellow because of the way your brain interprets the combination of the red and green light striking your eye. This combination of light waves looks the same as yellow light produced by a prism, even though these light waves have only a single wavelength.

**Figure 5** The color of an object depends on the light waves it reflects.

**Infer** why the blue socks look black when viewed under red light.

**Figure 6** By mixing light from the three primary colors—red, blue, and green—almost all of the visible colors can be made.





**Figure 7** The three primary color pigments—yellow, magenta, and cyan—can form almost all the visible colors when mixed together in various amounts.

**Primary Pigment Colors** Materials like paint that are used to change the color of other objects, such as the walls of a room or an artist’s canvas, are called pigments. Mixing pigments together forms colors in a different way than mixing colored lights does.

Like all materials that appear to be colored, pigments absorb some light waves and reflect others. The color of the pigment you see is the color of the light waves that are reflected from it. However, the primary pigment colors are not red, blue, and green—they are yellow, magenta, and cyan. You can make almost any color by mixing different amounts of these primary pigment colors, as shown in **Figure 7**.

Although primary pigment colors are not the same as the primary light colors, they are related. Each primary pigment color results when a pigment absorbs a primary light color. For example, a yellow pigment absorbs blue light and it reflects red and green light, which you see as yellow. A magenta pigment, on the other hand, absorbs green light and reflects red and blue light, which you see as magenta. Each of the primary pigment colors is the same color as white light with one primary color removed.

## section 1 review

### Summary

#### Light and Matter

- Light is an electromagnetic wave that can travel in a vacuum as well as through matter.
- When light waves strike an object some light waves might be absorbed by the object, some waves might be reflected from the object, and some waves might pass through the object.
- Materials can be opaque, translucent, or transparent, depending on how much light passes through the material.

#### Color

- Light waves with different wavelengths have different colors.
- White light is a combination of all the colors ranging from red to violet.
- The color of an object is the color of the light waves that it reflects.
- The primary light colors are red, green, and blue. The primary pigment colors are yellow, magenta and cyan.

### Self Check

1. **Diagram** the path followed by a light ray that enters one of your eyes when you are reading at night in a room.
2. **Determine** the colors that are reflected from an object that appears black.
3. **Compare and contrast** primary light colors and primary pigment colors.
4. **Describe** the difference between an opaque object and a transparent object.
5. **Think Critically** A white shirt is viewed through a filter that allows only blue light to pass through the filter. What color will the shirt appear to be?

### Applying Skills

6. **Draw Conclusions** A black plastic bowl and a white plastic bowl are placed in sunlight. After 15 minutes, the temperature of the black bowl is higher than the temperature of the white bowl. Which bowl absorbs more light waves and which bowl reflects more light waves?

# Reflection and Mirrors

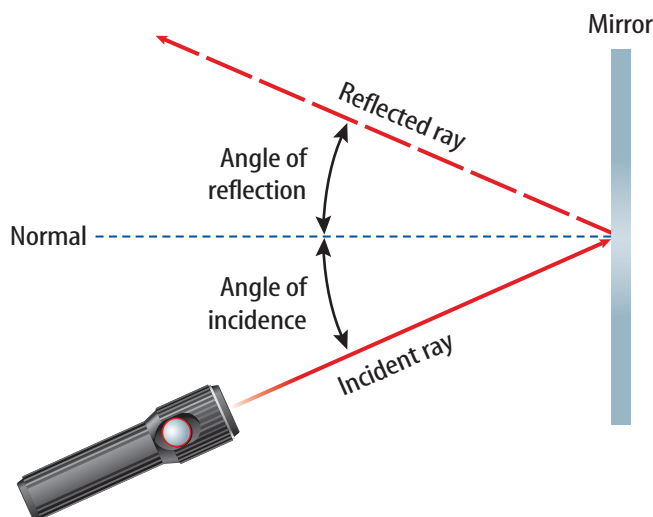
## The Law of Reflection

You've probably noticed your image on the surface of a pool or lake. If the surface of the water was smooth, you could see your face clearly. If the surface of the water was wavy, however, your face might have seemed distorted. The image you saw was the result of light reflecting from the surface and traveling to your eyes. How the light was reflected determined the sharpness of the image you saw.

When a light ray strikes a surface and is reflected, as in **Figure 8**, the reflected ray obeys the law of reflection. Imagine a line that is drawn perpendicular to the surface where the light ray strikes. This line is called the normal to the surface. The incoming ray and the normal form an angle called the angle of incidence. The reflected light ray forms an angle with the normal called the angle of reflection. According to the **law of reflection**, the angle of incidence is equal to the angle of reflection. This is true for any surface, no matter what material it is made of.

## Reflection from Surfaces

Why can you see your reflection in some surfaces and not others? Why does a piece of shiny metal make a good mirror, but a piece of paper does not? The answers have to do with the smoothness of each surface.



### as you read

#### What You'll Learn

- **Explain** how light is reflected from rough and smooth surfaces.
- **Determine** how mirrors form an image.
- **Describe** how concave and convex mirrors form an image.

#### Why It's Important

Mirrors can change the direction of light waves and enable you to see images, such as your own face.

#### Review Vocabulary

**normal:** a line drawn perpendicular to a surface or line

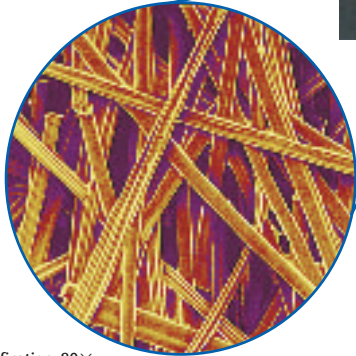
#### New Vocabulary

- law of reflection
- focal point
- focal length

**Figure 8** A light ray strikes a surface and is reflected. The angle of incidence is always equal to the angle of reflection. This is the law of reflection.



**Figure 9** A highly magnified view of the surface of a sheet of paper shows that the paper is made of many cellulose wood fibers that make the surface rough and uneven.



Magnification: 80×

**Regular and Diffuse Reflection** Even though the surface of the paper might seem smooth, it's not as smooth as the surface of a mirror. **Figure 9** shows how rough the surface of a piece of paper looks when it is viewed under a microscope. The rough surface causes light rays to be reflected from it in many directions, as shown in **Figure 10**. This uneven reflection of light waves from a rough surface is diffuse reflection. The smoother surfaces of mirrors, as shown in **Figure 10**, reflect light waves in a much more regular way. For example, parallel rays remain parallel after they are reflected from a mirror. Reflection from mirrors is known as regular reflection. Light waves that are regularly reflected from a surface form the image you see in a mirror or any other smooth surface. Whether a surface is smooth or rough, every light ray that strikes it obeys the law of reflection.

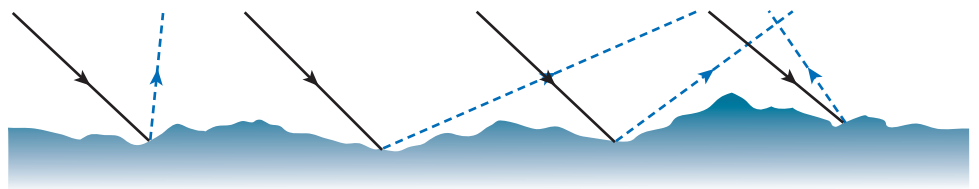
 **Reading Check**

*Why does a rough surface cause a diffuse reflection?*

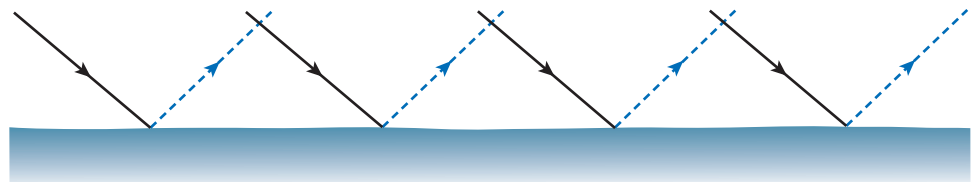
**Scattering of Light** When diffuse reflection occurs, light waves that were traveling in a single direction are reflected and then travel in many different directions. Scattering occurs when light waves traveling in one direction are made to travel in many different directions. Scattering also can occur when light waves strike small particles, such as dust. You may have seen dust particles floating in a beam of sunlight. When the light waves in the sunbeam strike a dust particle, they are scattered in all directions. You see the dust particles as bright specks of light when some of these scattered light waves enter your eye.

**Figure 10** The roughness of a surface determines whether it looks like a mirror.

A rough surface causes parallel light rays to be reflected in many different directions.



A smooth surface causes parallel light rays to be reflected in a single direction. This type of surface looks like a mirror.





**A** Light rays that bounce off a person strike the mirror. Some of these light rays are reflected into the person's eye. **B** The light rays that are shown entering the person's eye seem to be coming from a person behind the mirror.

**Reflection by Plane Mirrors** Did you glance in the mirror before leaving for school this morning? If you did, you probably looked at your reflection in a plane mirror. A plane mirror is a mirror with a flat reflecting surface. In a plane mirror, your image looks much the same as it would in a photograph. However, you and your image are facing in opposite directions. This causes your left side and your right side to switch places on your mirror image. Also, your image seems to be coming from behind the mirror. How does a plane mirror form an image?

**Reading Check** *What is a plane mirror?*

**Figure 11** shows a person looking into a plane mirror. Light waves from the Sun or another source of light strike each part of the person. These light rays bounce off the person according to the law of reflection, and some of them strike the mirror. The rays that strike the mirror also are reflected according to the law of reflection. **Figure 11A** shows the path traveled by a few of the rays that have been reflected off the person and reflected back to the person's eye by the mirror.

**The Image in a Plane Mirror** Why does the image you see in a plane mirror seem to be behind the mirror? This is a result of how your brain processes the light rays that enter your eyes. Although the light rays bounced off the mirror's surface, your brain interprets them as having followed the path shown by the dashed lines in **Figure 11B**. In other words, your brain always assumes that light rays travel in straight lines without changing direction. This makes the reflected light rays look as if they are coming from behind the mirror, even though no source of light is there. The image also seems to be the same distance behind the mirror as the person is in front of the mirror.

**Figure 11** A plane mirror forms an image by changing the direction of light rays.

**Describe** how you and your image in a plane mirror are different.

**INTEGRATE**  
**Physics**

**Light Waves and Photons**

When an object like a marble or a basketball bounces off a surface, it obeys the law of reflection. Because light also obeys the law of reflection, people once thought that light must be a stream of particles. Today, experiments have shown that light can behave as though it were both a wave and a stream of energy bundles called photons. Read an article about photons and write a description in your Science Journal.

**Topic: Concave Mirrors**

Visit [ips.msscience.com](http://ips.msscience.com) for Web links to information about the concave mirrors used in telescopes.

**Activity** Make a chart showing the five largest telescope mirrors and where they are located.

## Concave and Convex Mirrors

Some mirrors are not flat. A concave mirror has a surface that is curved inward, like the bowl of a spoon. Unlike plane mirrors, concave mirrors cause light rays to come together, or converge. A convex mirror, on the other hand, has a surface that curves outward, like the back of a spoon. Convex mirrors cause light waves to spread out, or diverge. These two types of mirrors form images that are different from the images that are formed by plane mirrors. Examples of a concave and a convex mirror are shown in **Figure 12**.



**Reading Check**

*What's the difference between a concave and convex mirror?*

**Concave Mirrors** The way in which a concave mirror forms an image is shown in **Figure 13**. A straight line drawn perpendicular to the center of a concave or convex mirror is called the optical axis. Light rays that travel parallel to the optical axis and strike the mirror are reflected so that they pass through a single point on the optical axis called the **focal point**. The distance along the optical axis from the center of the mirror to the focal point is called the **focal length**.

The image formed by a concave mirror depends on the position of the object relative to its focal point. If the object is farther from the mirror than the focal point, the image appears to be upside down, or inverted. The size of the image decreases as the object is moved farther away from the mirror. If the object is closer to the mirror than one focal length, the image is upright and gets smaller as the object moves closer to the mirror.

A concave mirror can produce a focused beam of light if a source of light is placed at the mirror's focal point, as shown in **Figure 13**. Flashlights and automobile headlights use concave mirrors to produce directed beams of light.

**Figure 12** Convex and concave mirrors have curved surfaces.



A concave mirror has a surface that's curved inward.

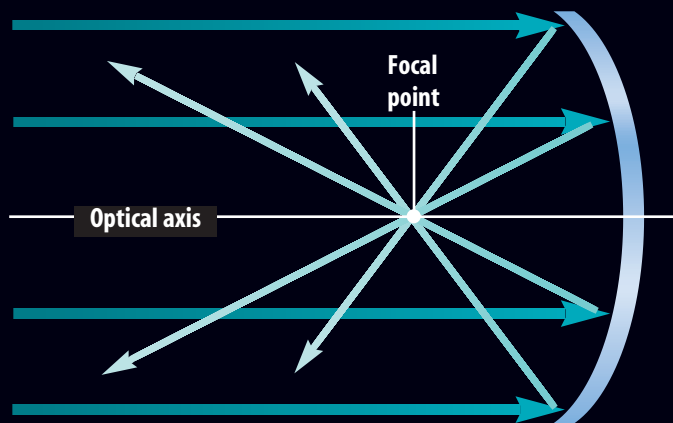


A convex mirror has a surface that's curved outward.

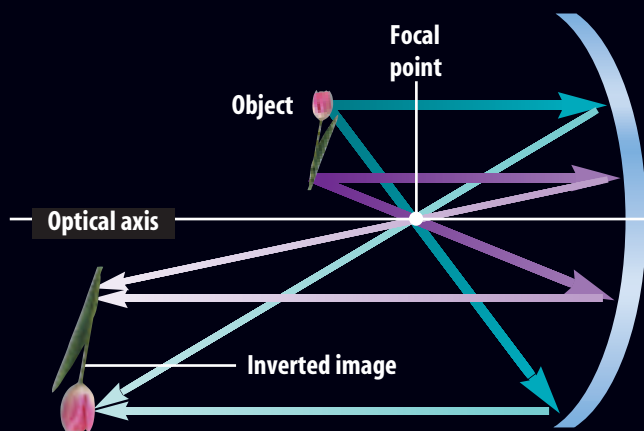


Figure 13

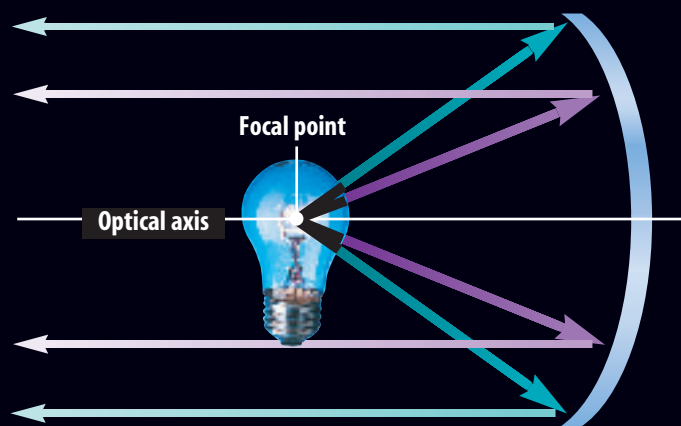
**G**lance into a flat plane mirror and you'll see an upright image of yourself. But look into a concave mirror, and you might see yourself larger than life, right side up, or upside down—or not at all! This is because the way a concave mirror forms an image depends on the position of an object in front of the mirror, as shown here.



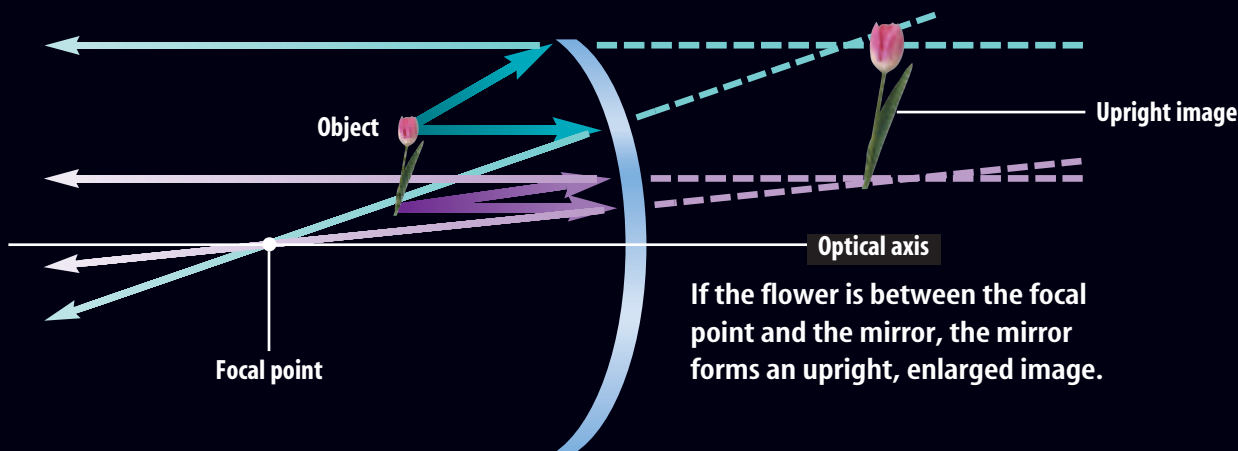
A concave mirror reflects all light rays traveling parallel to the optical axis so that they pass through the focal point.



When an object, such as this flower, is placed beyond the focal point, the mirror forms an image that is inverted.

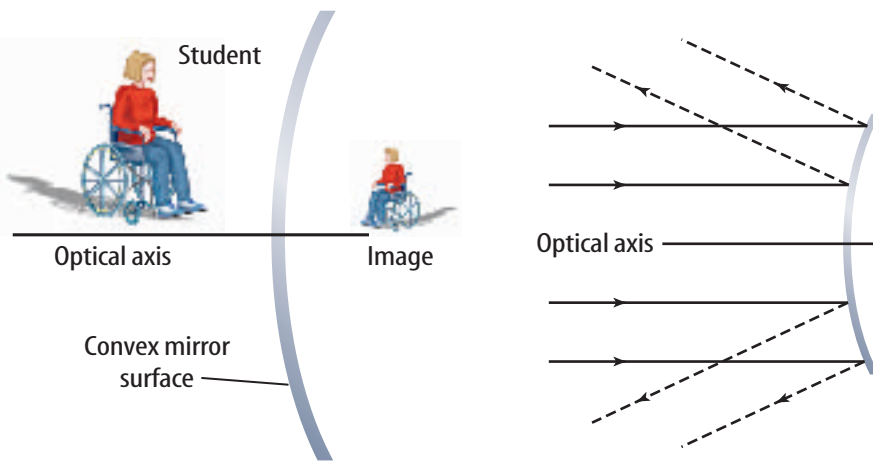


When a source of light is placed at the focal point, a beam of parallel light rays is formed. The concave mirror in a flashlight, for example, creates a beam of parallel light rays.



If the flower is between the focal point and the mirror, the mirror forms an upright, enlarged image.

**Figure 14** A convex mirror is a mirror that curves outward.



A convex mirror causes light rays that are traveling parallel to the optical axis to spread apart after they are reflected.

No matter how far an object is from a convex mirror, the image is always upright and smaller than the object.

**Convex Mirrors** A convex mirror has a reflecting surface that curves outward and causes light rays to spread apart, or diverge, as shown in **Figure 14**. Like the image formed by plane mirror, the image formed by a convex mirror seems to be behind the mirror. **Figure 14** shows that the image always is upright and smaller than the object.

Convex mirrors often are used as security mirrors in stores and as outside rearview mirrors on cars and other vehicles. You can see a larger area reflected in a convex mirror than in other mirrors.

## section 2 review

### Summary

#### Reflection and Plane Mirrors

- The law of reflection states that the angle of incidence equals the angle of reflection.
- A regular reflection is produced by a smooth surface, such as a mirror. A rough surface forms a diffuse reflection.
- Scattering occurs when light rays traveling in one direction are made to travel in many directions.
- A plane mirror forms a image that is reversed left to right and seems to be behind the mirror.

#### Concave and Convex Mirrors

- Concave mirrors curve inward and make light rays converge.
- Images formed by a concave mirror can be either upright or inverted and can vary from larger to smaller than the object.
- Convex mirrors curve outward and make light rays diverge.
- Images formed by a convex mirror are always upright and smaller than the object.

### Self Check

1. **Describe** the image formed by a concave mirror when an object is less than one focal length from the mirror.
2. **Explain** why concave mirrors are used in flashlights and automobile headlights.
3. **Describe** If an object is more than one focal length from a concave mirror, how does the image formed by the mirror change as the object moves farther from the mirror?
4. **Determine** which light rays striking a concave mirror are reflected so that they pass through the focal point.
5. **Think Critically** After you wash and wax a car, you can see your reflection in the car's surface. Before you washed and waxed the car, no reflection could be seen. Explain.

### Applying Skills

6. **Use a Spreadsheet** Make a table using a spreadsheet comparing the images formed by plane, concave, and convex mirrors. Include in your table how the images depend on the distance of the object from the mirror.

## Reflection from a Plane Mirror

A light ray strikes the surface of a plane mirror and is reflected. Does a relationship exist between the direction of the incoming light ray and the direction of the reflected light ray?

### Real-World Question

How does the angle of incidence compare with the angle of reflection for a plane mirror?

#### Goals

- **Measure** the angle of incidence and the angle of reflection for a light ray reflected from a plane mirror.

#### Materials

flashlight	small plane mirror,
protractor	at least 10 cm on a side
metric ruler	black construction paper
scissors	modeling clay
tape	white unlined paper

#### Safety Precautions



### Procedure

1. With the scissors, cut a slit in the construction paper and tape it over the flashlight lens.
2. Place the mirror at one end of the unlined paper. Push the mirror into lumps of clay so it stands vertically, and tilt the mirror so it leans slightly toward the table.
3. **Measure** with the ruler to find the center of the bottom edge of the mirror, and mark it. Then use the protractor and the ruler to draw a line on the paper perpendicular to the mirror from the mark. Label this line *P*.



4. Draw lines on the paper from the center mark at angles of  $30^\circ$ ,  $45^\circ$ , and  $60^\circ$  to line *P*.
5. Turn on the flashlight and place it so the beam is along the  $60^\circ$  line. This is the angle of incidence. Measure and record the angle that the reflected beam makes with line *P*. This is the angle of reflection. If you cannot see the reflected beam, slightly increase the tilt of the mirror.
6. Repeat step 5 for the  $30^\circ$ ,  $45^\circ$ , and *P* lines.

### Conclude and Apply

**Infer** from your results the relationship between the angle of incidence and the angle of reflection.

### Communicating Your Data

Make a poster that shows your measured angles of reflection for angles of incidence of  $30^\circ$ ,  $45^\circ$ , and  $60^\circ$ . Write the relationship between the angles of incidence and reflection at the bottom.

# Refraction and Lenses

## as you read

### What You'll Learn

- **Determine** why light rays refract.
- **Explain** how convex and concave lenses form images.

### Why It's Important

Many of the images you see every day in photographs, on TV, and in movies are made using lenses.

### Review Vocabulary

**refraction:** bending of a wave as it changes speed, moving from one medium to another

### New Vocabulary

- lens
- convex lens
- concave lens

**Figure 15** Light travels at different speeds in different materials.

## Bending of Light Rays

Objects that are in water can sometimes look strange. A pencil in a glass of water sometimes looks as if it's bent, or as if the part of the pencil in air is shifted compared to the part in water. A penny that can't be seen at the bottom of a cup suddenly appears as you add water to the cup. Illusions such as these are due to the bending of light rays as they pass from one material to another. What causes light rays to change direction?

**The Speeds of Light** The speed of light in empty space is about 300 million m/s. Light passing through a material such as air, water, or glass, however, travels more slowly than this. This is because the atoms that make up the material interact with the light waves and slow them down. **Figure 15** compares the speed of light in some different materials.



The speed of light through air is about 300 million m/s.



The speed of light through water is about 227 million m/s.



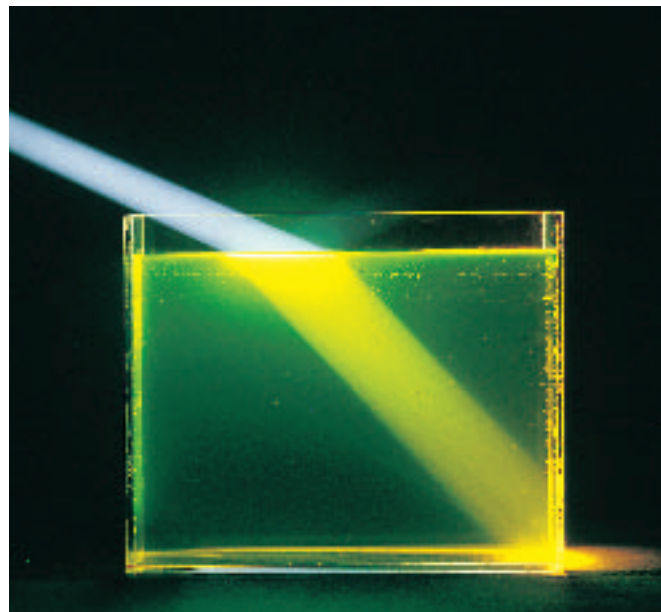
The speed of light through glass is about 197 million m/s.



The speed of light through diamond is about 125 million m/s.

## The Refraction of Light Waves

Light rays from the part of a pencil that is underwater travel through water, glass, and then air before they reach your eye. The speed of light is different in each of these mediums. What happens when a light wave travels from one medium into another in which its speed is different? If the wave is traveling at an angle to the boundary between the two media, it changes direction, or bends. This bending is due to the change in speed the light wave undergoes as it moves from one medium into the other. The bending of light waves due to a change in speed is called refraction. **Figure 16** shows an example of refraction. The greater the change in speed is, the more the light wave bends, or refracts.



### Reading Check

*What causes light to bend?*

Why does a change in speed cause the light wave to bend? Think about what happens to the wheels of a car as they move from pavement to mud at an angle, as in **Figure 17**. The wheels slip a little in the mud and don't move forward as fast as they do on the pavement. The wheel that enters the mud first gets slowed down a little, but the other wheel on that axle continues at the original speed. The difference in speed between the two wheels then causes the wheel axle to turn, so the car turns a little. Light waves behave in the same way.

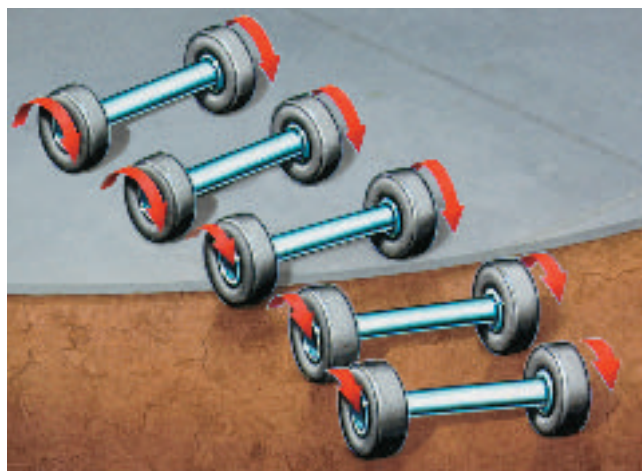
Imagine again a light wave traveling at an angle from air into water. The first part of the wave to enter the water is slowed, just as the car wheel that first hit the mud was slowed. The rest of the wave keeps slowing down as it moves from the air into the water. As long as one part of the light wave is moving faster than the rest of the wave, the wave continues to bend.

**Figure 16** A light ray is bent as it slows down traveling from air into water.

**Figure 17** An axle turns as the wheels cross the boundary between pavement and mud. **Predict** how the axle would turn if the wheels were going from mud to pavement.

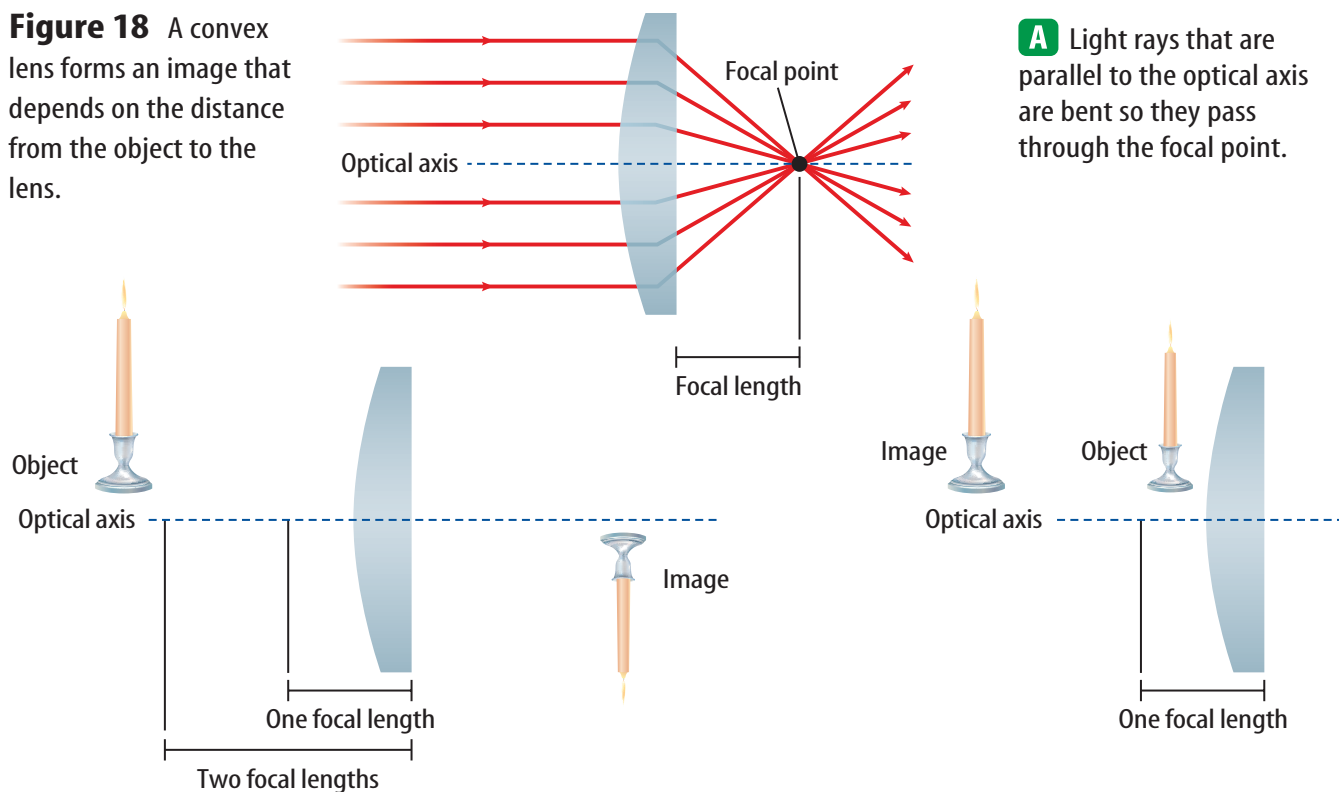
## Convex and Concave Lenses

Do you like photographing your friends and family? Have you ever watched a bird through binoculars or peered at something tiny through a magnifying glass? All of these activities involve the use of lenses. A **lens** is a transparent object with at least one curved side that causes light to bend. The amount of bending can be controlled by making the sides of the lenses more or less curved. The more curved the sides of a lens are, the more light will be bent after it enters the lens.





**Figure 18** A convex lens forms an image that depends on the distance from the object to the lens.



**A** Light rays that are parallel to the optical axis are bent so they pass through the focal point.

**B** If the object is more than two focal lengths from the lens, the image formed is smaller than the object and inverted.

**C** If the object is closer to the lens than one focal length, the image formed is enlarged and upright.

**Convex Lenses** A lens that is thicker in the center than at the edges is a **convex lens**. In a convex lens, light rays traveling parallel to the optical axis are bent so they pass through the focal point, as shown in **Figure 18A**. The more curved the lens is, the closer the focal point is to the lens, and so the shorter the focal length of the lens is. Because convex lenses cause light waves to meet, they also are called converging lenses.

The image formed by a convex lens is similar to the image formed by a concave mirror. For both, the type of image depends on how far the object is from the mirror or lens. Look at **Figure 18B**. If the object is farther than two focal lengths from the lens, the image seen through the lens is inverted and smaller than the object.

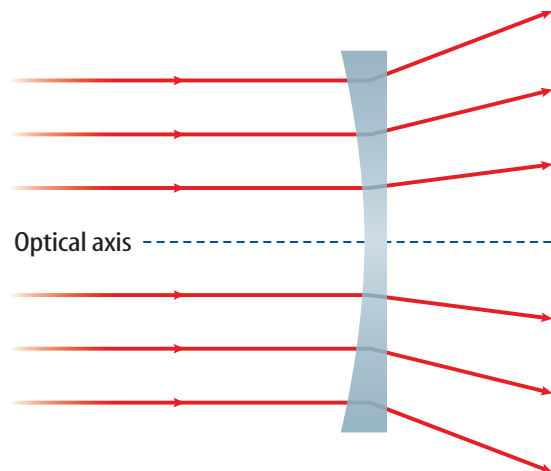
**Reading Check**

*How does the focal length of a convex lens change if the lens becomes more curved?*

If the object is closer to the lens than one focal length, then the image formed is right-side up and larger than the object, as shown in **Figure 18C**. A magnifying glass forms an image in this way. As long as the magnifying glass is less than one focal length from the object, you can make the image appear larger by moving the magnifying glass away from the object.

**Concave Lenses** A lens that is thicker at the edges than in the middle is a **concave lens**. A concave lens also is called a diverging lens. **Figure 19** shows how light rays traveling parallel to the optical axis are bent after passing through a concave lens.

A concave lens causes light rays to diverge, so light rays are not brought to a focus. The type of image that is formed by a concave lens is similar to one that is formed by a convex mirror. The image is upright and smaller than the object.



**Figure 19** A concave lens causes light rays traveling parallel to the optical axis to diverge.

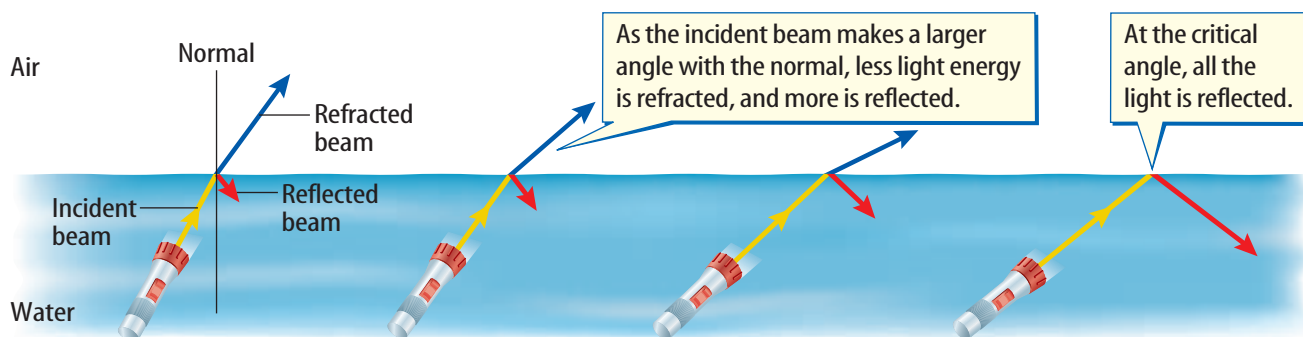
## Total Internal Reflection

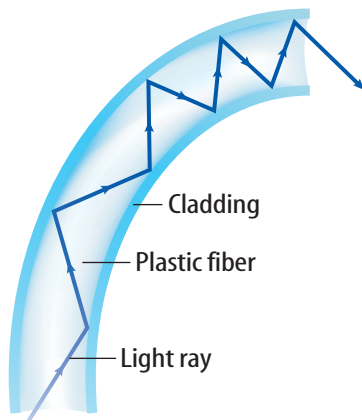
When you look at a glass window, you sometimes can see your reflection. You see a reflection because some of the light waves reflected from you are reflected back to your eyes when they strike the window. This is an example of a partial reflection—only some of the light waves striking the window are reflected. However, sometimes all the light waves that strike the boundary between two transparent materials can be reflected. This process is called total internal reflection.

**The Critical Angle** To see how total internal reflection occurs, look at **Figure 20**. Light travels faster in air than in water, and the refracted beam is bent away from the normal. As the angle between the incident beam and the normal increases, the refracted beam bends closer to the air-water boundary. At the same time, more of the light energy striking the boundary is reflected and less light energy passes into the air.

If a light beam in water strikes the boundary so that the angle with the normal is greater than an angle called the critical angle, total internal reflection occurs. Then all the light waves are reflected at the air-water boundary, just as if a mirror were there. The size of the critical angle depends on the two materials involved. For light passing from water to air, the critical angle is about 48 degrees.

**Figure 20** When a light beam passes from one medium to another, some of its energy is reflected (red) and some is refracted (blue).





**Figure 21** An optical fiber is made of materials that cause total internal reflection to occur. A light beam can travel for many kilometers through an optical fiber and lose almost no energy.

**Optical Fibers** Optical fibers are thin, flexible, transparent fibers. An optical fiber is like a light pipe. Even if the fiber is bent, light that enters one end of the fiber comes out the other end.

Total internal reflection makes light transmission in optical fibers possible. A thin fiber of glass or plastic is covered with another material called cladding in which light travels faster. When light strikes the boundary between the fiber and the cladding, total internal reflection can occur. In this way, the beam bounces along inside the fiber as shown in **Figure 21**.

Optical fibers are used most commonly in the communications industry. For example, television programs, computer information, and phone conversations can be coded into light signals. These signals then can be sent from one place to another using optical fibers. Because of total internal reflection, signals can't leak from one fiber to another and interfere with others. As a result, the signal is transmitted clearly. One optical fiber the thickness of a human hair can carry thousands of phone conversations.

## section 3 review

### Summary

#### The Refraction of Light

- Light travels at different speeds in different materials.
- Refraction occurs when light changes speed as it travels from one material into another.

#### Convex and Concave Lenses

- A lens is a transparent object with at least one curved side that causes light to bend.
- A convex lens is thicker in the center than at the edges and causes light waves to converge.
- A concave lens is thinner in the center than at the edges and causes light waves to diverge.

#### Total Internal Reflection

- Total internal reflection occurs at the boundary between two transparent materials when light is completely reflected.
- Optical fibers use total internal reflection to transmit information over long distances with light waves.

### Self Check

1. **Compare** the image formed by a concave lens and the image formed by a convex mirror.
2. **Explain** whether you would use a convex lens or a concave lens to magnify an object.
3. **Describe** the image formed by convex lens if an object is less than one focal length from the lens.
4. **Describe** how light rays traveling parallel to the optical axis are bent after they pass through a convex lens.
5. **Infer** If the speed of light were the same in all materials, would a lens cause light rays to bend?
6. **Think Critically** A light wave is bent more when it travels from air to glass than when it travels from air to water. Is the speed of light greater in water or in glass? Explain.

### Applying Math

7. **Calculate Time** If light travels at 300,000 km/s and Earth is 150 million km from the Sun, how long does it take light to travel from the Sun to Earth?

# Using Mirrors and Lenses

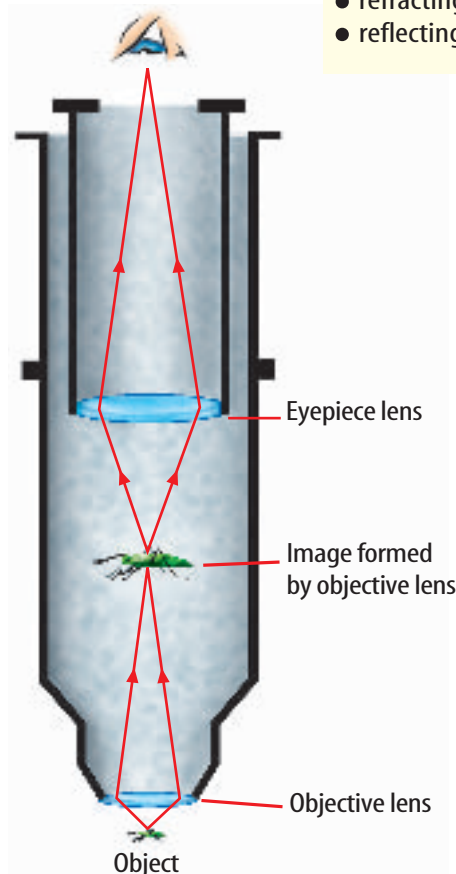
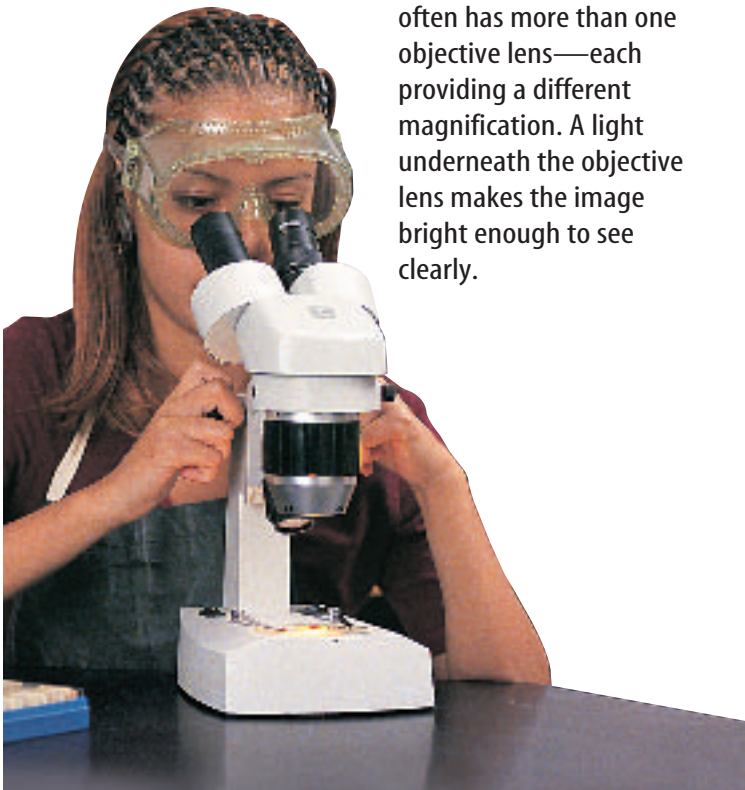
## Microscopes

For almost 500 years, lenses have been used to observe objects that are too small to be seen with the unaided eye. The first microscopes were simple and magnified less than 100 times. Today, a compound microscope like the one in **Figure 22** uses a combination of lenses to magnify objects by as much as 2,500 times.

**Figure 22** also shows how a microscope forms an image. An object, such as an insect or a drop of water from a pond, is placed close to a convex lens called the objective lens. This lens produces an enlarged image inside the microscope tube. The light rays from that image then pass through a second convex lens called the eyepiece lens. This lens further magnifies the image formed by the objective lens. By using two lenses, a much larger image is formed than a single lens can produce.

**Figure 22** A compound microscope uses lenses to magnify objects.

A compound microscope often has more than one objective lens—each providing a different magnification. A light underneath the objective lens makes the image bright enough to see clearly.



The objective lens in a compound microscope forms an enlarged image, which is then magnified by the eyepiece lens.

### as you read

#### What You'll Learn

- **Explain** how microscopes magnify objects.
- **Explain** how telescopes make distant objects visible.
- **Describe** how a camera works.

#### Why It's Important

Microscopes and telescopes are used to view parts of the universe that can't be seen with the unaided eye.

#### Review Vocabulary

**retina:** region on the inner surface of the back of the eye that contains light-sensitive cells

#### New Vocabulary

- refracting telescope
- reflecting telescope

## Forming an Image with a Lens

### Procedure

1. Fill a **glass test tube** with **water** and seal it with a **stopper**.
2. Write your name on a **10-cm × 10-cm card**. Lay the test tube on the card and observe the appearance of your name.
3. Hold the test tube about 1 cm above the card and observe the appearance of your name through it again.
4. Observe what happens to your name as you slowly move the test tube away from the card.

### Analysis

1. Is the water-filled test tube a concave or a convex lens?
2. Compare the images formed when the test tube was close to the card and far from the card.

## Telescopes

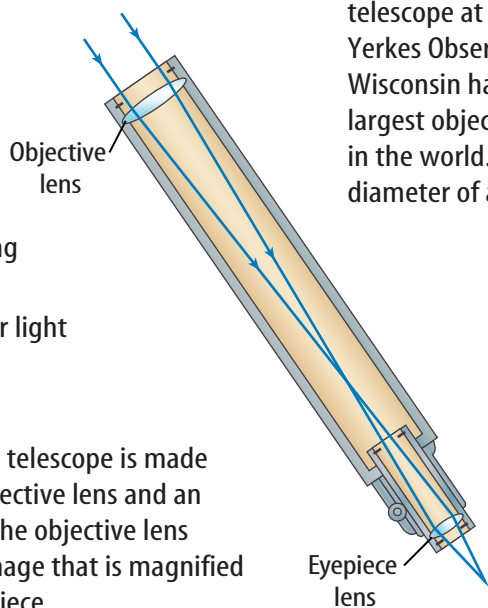
Just as microscopes are used to magnify very small objects, telescopes are used to examine objects that are very far away. The first telescopes were made at about the same time as the first microscopes. Much of what is known about the Moon, the solar system, and the distant universe has come from images and other information gathered by telescopes.

**Refracting Telescopes** The simplest **refracting telescopes** use two convex lenses to form an image of a distant object. Just as in a compound microscope, light passes through an objective lens that forms an image. That image is then magnified by an eyepiece, as shown in **Figure 23**.

An important difference between a telescope and a microscope is the size of the objective lens. The main purpose of a telescope is not to magnify an image. A telescope's main purpose is to gather as much light as possible from distant objects. The larger an objective lens is, the more light can enter it. This makes images of faraway objects look brighter and more detailed when they are magnified by the eyepiece. With a large enough objective lens, it's possible to see stars and galaxies that are many trillions of kilometers away. **Figure 23** also shows the largest refracting telescope ever made.

### Reading Check

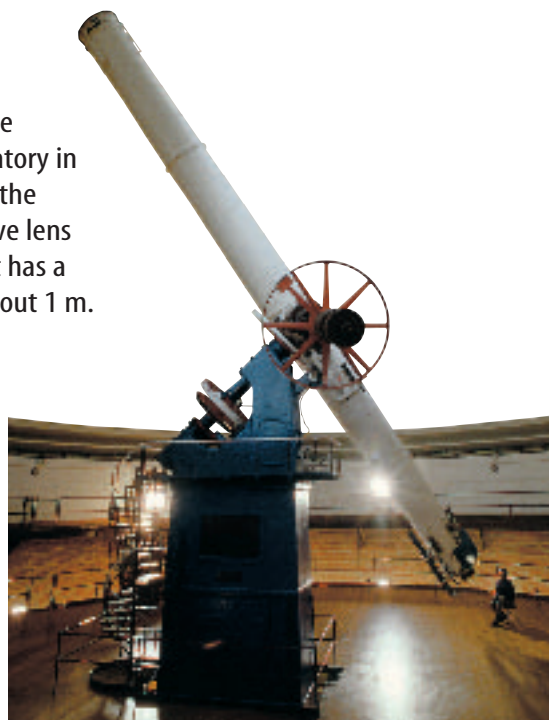
*How does a telescope's objective lens enable distant objects to be seen?*



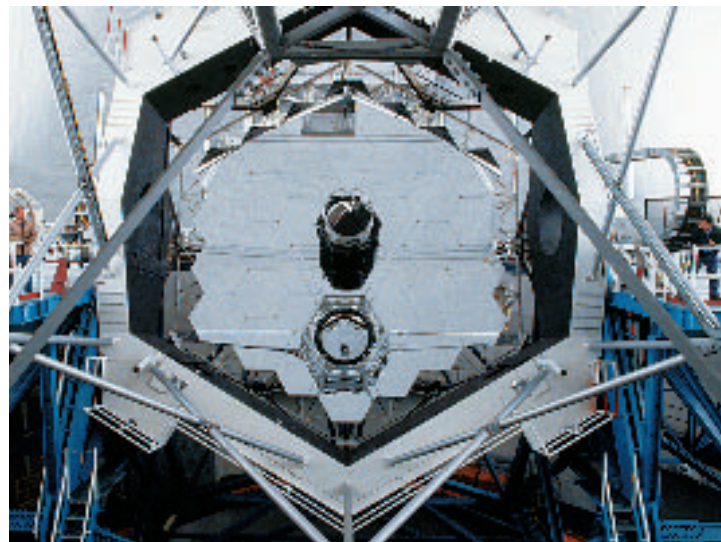
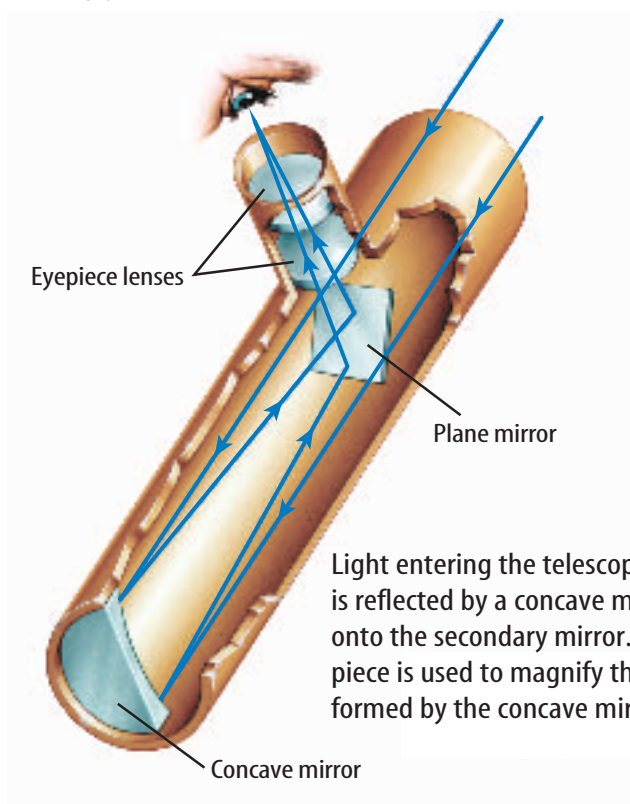
**Figure 23** Refracting telescopes use a large objective lens to gather light from distant objects.

A refracting telescope is made from an objective lens and an eyepiece. The objective lens forms an image that is magnified by the eyepiece.

The refracting telescope at the Yerkes Observatory in Wisconsin has the largest objective lens in the world. It has a diameter of about 1 m.



**Figure 24** Reflecting telescopes gather light by using a concave mirror.



The Keck telescope in Mauna Kea, Hawaii, is the largest reflecting telescope in the world.

**Reflecting Telescopes** Refracting telescopes have size limitations. One problem is that the objective lens can be supported only around its edges. If the lens is extremely large, it cannot be supported enough to keep the glass from sagging slightly under its own weight. This causes the image that the lens forms to become distorted.

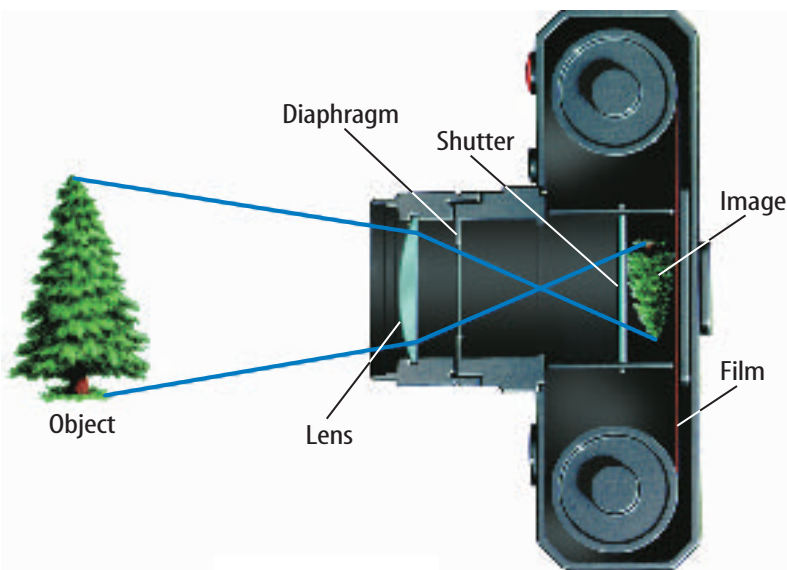
Reflecting telescopes can be made much larger than refracting telescopes. **Reflecting telescopes** have a concave mirror instead of a concave objective lens to gather the light from distant objects. As shown in **Figure 24**, the large concave mirror focuses light onto a secondary mirror that directs it to the eyepiece, which magnifies the image.

Because only the one reflecting surface on the mirror needs to be made carefully and kept clean, telescope mirrors are less expensive to make and maintain than lenses of a similar size. Also, mirrors can be supported not only at their edges but also on their backsides. They can be made much larger without sagging under their own weight. The Keck telescope in Hawaii, shown in **Figure 24**, is the largest reflecting telescope in the world. Its large concave mirror is 10 m in diameter, and is made of 36 six-sided segments. Each segment is 1.8 m in size and the segments are pieced together to form the mirror.



### The First Telescopes

A Dutch eyeglass maker, Hans Lippershey, constructed a refracting telescope in 1608 that had a magnification of 3. In 1609 Galileo built a refracting telescope with a magnification of 20. By 1668, the first reflecting telescope was built by Isaac Newton that had a metal concave mirror with a diameter of about 5 cm. More than a century later, William Herschel built the first large reflecting telescopes with mirrors as large as 50 cm. Research the history of the telescope and make a timeline showing important events.



**Figure 25** A camera uses a convex lens to form an image on a piece of light-sensitive film. The image formed by a camera lens is smaller than the object and is inverted.

## Cameras

You probably see photographs taken by cameras almost every day. A typical camera uses a convex lens to form an image on a section of film, just as your eye's lens focuses an image on your retina. The convex lens has a short focal length, so it forms an image that is smaller than the object and inverted on the film. Look at the camera shown in **Figure 25**. When the shutter is open, the convex lens focuses an image on a

piece of film that is sensitive to light. Light-sensitive film contains chemicals that undergo chemical reactions when light hits it. The brighter parts of the image affect the film more than the darker parts do.

### ✓ Reading Check

*What type of lens does a camera use?*

If too much light strikes the film, the image formed on the film is overexposed and looks washed out. On the other hand, if too little light reaches the film, the photograph might be too dark. To control how much light reaches the film, many cameras have a device called a diaphragm. The diaphragm is opened to let more light onto the film and closed to reduce the amount of light that strikes the film.

## Lasers

Perhaps you've seen the narrow, intense beams of laser light used in a laser light show. Intense laser beams are also used for different kinds of surgery. Why can laser beams be so intense? One reason is that a laser beam doesn't spread out as much as ordinary light as it travels.

**Spreading Light Beams** Suppose you shine a flashlight on a wall in a darkened room. The size of the spot of light on the wall depends on the distance between the flashlight and the wall. As the flashlight moves farther from the wall, the spot of light gets larger. This is because the beam of light produced by the flashlight spreads out as it travels. As a result, the energy carried by the light beam is spread over an increasingly larger area as the distance from the flashlight gets larger. As the energy is spread over a larger area, the energy becomes less concentrated and the intensity of the beam decreases.

ScienceOnline

### Topic: Lasers

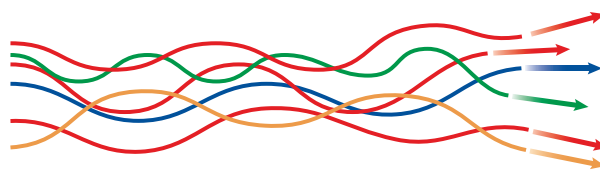
Visit [ips.msscience.com](http://ips.msscience.com) for Web links to information about uses for lasers.

**Activity** Make a table listing different types of lasers and how they are used.

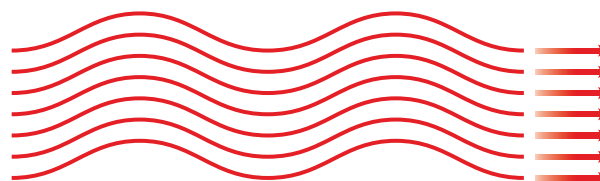
**Using Laser Light** Laser light is different from the light produced by the flashlight in several ways, as shown in **Figure 26**. One difference is that in a beam of laser light, the crests and troughs of the light waves overlap, so the waves are in phase.

Because a laser beam doesn't spread out as much as ordinary light, a large amount of energy can be applied to a very small area. This property enables lasers to be used for cutting and welding materials and as a replacement for scalpels in surgery. Less intense laser light is used for such applications as reading and writing to CDs or in grocery store bar-code readers. Surveyors and builders use lasers to measure distances, angles, and heights. Laser beams also are used to transmit information through space or through optical fibers.

**Figure 26** Laser light is different from the light produced by a lightbulb.



The light from a bulb contains waves with many different wavelengths that are out of phase and traveling in different directions.



The light from a laser contains waves with only one wavelength that are in phase and traveling in the same direction.

## section 4 review

### Summary

#### Microscopes, Telescopes, and Cameras

- A compound microscope uses an objective lens and an eyepiece lens to form an enlarged image of an object.
- A refracting telescope contains a large objective lens to gather light and a smaller eyepiece lens to magnify the image.
- A reflecting telescope uses a large concave mirror to gather light and an eyepiece lens to magnify the image.
- The image formed by a telescope becomes brighter and more detailed as the size of the objective lens or concave mirror increases.
- A camera uses a convex lens to form an image on light-sensitive film.

#### Laser Light

- Light from a laser contains light waves that are in phase, have only one wavelength, and travel in the same direction.
- Because laser light does not spread out much as it travels the energy it carries can be applied over a very small area.

### Self Check

1. **Explain** why the concave mirror of a reflecting telescope can be made much larger than the objective lens of a refracting telescope.
2. **Describe** how a beam of laser light is different than the beam of light produced by a flashlight.
3. **Explain** why the objective lens of a refracting telescope is much larger than the objective lens of a compound microscope.
4. **Infer** how the image produced by a compound microscope would be different if the eyepiece lens were removed from the microscope.
5. **Think Critically** Explain why the intensity of the light in a flashlight beam decreases as the flashlight moves farther away.

### Applying Math

6. **Calculate Image Size** The size of an image is related to the magnification of an optical instrument by the following formula:

$$\text{Image size} = \text{magnification} \times \text{object size}$$

A blood cell has a diameter of 0.001 cm. How large is the image formed by a microscope with a magnification of 1,000?



## Image Formation by a Convex Lens

### Goals

- **Measure** the image distance as the object distance changes.
- **Observe** the type of image formed as the object distance changes.

### Possible Materials

convex lens  
modeling clay  
meterstick  
flashlight  
masking tape  
20-cm square piece of cardboard with a white surface

### Safety Precautions



### Real-World Question

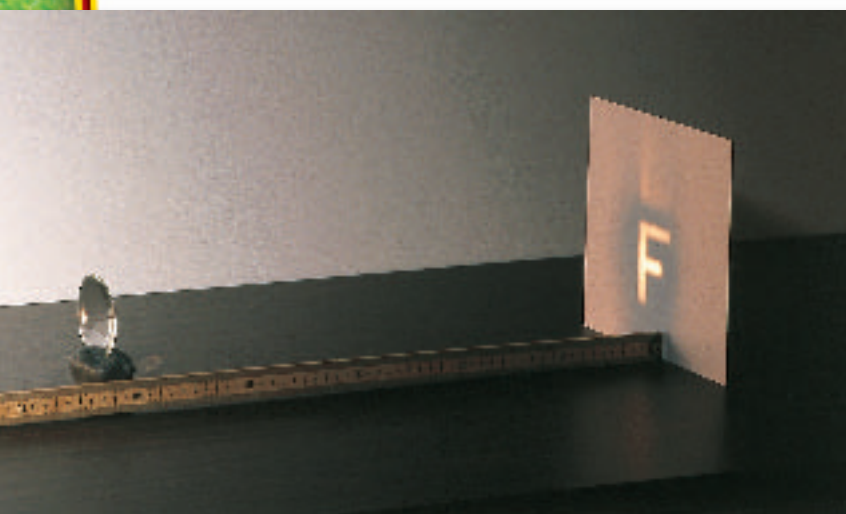
The type of image formed by a convex lens, also called a converging lens, is related to the distance of the object from the lens. This distance is called the object distance. The location of the image also is related to the distance of the object from the lens. The distance from the lens to the image is called the image distance. How are the image distance and object distance related for a convex lens?

### Procedure

1. **Design** a data table to record your data. Make three columns in your table—one column for the object distance, another for the image distance, and the third for the type of image.
2. Use the modeling clay to make the lens stand upright on the lab table.
3. Form the letter *F* on the glass surface of the flashlight with masking tape.
4. Turn on the flashlight and place it 1 m from the lens. Position the flashlight so the flashlight beam is shining through the lens.
5. **Record** the distance from the flashlight to the lens in the object distance column in your data table.
6. Hold the cardboard vertically upright on the other side of the lens, and move it back and forth until a sharp image of the letter *F* is obtained.

#### Convex Lens Data

Object Distance (m)	Image Distance (m)	Image Type
Do not write in this book.		



## Using Scientific Methods

7. **Measure** the distance of the card from the lens using the meterstick, and record this distance in the Image Distance column in your data table.
8. **Record** in the third column of your data table whether the image is upright or inverted, and smaller or larger.
9. Repeat steps 4 through 8 for object distances of 0.50 m and 0.25 m and record your data in your data table.

### Analyze Your Data

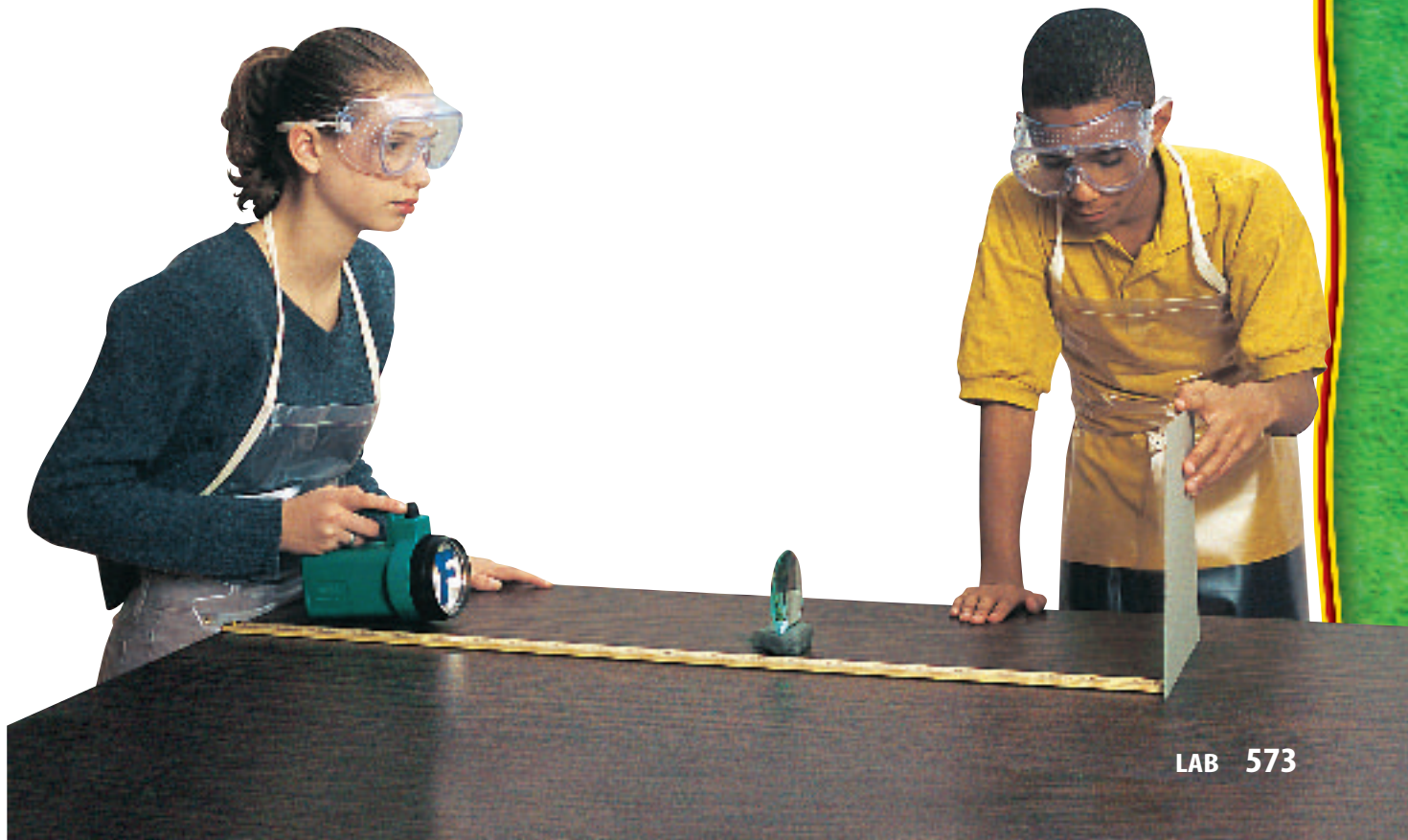
1. **Describe** any observed relationship between the object distance, and the image type.
2. **Identify** the variables involved in determining the image type for a convex lens.

### Conclude and Apply

1. **Explain** how the image distance changed as the object distance decreased.
2. **Identify** how the image changed as the object distance decreased.
3. **Predict** what would happen to the size of the image if the flashlight were much farther away than 1 m.

### Communicating Your Data

Demonstrate this lab to a third-grade class and explain how it works. For more help, refer to the **Science Skill Handbook**.



## Eyeglasses



“It is not yet twenty years since the art of making spectacles, one of the most useful arts on Earth, was discovered.

I, myself, have seen and conversed with the man who made them first.”

This quote from an Italian monk dates back to 1306 and is one of the first historical records to refer to eyeglasses. Unfortunately, the monk, Giordano, never actually named the man he met. Thus, the inventor of eyeglasses remains unknown.

The mystery exists, in part, because different cultures in different places used some type of magnifying tool to improve their vision. For example, a rock-crystal lens, made by early Assyrians who lived 3,500 years ago in what is now Iraq, may have been used to improve vision. About 2,000 years ago, the Roman writer Seneca looked through a glass globe of water to make the letters appear bigger in the books he read. By the tenth century, glasses had been invented in China, but they were used to keep away bad luck, not to improve vision.

In the mid 1400s in Europe, eyeglasses began to appear in paintings of scholars, clergy, and the upper classes—eyeglasses were so expensive that only the rich could afford them. In the early 1700s, for example,



**This Italian engraving from the 1600s shows some different types of glasses.**

glasses cost roughly \$200, which is comparable to thousands of dollars today. By the mid-1800s, improvements in manufacturing techniques made eyeglasses much less expensive to make, and thus this important invention became widely available to people of all walks of life.

## How Eyeglasses Work

Eyeglasses are used to correct farsightedness and nearsightedness, as well as other vision problems. The eye focuses light rays to form an image on a region called the retina on the back of the eye. Farsighted people have difficulty seeing things close up because light rays from nearby objects do not converge enough to form an image on the retina. This problem can be corrected by using convex lenses that cause light rays to converge before they enter the eye. Nearsighted people have problems seeing distant objects because light rays from far-away objects are focused in front of the retina. Concave lenses that cause light rays to diverge are used to correct this vision problem.

**Research** In many parts of the world, people have no vision care, and eye diseases and poor vision go untreated. Research the work of groups that bring eye care to people.

Science  **online**

For more information, visit  
[ips.msscience.com/oops](http://ips.msscience.com/oops)

## Reviewing Main Ideas

### Section 1 Properties of Light

1. Light waves can be absorbed, reflected, or transmitted when they strike an object.
2. The color of an object depends on the wavelengths of light reflected by the object.

### Section 2 Reflection and Mirrors

1. Light reflected from the surface of an object obeys the law of reflection—the angle of incidence equals the angle of reflection.
2. Concave mirrors cause light waves to converge, or meet. Convex mirrors cause light waves to diverge, or spread apart.

### Section 3 Refraction and Lenses

1. Light waves bend, or refract, when they

change speed in traveling from one medium to another.

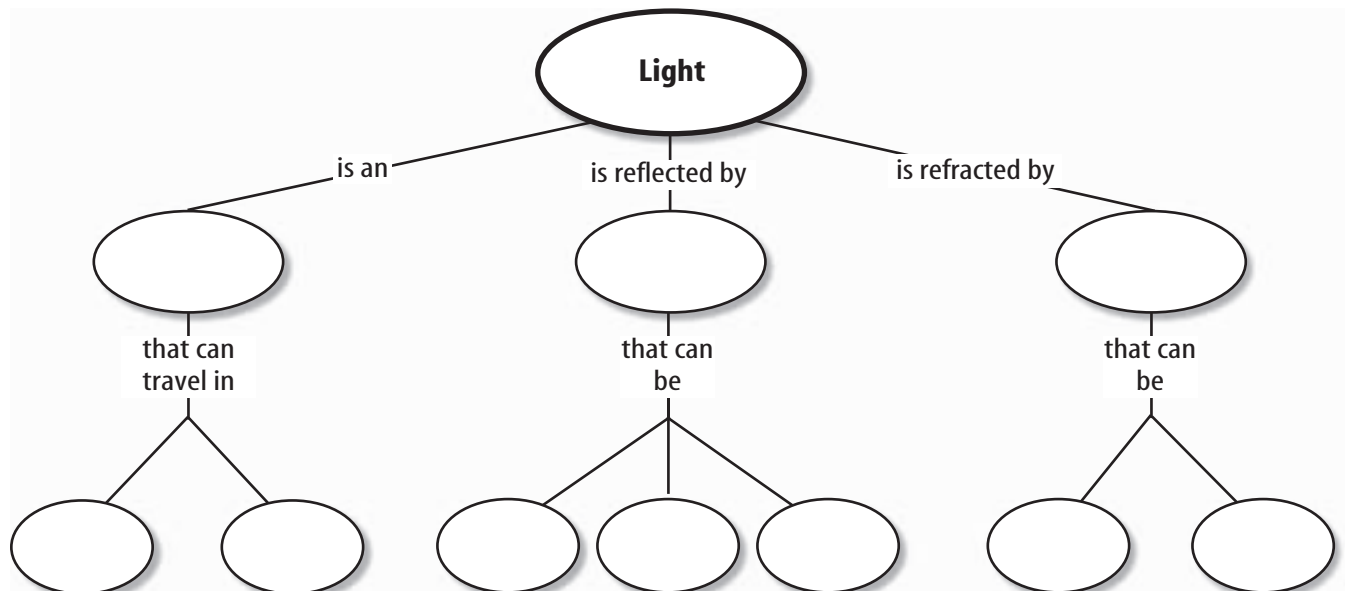
2. A convex lens causes light waves to converge, and a concave lens causes light waves to diverge.

### Section 4 Using Mirrors and Lenses

1. A compound microscope uses a convex objective lens to form an enlarged image that is further enlarged by an eyepiece.
2. A refracting telescope uses a large objective lens and an eyepiece lens to form an image of a distant object.
3. A reflecting telescope uses a large concave mirror that gathers light and an eyepiece lens to form an image of a distant object.
4. Cameras use a convex lens to form an image on light-sensitive film.

## Visualizing Main Ideas

Copy and complete the following concept map.



### Using Vocabulary

concave lens p.565	lens p.563
convex lens p.564	light ray p.550
focal length p.558	medium p.551
focal point p.558	reflecting telescope p.569
law of reflection p.555	refracting telescope p.568

Complete each statement using a word or words from the vocabulary list above.

- A \_\_\_\_\_ is the material in which a light wave travels.
  - A narrow beam of light that travels in a straight line is a \_\_\_\_\_.
  - The \_\_\_\_\_ is the distance from a lens or a mirror to the focal point.
  - Light rays traveling parallel to the optical axis of a convex lens are bent so they pass through the \_\_\_\_\_.
  - A transparent object with at least one curved surface that causes light waves to bend is a \_\_\_\_\_.
  - A \_\_\_\_\_ is thicker in the center than it is at the edges.
  - A \_\_\_\_\_ uses a large concave mirror to gather light from distant objects.
- If an object reflects red and green light, what color does the object appear to be?  
A) yellow                      C) green  
B) red                            D) purple
  - If an object absorbs all the light that hits it, what color is it?  
A) white                        C) black  
B) blue                          D) green
  - What type of image is formed by a plane mirror?  
A) upright                      C) magnified  
B) inverted                     D) all of these
  - How is the angle of incidence related to the angle of reflection?  
A) It's greater.                C) It's the same.  
B) It's smaller.                D) It's not focused.
  - Which of the following can be used to magnify objects?  
A) a concave lens            C) a convex mirror  
B) a convex lens              D) all of these
  - Which of the following describes the light waves that make up laser light?  
A) same wavelength  
B) same direction  
C) in phase  
D) all of these
  - What is an object that reflects some light and transmits some light called?  
A) colored                      C) opaque  
B) diffuse                        D) translucent
  - What is the main purpose of the objective lens or concave mirror in a telescope?  
A) invert images              C) gather light  
B) reduce images             D) magnify images
  - Which of the following types of mirror can form an image larger than the object?  
A) convex                        C) plane  
B) concave                        D) all of these

### Checking Concepts

Choose the word or phrase that best answers the question.

- Light waves travel the fastest through which of the following?  
A) air                              C) water  
B) diamond                      D) a vacuum
- Which of the following determines the color of light?  
A) a prism                        C) its wavelength  
B) its refraction                D) its incidence

**Thinking Critically**

19. **Diagram** Suppose you can see a person's eyes in a mirror. Draw a diagram to determine whether or not that person can see you.
20. **Determine** A singer is wearing a blue outfit. What color spotlights could be used to make the outfit appear to be black?
21. **Form a hypothesis** to explain why sometimes you can see two images of yourself reflected from a window at night.
22. **Explain** why a rough surface, such as a road, becomes shiny in appearance and a better reflector when it is wet.
23. **Infer** An optical fiber is made of a material that forms the fiber and a different material that forms the outer covering. For total internal reflection to occur, how does the speed of light in the fiber compare with the speed of light in the outer covering?

Use the table below to answer question 24.

Magnification by a Convex Lens	
Object Distance (cm)	Magnification
25	4.00
30	2.00
40	1.00
60	0.50
100	0.25

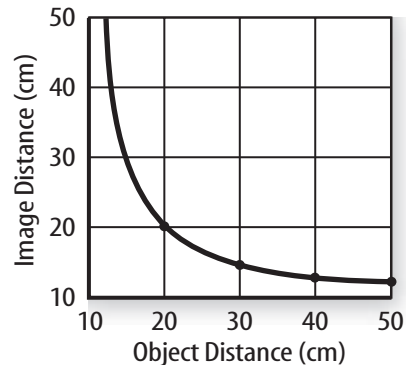
24. **Use a Table** In the table above, the object distance is the distance of the object from the lens. The magnification is the image size divided by the object size. If the focal length of the lens is 20 cm, how does the size of the image change as the object gets farther from the focal point?
25. **Calculate** What is the ratio of the distance at which the magnification equals 1.00 to the focal length of the lens?

**Performance Activities**

26. **Oral Presentation** Investigate the types of mirrors used in fun houses. Explain how these mirrors are formed, and why they produce distorted images. Demonstrate your findings to your class.
27. **Reverse Writing** Images are reversed left to right in a plane mirror. Write a note to a friend that can be read only in a plane mirror.
28. **Design an experiment** to determine the focal length of a convex lens. Write a report describing your experiment, including a diagram.

**Applying Math**

Use the graph below to answer questions 29 and 30.



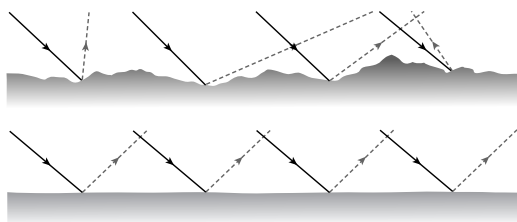
29. **Image Position** The graph shows how the distance of an image from a convex lens is related to the distance of the object from the lens. How does the position of the image change as the object gets closer to the lens?
30. **Magnification** The magnification of the image equals the image distance divided by the object distance. At what object distance does the magnification equal 2?

## Part 1 Multiple Choice

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

- Which of the following describes an object that allows no light to pass through it?
  - transparent
  - translucent
  - opaque
  - diffuse
- Which statement is always true about the image formed by a concave lens?
  - It is upside down and larger than the object.
  - It is upside down and smaller than the object.
  - It is upright and larger than the object.
  - It is upright and smaller than the object.

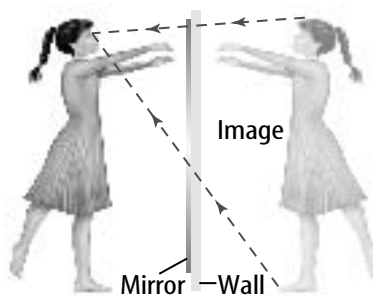
Use the figure below to answer questions 3 and 4.



- Which of the following describes the process occurring in the upper panel of the figure?
  - refraction
  - diffuse reflection
  - regular reflection
  - total internal reflection
- The surface in the lower panel of the figure would be like which of the following?
  - a mirror
  - waxed paper
  - a sheet of paper
  - a painted wall
- Why does a leaf look green?
  - It reflects green light.
  - It absorbs green light.
  - It reflects all colors of light.
  - It reflects all colors except green.

- What does a refracting telescope use to form an image of a distant object?
  - two convex lenses
  - a concave mirror and a plane mirror
  - two concave lenses
  - two concave mirrors
- Through which of the following does light travel the slowest?
  - air
  - diamond
  - water
  - vacuum
- What is the bending of a light wave due to a change in speed?
  - reflection
  - diffraction
  - refraction
  - transmission

Use the figure below to answer questions 9 and 10.



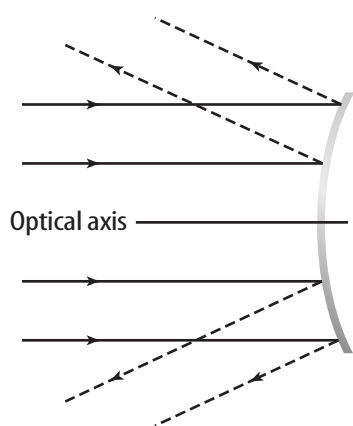
- If the girl is standing 1 m from the mirror, where will her image seem to be located?
  - 2 m behind the mirror
  - 1 m behind the mirror
  - 2 m in front of the mirror
  - 1 m in front of the mirror
- Which of the following describes the image of the girl formed by the plane mirror?
  - It will be upside down.
  - It will be in front of the mirror.
  - It will be larger than the girl.
  - It will be reversed left to right.

## Part 2 Short Response/Grid In

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

- 11.** Light travels slower in diamond than in air. Explain whether total internal reflection could occur for a light wave traveling in the diamond toward the diamond's surface.

Use the figure below to answer question 12.



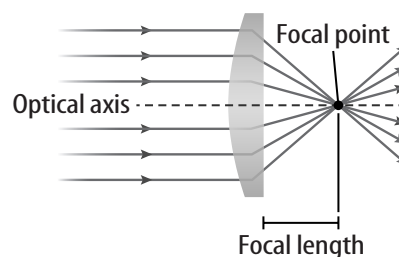
- 12.** Identify the type of mirror shown in the figure and describe the image this mirror forms.
- 13.** Under white light the paper of this page looks white and the print looks black. What color would the paper and the print appear to be under red light?
- 14.** A light ray strikes a plane mirror such that the angle of incidence is  $30^\circ$ . What is the angle between the light ray and the surface of the mirror?
- 15.** Contrast the light beam from a flashlight and a laser light beam.
- 16.** An actor on stage is wearing a magenta outfit. Explain what color the outfit would appear in red light, in blue light, and in green light.
- 17.** To use a convex lens as a magnifying lens, where must the object be located?

## Part 3 Open Ended

Record your answers on a sheet of paper.

- 18.** Explain why you can see the reflection of trees in the water of a lake on a calm day, but not a very windy day.
- 19.** Describe how total internal reflection enables optical fibers to transmit light over long distances.
- 20.** What happens when a source of light is placed at the focal point of a concave mirror? Give an example.

Use the illustration below to answer question 21.



- 21.** Describe how the position of the focal point changes as the lens becomes flatter and less curved.
- 22.** Compare the images formed by a concave mirror when an object is between the focal point and the mirror and when an object is beyond the focal point.
- 23.** Explain why increasing the size of the concave mirror in a reflecting telescope improves the images formed.

### Test-Taking Tip

**Organize Your Main Points** For essay questions, spend a few minutes listing and organizing the main points that you plan to discuss. Make sure to do all of this work on your scratch paper, not your answer sheet.

**Question 19** Organize your discussion points by first listing what you know about optical fibers and total internal reflection.