Launch Lab
Water Lenses

Have you ever used a magnifying glass, a camera, a microscope, or a telescope? If so, you were using a lens to create an image. A lens is a transparent material that bends rays of light and forms an image. In this activity, you will use water to create a lens.

For a lab worksheet, use your StudentWorks™ Plus Online.
THEMES FOCUS  Technology
Mirrors and lenses are integral parts of telescopes, microscopes, cameras, and other devices.

**BIG Idea** Mirrors and lenses form images by causing light rays to change direction.

---

**Section 1** • Mirrors

**Section 2** • Lenses

**Section 3** • Optical Instruments

---

Chapter 13 • Mirrors and Lenses  399
Mirrors

Mirrors form images by reflecting light rays.

Real-World Reading Link You might use a mirror to check your appearance before going to school. Astronomers use very large concave mirrors to form images of distant stars and galaxies.

Light and Vision

Have you ever tried to find an address on a house or an apartment at night on a poorly lit street? It is harder to do those activities in the dark than it is when there is plenty of light. Your eyes see by detecting light, so when you can see something, it is because light came from that object to your eyes. Light is emitted from a light source, such as the Sun or a light-bulb, and then reflects off an object, such as the page of a book, as shown in Figure 1.

When light travels from an object to your eye, you see the object. Light can reflect more than once. For example, light can reflect off an object into a mirror and then reflect into your eyes. When no light is available to reflect off objects and into your eyes, you cannot see anything. This is why it is hard to see an address in the dark.

Light rays Light sources send out light waves that travel in all directions. These waves spread out from the light source, just as ripples on the surface of water spread out from the point of impact of a pebble.

You could also think of the light coming from the source as traveling in narrow beams. Each narrow beam travels in a straight line and is called a light ray. Even though light rays can change direction when they are reflected or refracted, your brain interprets images as if light rays travel in a straight line.
Plane Mirrors

Greek mythology tells the story of a handsome young man named Narcissus who noticed his image in a pond and fell in love with himself. Like pools of water, mirrors are smooth surfaces that reflect light to form images. Just as Narcissus did, you can see yourself as you glance into a quiet pool of water or walk past a shop window. Most of the time, however, you probably look for your image in a flat, smooth mirror. A flat, smooth mirror is a **plane mirror**.

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

**Reflections from plane mirrors**  What do you see when you look into a plane mirror? Your reflection is upright. If you were one meter in front of the mirror, your image would appear to be one meter behind the mirror, or two meters from you. You might notice that the reflection of any writing in a plane mirror appears backward.

**Figure 2** shows how you see yourself in a plane mirror. First, light rays from a light source strike you. Every point that is struck by the light rays reflects these rays so they travel outward in all directions. If your friend were looking at you, these reflected light rays coming from you would enter her eyes so she could see you. However, if a mirror is placed between you and your friend, the light rays are reflected from the mirror into your eyes.
Virtual images  You can understand your brain’s interpretation of your reflection in a mirror by looking at Figure 3. The light waves that are reflected off you travel in all directions. Light rays reflected from your chin strike the mirror at different places. Then, they reflect off the mirror in different directions. A few of these light rays reflect off the mirror in just the right way to enter your eyes.

Recall that your brain always interprets light rays as if they have traveled in a straight line. It does not realize that the light rays have been reflected and that they changed direction. Your reflected image appears to be behind the mirror.

An image that your brain perceives even though no light rays pass through the location of that image is a virtual image. The imaginary light rays that appear to come from virtual images are called virtual rays. The dashed line in Figure 3 is a virtual ray. Plane mirrors always form upright, virtual images.

Concave Mirrors

Not all mirrors are flat like plane mirrors. A concave mirror is a mirror whose surface curves inward. Concave mirrors, like plane mirrors, reflect light waves to form images. However, a concave mirror’s curved surface produces different images from a plane mirror’s flat surface.

Features of concave mirrors  A concave mirror has an optical axis. The optical axis is an imaginary straight line drawn perpendicular to the surface of the mirror at the mirror’s center. Concave mirrors are made so that every light ray traveling toward the mirror parallel to the optical axis is reflected through a point on the optical axis called the focal point.

The focal point for a concave mirror is the point on the optical axis on which light rays that are initially parallel to the optical axis converge after they reflect off the mirror. The distance from the center of the mirror to the focal point is the focal length. Using the focal point and the optical axis, you can diagram how some of the light rays that travel to a concave mirror are reflected, as shown in Figure 4.
**Ray tracing for concave mirrors** You can diagram how concave mirrors form images by tracing some of the light rays involved. Suppose that the distance between an object, such as the candle in **Figure 5**, and the mirror is greater than the focal length. Light rays bounce off the candle in all directions. One light ray, labeled Ray A, starts from a point on the flame of the candle and passes through the focal point on its way to the mirror. Ray A is then reflected parallel to the optical axis.

Another ray, Ray B, starts from the same point on the candle's flame, but it travels parallel to the optical axis as it moves toward the mirror. The mirror then reflects Ray B through the focal point. The place where Ray A and Ray B meet after they are reflected is a point on the reflected image of the flame.

More points on the reflected image can be located in this way. From each point on the candle, one ray can be drawn that passes through the focal point and is reflected parallel to the optical axis. Another ray can be drawn that travels parallel to the optical axis and then reflects through the focal point. The point where the two rays meet is on the reflected image.

**Real images** The image that is diagrammed in **Figure 5** is not virtual. Rays of light pass through the location of the image. A **real image** is an image that is formed when light rays converge to form the image. You could hold a sheet of paper at the location of a real image and see the image projected on the paper.

**Figure 5** Ray A first passes through the focal point and then reflects parallel to the optical axis. Ray B is first parallel to the optical axis and then reflects through the focal point. An image of the candle forms where the two rays converge.

**Diagram how other points on the image of the candle are formed.**

---

**Observe Images in a Spoon**

**Procedure**

1. Read the procedure and safety information, and complete the lab form.
2. Look at a **concave mirror**. Move it close to your face and then far away. The place where your image blurs is the focal point.
3. Hold the inside of the mirror facing a **bright light** a little farther away than the focal length of the mirror.
4. Place a piece of **poster board** between the light and the mirror without blocking all of the light.
5. Move the poster board between the mirror and the light until you see the reflected light on the poster board.

**Analysis**

1. **Identify** which of the images that you observed were real and which were virtual.
**Spotlights** What happens when you place an object exactly at the focal point of a concave mirror? **Figure 6** shows that when the object is at the focal point, the mirror reflects all light rays parallel to the optical axis. The rays never meet, and no image forms. Even the virtual rays that extend behind the mirror do not meet. Therefore, a light placed at the focal point is reflected in a beam. Car headlights, flashlights, spotlights, and other devices use concave mirrors in this way to produce light beams with nearly parallel rays.

**Mirrors that magnify** A concave mirror magnifies an object when you place that object between the concave mirror and that mirror’s focal point. **Figure 7** shows that the reflected rays diverge and a virtual image forms.

Just as it does with a plane mirror, your brain interprets the diverging rays as if they came from one point behind the mirror. You can find this point by imagining virtual rays that extend behind the mirror. The resulting image is magnified. Shaving mirrors and makeup mirrors are concave mirrors that are used for magnification. They form enlarged, upright images of a person’s face so that it is easier to see small details.
Convex Mirrors

Why do you think the security mirrors in banks and stores are shaped the way that they are? The next time that you are in a store, look at one of the back corners or at the end of an aisle to see if a large, rounded mirror is mounted there. You can see a large area of the store in the mirror. A **convex mirror** is a mirror that curves outward, like the back of a spoon.

Light rays that hit a convex mirror spread apart after they are reflected. Look at [Figure 8](#) to see how the rays from an object are reflected off a convex mirror to form an image. The reflected rays diverge and never meet, so the image formed by a convex mirror is a virtual image. The image is also always upright and is smaller than the actual object.

**Reading Check** Describe the image formed by a convex mirror.

**Uses of convex mirrors** Because convex mirrors cause light rays to diverge, they allow large areas to be viewed. As a result, a convex mirror is said to have a wide field of view. In addition to increasing the field of view in places like grocery stores and factories, convex mirrors can widen the view of traffic that can be seen in rear-view or side-view mirrors of automobiles.

However, because the image that a convex mirror forms is smaller than the object, your perception of distance can be distorted. Objects look farther away than they truly are in a convex mirror. Distances and sizes seen in a convex mirror are not realistic, so most convex side mirrors on cars carry a printed warning that states “Objects in mirror are closer than they appear.”
Table 1  Images Formed by Mirrors

<table>
<thead>
<tr>
<th>Mirror Shape</th>
<th>Distance of Object from Mirror</th>
<th>Virtual/Real</th>
<th>Image Created Upright/Upside Down</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plane</td>
<td>any distance</td>
<td>virtual</td>
<td>upright</td>
<td>same as object</td>
</tr>
<tr>
<td>Concave</td>
<td>object more than two focal lengths from mirror</td>
<td>real</td>
<td>upside down</td>
<td>smaller than object</td>
</tr>
<tr>
<td></td>
<td>object between one and two focal lengths</td>
<td>real</td>
<td>upside down</td>
<td>larger than object</td>
</tr>
<tr>
<td></td>
<td>object at focal point</td>
<td>none</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>object within focal length</td>
<td>virtual</td>
<td>upright</td>
<td>larger than object</td>
</tr>
<tr>
<td>Convex</td>
<td>any distance</td>
<td>virtual</td>
<td>upright</td>
<td>smaller than object</td>
</tr>
</tbody>
</table>

**Mirror images** The different shapes of plane, concave, and convex mirrors cause them to reflect light in distinct ways. For example, concave mirrors are the only mirrors that magnify images. Convex mirrors always make objects appear to be smaller and farther away than they actually are. Each type of mirror has different uses. Most wall mirrors are plane mirrors. Most makeup and shaving mirrors are concave mirrors. Most store security mirrors are convex mirrors. **Table 1** summarizes the characteristics of plane mirrors, concave mirrors, and convex mirrors.

**Section 1  Review**

**Section Summary**
- You see an object because your eyes detect the light reflected from that object.
- Plane mirrors are smooth and flat.
- No light rays pass through the location of a virtual image.
- A concave mirror curves inward.
- A convex mirror curves outward.

1. **MAIN IDEA** [Diagram] how both concave mirrors and convex mirrors form images.
2. **Identify** at least one example of a plane mirror, one example of a concave mirror, and one example of a convex mirror.
3. **Describe** the image of an object that is 38 cm from a concave mirror that has a focal length of 10 cm.
4. **Infer** whether a virtual image can be photographed.
5. **Think Critically** An object is less than one focal length from a concave mirror. How does the size of the image change as the object gets closer to the mirror?

**Apply Math**

6. **Calculate Distance** If you stand 2 m away from a plane mirror, how far away does your reflection appear to be from you?
Objectives

- Infer how the number of reflections depends on the angle between mirrors.

Background: How can you see the back of your head? If you have ever been to a barbershop or a hair salon, you probably know the answer. You can use two mirrors to view a reflection of a reflection of the back of your head.

Question: How many reflections can you see with two mirrors?

Materials

- plane mirrors (2)
- masking tape
- protractor
- paper clip

Safety Precautions

WARNING: Handle glass mirrors and paper clips carefully.

Procedure

1. Read the procedure and safety information, and complete the lab form.
2. Lay one mirror on top of the other with the mirror surfaces inward. Tape them together so they will open and close. Use tape to label them “L” and “R.”
3. Stand up the mirrors on a sheet of paper. Using the protractor, close the mirrors to an angle of 72°.
4. Bend one leg of a paper clip up 90°, and place it close to the front of the R mirror.
5. Count the number of images of the clip that you see in the L and R mirrors. Record these numbers in a data table.
6. The mirror arrangement creates an image of a circle divided into wedges by the mirrors. Record the number of wedges in your data table.
7. Hold the R mirror still, and slowly open the L mirror to 90°. Count and record the images of the clip and the wedges in the circle. Repeat, this time opening the mirrors to 120°.

Conclude and Apply

1. Infer the relationship between the number of wedges and paper clip images that you can see.
2. Determine the angle that would divide a circle into six wedges. Hypothesize how many images would be produced.
3. Infer how many images would be produced if two mirrors were directly opposite one another, as in a barbershop or a hair salon.

Communicate Your Data

Demonstrate Prepare a short video for middle school students that demonstrates the relationship between the angle of the mirrors and the number of reflections.
Lenses

MAIN Idea Lenses form images by refracting light rays.

Real-World Reading Link Anyone who wears glasses uses lenses to improve their vision. Without lenses, even people who do not wear glasses or contacts could not see. Each human eye contains a pair of lenses to help bring images into focus.

What is a lens?

What do your eyes have in common with cameras and eyeglasses? Each of these things contains at least one lens. A lens is a transparent material with at least one curved surface that causes light rays to bend, or refract, as those rays pass through the lens. The image that a lens forms depends on the shape of the lens. Like curved mirrors, a lens can be convex or concave.

Convex Lenses

A convex lens is a lens that is thicker in the middle than at the edges. Its optical axis is an imaginary straight line that is perpendicular to the surface of the lens at its thickest point. When light rays approach a convex lens traveling parallel to its optical axis, the rays are refracted toward the center of the lens, as shown in Figure 9.

All light rays traveling parallel to the optical axis in Figure 9 are refracted so they pass through a single point, which is the focal point of the lens. The focal length of the lens depends on the shape of the lens. If the sides of a convex lens are less curved, light rays are bent less. As a result, lenses with flatter sides have longer focal lengths. Figure 9 also shows that light rays traveling along the optical axis are not bent at all.
**Forming images with convex lenses** The type of image that a convex lens forms depends on where the object is relative to the focal point of the lens. If an object is more than two focal lengths from the lens, as in the top panel of Figure 10, the image is real, reduced, inverted, and on the opposite side of the lens from the object.

As the object moves closer to the lens, the image gets larger. The middle panel of Figure 10 shows the image formed when the object is between one and two focal lengths from the lens. Now the image is larger than the object but is still inverted.

When an object is less than one focal length from the lens, as shown in the bottom panel of Figure 10, the image becomes an enlarged, virtual image. The image is virtual because the light rays from the object are not converging after they have passed through the lens. When you use a magnifying glass, you move a convex lens so that it is less than one focal length from an object. This causes the image of the object to be magnified.

---

**Figure 10** The image that a convex lens forms depends on the relative positions of the lens and the object.

*Identify the type of mirror that produces images that are similar to the images produced by a convex lens.*
Figure 11 A concave lens causes light rays to diverge.

Classify Does a concave lens behave more like a concave mirror or a convex mirror?

Concave Lenses

A concave lens is a lens that is thinner in the middle and thicker at the edges. As shown in Figure 11, light rays that pass through a concave lens bend outward, away from the optical axis. The rays spread out and never meet at a focal point, so they never form a real image. However, a concave lens can form virtual images. These virtual images are always upright and smaller than the actual object. Notice that concave lenses and convex mirrors both produce the same types of images.

Concave lenses are used in some types of eyeglasses and in some microscopes. Concave lenses are usually placed in combination with other lenses. A summary of the images formed by concave and convex lenses is shown in Table 2.

<table>
<thead>
<tr>
<th>Lens Shape</th>
<th>Location of Object</th>
<th>Virtual/Real</th>
<th>Type of Image Upright/Inverted</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convex</td>
<td>object beyond 2 focal lengths from lens</td>
<td>real</td>
<td>inverted</td>
<td>smaller than object</td>
</tr>
<tr>
<td></td>
<td>object between 1 and 2 focal lengths</td>
<td>real</td>
<td>inverted</td>
<td>larger than object</td>
</tr>
<tr>
<td></td>
<td>object within 1 focal length</td>
<td>virtual</td>
<td>upright</td>
<td>larger than object</td>
</tr>
<tr>
<td>Concave</td>
<td>object at any position</td>
<td>virtual</td>
<td>upright</td>
<td>smaller than object</td>
</tr>
</tbody>
</table>
How do object distance and image distance compare?

The size and orientation of an image formed by a lens depends on the location of the object and on the nature of the lens. Convex lenses form both real images and virtual images. Concave lenses can form only virtual images. What happens to the location of the image formed by a lens as the object moves closer to or farther from the lens? The distance from the lens to the object is the object distance, and the distance from the lens to the image is the image distance. How are the focal length, object distance, and image distance related to each other?

Identify the Problem

A 5-cm-tall object is placed at different lengths from a convex lens with a focal length of 15 cm. The table at the right shows the different object and image distances. How are these two measurements related?

<table>
<thead>
<tr>
<th>Focal Length (cm)</th>
<th>Object Distance (cm)</th>
<th>Image Distance (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.0</td>
<td>45.0</td>
<td>22.5</td>
</tr>
<tr>
<td>15.0</td>
<td>30.0</td>
<td>30.0</td>
</tr>
<tr>
<td>15.0</td>
<td>20.0</td>
<td>60.0</td>
</tr>
</tbody>
</table>

Solve the Problem

1. Describe the relationship between the object distance and the image distance.

2. The lens equation describes the relationship between the focal length and the image and object distances.

\[
\frac{1}{\text{focal length}} = \frac{1}{\text{object distance}} + \frac{1}{\text{image distance}}
\]

Using this equation, calculate the image distance when the object is placed at a distance of 60.0 cm from the lens.

Eyesight and Lenses

What determines how well you can see the words on this page? If you do not need eyeglasses, the structure of your eye gives you the ability to focus on these words and on other objects around you. Look at Figure 12. Light enters your eye through a transparent covering on your eyeball called the cornea (KOR nee uh). The cornea causes light rays to bend so that they converge.

Reading Check Describe the function of the cornea.

After passing through the cornea, the light then passes through an opening called the pupil. Behind the pupil is a flexible, convex lens, called the eye lens. The eye lens helps focus light rays so that a sharp image is formed on your retina. Your retina is the inner lining of your eye, which has cells that convert the light image into electrical signals. These electric signals are then carried along the optic nerve to your brain where they can be interpreted.

Reading Check Describe the function of the retina.
Focusing on near and far  How can your eyes focus both on close objects, such as the watch on your wrist, and distant objects, such as a clock across the room? For you to see an object clearly, its image must be focused sharply on your retina. However, the retina is always a fixed distance from the lens. Remember that the location of an image formed by a convex lens depends on the focal length of the lens and the location of the object.

For an image to be formed on the retina, the focal length of the lens needs to be able to change as the distance to the object changes. The lens in your eye is flexible, and muscles attached to it change its shape and its focal length. This is why you can see objects that are near and far away.

Look at Figure 13. When you focus on an object far from your eye, the muscles around the lens relax. This pulls the lens into a less convex shape. When you focus on a nearby object, these muscles make the lens more curved, causing the focal length to decrease.

Reading Check  Describe how the shape of the lens in your eye changes when you focus on a nearby object.

- **Figure 13** The eye lens changes shape so that you can focus on objects at different distances.

Infer why you are more likely to get eyestrain by looking at a nearby object than by looking at a faraway object.
**Vision Problems**  People with good vision can see objects clearly that are about 25 cm or farther away from their eyes. However, people with the most common vision problems see objects clearly only at some distances, or they see all objects as being blurry.

**Astigmatism**  One vision problem, called astigmatism, occurs when the surface of the cornea is unevenly curved. When people have astigmatism, their corneas are more oval than round in shape. Astigmatism causes blurry vision at all distances. Corrective lenses for astigmatism also have an uneven curvature, canceling out the effect of an uneven cornea.

**Farsightedness**  Another vision problem is farsightedness. A farsighted person can see distant objects clearly, but cannot bring nearby objects into focus. Light rays from nearby objects do not converge enough after passing through the cornea and the lens to form a sharp image on the retina, as shown in Figure 14. The problem can be corrected with a convex lens that bends light rays so they are less spread out before they enter the eye, also shown in Figure 14.

Farsightedness is often related to age. As many people age, the lenses in their eyes become less flexible. The muscles around the lenses still contract as they try to change the shape of the lens. However, the lenses have become more rigid and cannot be made curved enough to focus on close objects. People who are more than 40 years old might not be able to focus on objects closer than 1 m from their eyes.
**Nearsightedness** A person who is nearsighted can see objects clearly only when those objects are nearby. Objects that are far away appear blurred. In a nearsighted eye, the cornea and the lens form a sharp image of a distant object before the light reaches the retina, as shown in Figure 15.

To correct this problem, a nearsighted person can wear concave lenses. Figure 15 shows how a concave lens causes incoming light rays to diverge before they enter the eye. Then the light rays from distant objects can be focused by the eye to form a sharp image on the retina and not in front of it.

**Figure 15** People use concave lenses to correct nearsightedness.
Optical Instruments

MAIN Idea Lenses and mirrors are used to make objects easier to see.

Real-World Reading Link With a good digital camera, you can zoom in on distant objects, bring them into focus, and record images to view later. Optical instruments, such as cameras, telescopes, and microscopes allow us to see things that we could not see without them.

Telescopes

You know from your experience that it is difficult to see far-away objects clearly. When you look at an object, only some of the light reflected from its surface enters your eyes. As you move farther away from the object, the amount of light entering your eyes decreases, as shown in Figure 16. As a result, the object appears dimmer and less detailed.

A telescope uses a lens or a concave mirror that is much larger than your eye to gather more of the light from distant objects. The largest telescopes can gather more than a million times more light than the human eye. As a result, objects such as distant galaxies appear much brighter. Because the image formed by a telescope is so much brighter, more detail can be seen when the image is magnified.
Refracting telescopes  One common type of telescope is the refracting telescope. A telescope that uses lenses to gather light from distant objects is called a refracting telescope. A simple refracting telescope, shown in Figure 17, uses two convex lenses to gather and focus light from distant objects.

Incoming light from distant objects passes through the first lens, called the objective lens. Light rays from distant objects are nearly parallel to the optical axis of the lens. As a result, the objective lens forms a real image at the focal point of the lens, within the body of the telescope.

The second convex lens, called the eyepiece lens, magnifies this real image. When you look through the eyepiece lens, you see an enlarged, inverted, virtual image of the real image formed by the objective lens.

In order to form detailed images of distant objects, the objective lens of a refracting telescope must be as large as possible. A telescope lens can be supported only around its edge. A large lens can sag or flex due to its own weight, distorting the image that it forms. Another class of telescopes, called reflecting telescopes, do not have this problem.

Reflecting telescopes  A telescope that uses mirrors and lenses to collect and focus light from distant objects is a reflecting telescope. Mirrors, unlike lenses, can be supported from behind. This additional support for mirrors prevents mirrors from sagging inside reflecting telescopes. As a result, reflecting telescopes can be much larger than refracting telescopes. Figure 18 shows a reflecting telescope.

For this reflecting telescope, light from a distant object enters one end of the telescope and strikes a concave mirror at the opposite end. The light reflects off this mirror and converges. Before it converges at a focal point, the light hits a plane mirror inside the telescope tube. The light is then reflected from the plane mirror toward the telescope's eyepiece. The light rays converge at the focal point, creating a real image of the distant object. Just like a refracting telescope, a convex lens in the eyepiece then magnifies this image.
**Space telescopes** Imagine being at the bottom of a swimming pool and trying to read a sign by the pool’s edge. The motion of the water in the pool would distort your view of any object beyond the water’s surface. In a similar way, Earth’s atmosphere distorts the view of objects in space.

To overcome the blurriness of humans’ view into space, the National Aeronautics and Space Administration (NASA) built a telescope called the *Hubble Space Telescope* and launched it into space, high above Earth’s atmosphere. Because *Hubble* is above Earth’s atmosphere, it has produced incredibly sharp and detailed images. Figure 19 shows the difference in the images produced by telescopes on Earth and the *Hubble* telescope.

With the *Hubble Space Telescope*, scientists can detect light from planets, stars, and galaxies that would otherwise be scattered by Earth’s atmosphere. *Hubble* is not the only space telescope. Other space telescopes, such as the *Chandra X-Ray Observatory* and the *Spitzer Space Telescope*, help scientists study the universe through X-ray and infrared radiation.

**Reading Check** Explain why a space telescope is able to produce clearer images than telescopes on Earth.

The *Hubble* telescope is a type of reflecting telescope that uses two mirrors to collect and focus light to form an image. The primary mirror in the telescope is 2.4 m across. A next-generation space telescope, called the *James Webb Space Telescope*, is due to be launched in 2014. The primary mirror on the *James Webb Space Telescope* will be 6.5 m across.
Microscopes

A telescope would be useless if you were trying to study the cells in a butterfly wing, a sample of pond scum, or the differences between a human hair and a horse hair. You would need a microscope to look at such small objects.

A **microscope** is a device that uses two convex lenses with relatively short focal lengths to magnify small, close objects. A microscope, like a telescope, has an objective lens and an eyepiece lens. However, it is designed differently because the objects viewed are close to the objective lens.

**Figure 20** shows a simple microscope. The object to be viewed is placed on a transparent slide and is illuminated from below. The light passes by or through the object on the slide and then travels through the objective lens. The objective lens is a convex lens.

It forms a real, enlarged image of the object because the distance from the object to the lens is between one and two focal lengths. The real image is then magnified again by the eyepiece lens (another convex lens) to create a virtual, enlarged image. This final image can be hundreds of times larger than the actual object, depending on the focal lengths of the two lenses. The total magnification is the magnification of the objective times the magnification of the eyepiece.

---

**Experiment with Focal Lengths**

**Procedure**

1. Read the procedure and safety information, and complete the lab form.
2. Fill a **glass test tube** with **water**, and seal it with a **lid** or a **stopper**.
3. Type or print the compound name **SULFUR DIOXIDE** in **capital letters** on a **piece of paper** or a **note card**.
4. Set the test tube horizontally over the words, and observe them. What do you notice?
5. Hold the tube 1 cm over the words, and observe them again. Record your observations. Repeat, holding the tube at several other heights above the words.

**Analysis**

1. **Describe** your observations of the words at the different distances.
2. **Identify** whether the image that you see at each height is real or virtual.

---

■ **Figure 20** A microscope uses two convex lenses to magnify small objects. The lens closest to the object that is being studied is called the objective lens. In a microscope, unlike in a refracting telescope, more than one lens magnifies the object. Explain why this microscope’s light source is placed below the bug instead of above the bug.
Cameras

With the click of a button, you can capture a beautiful scene in a photo. How does a digital camera make a reduced image of a life-sized scene? Figure 21 shows the path that light follows as it enters a camera from a distant object. The light rays from distant objects are almost parallel to each other. When you take a picture with a camera, a shutter opens to allow light to enter the camera for a specific length of time.

The light reflected off the object enters the camera through an opening called the aperture. The camera lens focuses the image onto an image sensor, which converts light into electric signals. A computer then processes these signals into an image that can be displayed on a screen or printed.

Section 3 • Optical Instruments

Figure 21 A camera’s lens focuses an image onto the image sensor. An image sensor converts the light from an image into a set of electric signals.

Compare a digital camera with the human eye.

Section 3 • Review

Section Summary

- Refracting telescopes use two convex lenses to gather and focus light.
- Reflecting telescopes use a concave mirror, a plane mirror, and a convex lens to collect, reflect, and focus light.
- Placing a telescope in orbit avoids the distorting effects of Earth’s atmosphere.
- A microscope uses two convex lenses with short focal lengths to magnify small, close objects.
- A camera lens focuses light onto an image sensor.

13. **MAIN IDEA** Identify the advantage to making the objective lens larger in a refracting telescope.

14. **Describe** the image formed by the objective lens in a microscope.

15. **Explain** why the largest telescopes are reflecting telescopes instead of refracting telescopes.

16. **Think Critically** Which optical instrument—a telescope, a microscope, or a camera—forms images in a way most like your eye? Explain.

Apply Math

17. **Calculate Magnification** Suppose the objective lens in a microscope forms an image that is 100 times the size of an object. The eyepiece lens magnifies this image 10 times. What is the total magnification?

Section 3 • Optical Instruments 419
Objectives
- Research three observatories.
- Calculate the area of the primary mirror or lens of each telescope.
- Draw schematic diagrams of each telescope.

Background: The largest telescopes today are much more than the small telescope that you or a friend might set up in a backyard or a field. The largest telescopes are housed in their own buildings or in space beyond Earth’s atmosphere. Some detect visible light, but others detect other forms of electromagnetic radiation that is invisible to the human eye.

Question: How do the largest telescopes in operation today work?

Preparation

Data Sources
The following sites might provide useful information for this lab.
- chandra.harvard.edu
- gemini.edu
- hubblesite.org
- jwst.nasa.gov
- keckobservatory.org
- naic.edu
- vla.nrao.edu

Make a Plan
1. Read the procedure and safety information, and complete the lab form.
2. Gather information on at least seven different telescopes, and select three telescopes to investigate further.
3. Outline how you will find out more about the design and operation of each of these three telescopes.
4. Determine how you will find the area of the primary mirror or lens for each of the three telescopes that you are researching.
5. Summarize the information that you will need to locate in order to make schematic diagrams of your telescopes.

Follow Your Plan
1. Make sure that your teacher approves your plan before you begin.
2. Research the design and operation of each of the three telescopes that you selected.
3. Calculate the area of the primary mirror or lens for each of the three telescopes that you selected.
4. Create schematic diagrams of each of the three telescopes that you selected.
Chapter 13 • Lab 421

Analyze Your Data

1. Identify Of the telescopes that you investigated, how many were refracting telescopes? How many were reflecting telescopes? Explain this result.

2. Analyze Of the telescopes that you investigated, did any detect electromagnetic radiation other than visible light? How did this affect the design of these telescopes?

3. Identify Of the telescopes that you investigated, how many were space telescopes?

4. Describe What kinds of elements in Earth-based telescopes can help eliminate the negative effects of Earth's atmosphere on the images that these telescopes collect?

Conclude and Apply

1. Infer Of the telescopes that you investigated, which do you believe is most active in astronomical research? Defend your answer.

2. Infer How does the limited ability to make repairs and adjustments in space affect the design of space telescopes?

3. Explain why the area of a reflecting telescope's primary mirror is a more direct measurement of that telescope's light-gathering power than the diameter of that mirror.

Communicate Your Data

Design In a small group, design a telescope to fill a need in astronomical research. Include a location for your telescope.
The Next Telescopes

Light from distant stars and galaxies reaches Earth day and night. Telescopes capture this light, helping astronomers study the universe. The next generation of telescopes might be able to detect Earth-like planets and uncover secrets of the ancient universe. Three teams are racing to build the world’s next giant telescope.

**Light buckets** Telescopes are light buckets, and telescope builders want to catch as much light in their buckets as possible. The larger the telescope’s mirror, the more light that the telescope catches. The more light captured, the fainter the objects that the telescope can detect.

Instead of collecting light from a single, continuous mirror, the next generation of telescopes will have mirrors made from many segments, as shown in **Figure 1**. A segmented mirror is more stable than a continuous mirror. As a result, a telescope with a segmented mirror can be much larger than a telescope with a continuous mirror.

**Figure 1** The next generation of giant telescopes will use carefully fitted, segmented mirrors rather than a single, continuous mirror to reflect ancient light.

**Possible new telescopes** The largest optical telescope in operation today is the Gran Telescopio Canaria. The primary mirror for this telescope has an area of 85 m². The smallest candidate for the world’s next great telescope is the Giant Magellan Telescope (GMT), which would have a segmented mirror with a total area of 470 m². **Table 1** summarizes the properties of the GMT as well as other possible future telescopes.

**Table 1** Potential New Telescopes

<table>
<thead>
<tr>
<th>Telescope</th>
<th>Area of Primary Mirror (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gran Telescopio Canaria</td>
<td>85 (This is about the area of six parking lot spaces.)</td>
</tr>
<tr>
<td>Giant Magellan Telescope</td>
<td>470 (This is about the area of a basketball court.)</td>
</tr>
<tr>
<td>Thirty Meter Telescope</td>
<td>700 (This is about the area of a baseball infield.)</td>
</tr>
<tr>
<td>European Extremely Large Telescope</td>
<td>1,400 (This is about the area of five tennis courts.)</td>
</tr>
</tbody>
</table>

**Race to first light** The first of the new telescopes to peer into the sky will open a new universe of discovery. The race is not so much to be the biggest but to be first. Even the smallest of these new telescopes would be large enough to be the first to spot planets circling nearby stars, as well as spot the oldest and most distant objects ever seen.

**WebQuest** **Writing** Draft a persuasive letter to a perspective donor, describing why your giant telescope deserves the several hundred million dollars in funding needed for construction and operation.
**Chapter 13 Study Guide**

**THEME FOCUS Technology**

Mirrors and lenses are integral parts of telescopes, microscopes, cameras, and other devices. These devices enable us to study and record the natural world beyond the ability of the unaided eye.

**BIG Idea** Mirrors and lenses form images by causing light rays to change direction.

### Section 1 Mirrors
- concave mirror (p. 402)
- convex mirror (p. 405)
- focal length (p. 402)
- focal point (p. 402)
- optical axis (p. 402)
- plane mirror (p. 401)
- real image (p. 403)
- virtual image (p. 402)

**MAIN Idea** Mirrors form images by reflecting light rays.
- You see an object because your eyes detect the light reflected from that object.
- Plane mirrors are smooth and flat.
- No light rays pass through the location of a virtual image.
- A concave mirror curves inward.
- A convex mirror curves outward.

### Section 2 Lenses
- concave lens (p. 410)
- convex lens (p. 408)
- cornea (p. 411)
- retina (p. 411)

**MAIN Idea** Lenses form images by refracting light rays.
- A convex lens is thicker in the middle than at the edges. Light rays are refracted toward the optical axis.
- The image formed by a convex lens depends on the distance of the object from the lens.
- A concave lens is thinner in the middle and thicker at the edges. Light rays are refracted away from the optical axis.
- The cornea and the lens focus light onto the retina.

### Section 3 Optical Instruments
- microscope (p. 418)
- reflecting telescope (p. 416)
- refracting telescope (p. 416)

**MAIN Idea** Lenses and mirrors are used to make objects easier to see.
- Refracting telescopes use two convex lenses to gather and focus light.
- Reflecting telescopes use a concave mirror, a plane mirror, and a convex lens to collect, reflect, and focus light.
- Placing a telescope in orbit avoids the distorting effects of Earth's atmosphere.
- A microscope uses two convex lenses with short focal lengths to magnify small, close objects.
- A camera lens focuses light onto an image sensor.

---

**Vocabulary eGames**

---

Chapter 13 • Study Guide 423
Use Vocabulary

Complete each sentence with the correct term from the Study Guide.

18. A flat, smooth surface that reflects light and forms an image is a(n) _________.

19. A(n) _________ uses two convex lenses to magnify small, close objects.

20. Every light ray that travels parallel to the optical axis before hitting a concave mirror is reflected such that it passes through the _________.

21. A(n) _________ is thicker in the middle than at the edges.

22. The inner lining of the eye that converts light images into electric signals is called the _________.

Check Concepts

23. Which best describes image formation by a plane mirror?
   A) A real image is formed in front of the mirror.
   B) A real image is formed behind the mirror.
   C) A virtual image is formed in front of the mirror.
   D) A virtual image is formed behind the mirror.

24. Which can form an enlarged image?
   A) convex mirror    C) convex lens
   B) plane mirror     D) concave lens

25. Which is NOT part of a reflecting telescope?
   A) plane mirror     C) convex lens
   B) concave mirror   D) concave lens

26. Which is being used in the figure above?
   A) concave lens    C) concave mirror
   B) convex lens     D) convex mirror

27. What do lenses do?
   A) reflect light    C) diffract light
   B) refract light   D) interfere with light

Use the figure below to answer question 28.

28. **BIG IDEA** Which way does the lens shown bend light that is parallel to the optical axis?
   A) toward its optical axis
   B) toward its focal point
   C) away from its optical axis
   D) away from its edges

29. What type of lens is used to correct farsightedness?
   A) flat lens
   B) convex lens
   C) concave lens
   D) plane lens
**Interpret Graphics**

Use the figure below to answer question 30.

![Diagram of focal lengths and image formation](image)

30. Suppose the image of the candle moves away from the focal point. How did the position of the candle change?

31. Copy and complete the following table about image formation by lenses and mirrors.

<table>
<thead>
<tr>
<th>Type of Lens or Mirror</th>
<th>Position of Object</th>
<th>Type of Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave lens</td>
<td>all positions of object</td>
<td>virtual, upright, reduced</td>
</tr>
<tr>
<td>Convex lens</td>
<td>closer than one focal length</td>
<td>a.</td>
</tr>
<tr>
<td></td>
<td>between one and two focal lengths</td>
<td>b.</td>
</tr>
<tr>
<td></td>
<td>farther than two focal lengths</td>
<td>real, inverted, reduced</td>
</tr>
<tr>
<td>Concave mirror</td>
<td>closer than one focal length</td>
<td>c.</td>
</tr>
<tr>
<td></td>
<td>object placed at focal point</td>
<td>d.</td>
</tr>
<tr>
<td></td>
<td>farther than two focal lengths</td>
<td>e.</td>
</tr>
<tr>
<td>Convex mirror</td>
<td>all positions of object</td>
<td>f.</td>
</tr>
</tbody>
</table>

**Think Critically**

32. Infer Could a person who is nearsighted use his or her glasses to focus light and start a fire?

33. **THEME FOCUS** Compare and contrast a refracting telescope and a microscope.

34. Infer why a convex mirror and a concave lens can never produce a real image.

35. Explain The top half of a bifocal lens helps a person to focus on distant objects. The bottom half of a bifocal lens helps a person to focus on nearby objects. Why might a person need glasses with bifocal lenses?

36. Infer why it would be easier to make a concave mirror for a reflecting telescope than an objective lens of the same size for a refracting telescope.

37. Compare A concave lens made of plastic is placed in a liquid. Light rays traveling in the liquid are not refracted when they pass through the lens. Compare the speed of light in the plastic and in the liquid.

**Apply Math**

38. **Calculate Magnification** The magnification of a refracting telescope can be calculated by dividing the focal length of the objective lens by the focal length of the eyepiece lens. If an objective lens has a focal length of 1 m and the eyepiece has a focal length of 1 cm, what is the magnification of the telescope?

39. **Infer Object Distance** You hold an object in front of a concave mirror with a 30-cm focal length. You don't see a reflected image. How far from the mirror is the object?
Standardized Test Practice

Multiple Choice

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

1. How far is an object from a concave mirror if the image formed is upright?
   A. one focal length
   B. less than one focal length
   C. more than two focal lengths
   D. two focal lengths

Use the figure below to answer questions 2 and 3.

2. Which describes a light ray that passes through the focal point and then is reflected by the mirror?
   A. It travels parallel to the optical axis.
   B. It forms a real image.
   C. It is reflected back through the focal point.
   D. It forms a virtual image.

3. If the mirror becomes flatter and the focal point moves farther from the mirror, which best describes the reflection of the parallel rays shown in the figure?
   A. They pass through the old focal point.
   B. They do not pass through either the old or the new focal point.
   C. They pass through the new focal point.
   D. They reverse direction.

4. Which describes the image formed by a convex mirror?
   A. real    C. inverted
   B. enlarged D. virtual

5. What is an advantage to increasing the diameter of the concave mirror in a reflecting telescope?
   A. The mirror forms brighter images.
   B. The mirror forms larger images.
   C. The mirror forms more magnified images.
   D. The focal length increases.

Use the table below to answer questions 6–8.

<table>
<thead>
<tr>
<th>Object Distance (cm)</th>
<th>Image Distance (cm)</th>
<th>Magnification</th>
</tr>
</thead>
<tbody>
<tr>
<td>250.0</td>
<td>62.5</td>
<td>0.25</td>
</tr>
<tr>
<td>200.0</td>
<td>66.7</td>
<td>0.33</td>
</tr>
<tr>
<td>150.0</td>
<td>75.0</td>
<td>0.50</td>
</tr>
<tr>
<td>100.0</td>
<td>100.0</td>
<td>1.00</td>
</tr>
<tr>
<td>75.0</td>
<td>150.0</td>
<td>2.00</td>
</tr>
</tbody>
</table>

6. How does the image change as the object gets closer to the lens?
   A. It gets larger.
   B. It gets smaller.
   C. It gets closer.
   D. It becomes real.

7. Which is the best estimate of the magnification if the object is 225 cm from the lens?
   A. 0.20
   B. 0.30
   C. 64
   D. 68

8. What should the object distance be if the lens is to be used as a magnifying glass?
   A. 150 cm
   B. 100 cm
   C. greater than 250 cm
   D. less than 100 cm
9. Describe how you could determine whether the image formed by a lens or a mirror is a real image or a virtual image.

10. The objective lens in a microscope has a magnification of 30. What is the magnification of the microscope if the eyepiece lens has a magnification of 20?

11. Describe how the focal length of a convex lens changes as the lens becomes more curved.

Use the figure below to answer questions 12 and 13.

12. Determine how far the image is from the lens when the object is 15 cm from the lens.

13. At what object distance are the image distance and the object distance equal?

14. Describe the vision problem shown in the figure. Why does this vision problem become more serious as people age?

15. Explain how the vision problem shown in the figure can be corrected.

16. Predict whether a camera that uses a concave lens to focus light onto the image sensor would work.

17. Describe the change in the lenses in your eyes when you look at this book and then look out the window at a distant object.

18. Explain why objects become dimmer and less detailed as they move farther away.