Chapter 6

Lenses refract light to form images.

Most of you have probably heard about starting a fire with a magnifying glass like the boy in this photograph is doing. Imagine, however, that you are on a camping trip in the early spring. Someone forgot to bring matches and you have nothing to use to start a fire. You probably did not bring a magnifying glass. However, there is some clear ice at the edge of the lake. Could you start a fire with a piece of ice? You could if you understood how lenses are shaped and how to use them. If you knew how to shape the ice into a lens, you could use it to focus the Sun's rays onto some dry grass and start a fire. In this chapter, you will learn about lenses and how they focus light. You will also explore the role of lenses in human vision and optical technologies.

What You Will Learn

In this chapter, you will
- **classify** concave and convex lenses
- **explain** how refraction of light by lenses can affect images of objects
- **explain** how optical devices magnify objects
- **explain** how human vision works
- **investigate** ways to correct and enhance human vision

Why It Is Important

Nearly every day, you use something that contains a lens or lenses. You might wear corrective lenses or use a camera to take pictures. Understanding refraction and lenses will help you understand how cameras, telescopes, and microscopes work. When you understand how an instrument works, you can make better use of it.

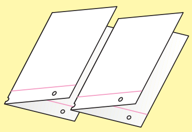
Skills You Will Use

In this chapter, you will
- **predict** the direction of refracted rays of light
- **draw** ray diagrams for concave and convex lenses
- **design** and **build** a simple telescope or microscope

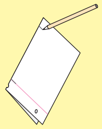
FOLDABLES™
Reading & Study Skills

Make the following Foldable to take notes on what you will learn in Chapter 6.

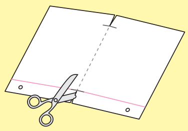
STEP 1 **Fold** two sheets of notebook paper in half along the short axis.



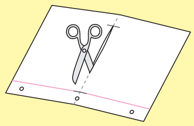
STEP 2 **Mark** both folds 2.5 cm from the outer edges. (On notebook paper, the margins are marked 2.5 cm from the outer edges.)



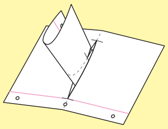
STEP 3 On one of the folded sheets, **cut** from the top and bottom edge to the marked spot on both sides.



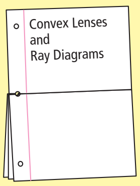
STEP 4 On the second folded sheet, start at one of the marked spots and **cut** the fold between the marks.



STEP 5 **Roll** the first sheet of paper into a long tube, place it through the large opening cut in the second sheet, and **open** the tube so that the folds of the first and second sheet align.



STEP 6 **Fold** the connected sheets in half along the original fold line to form an 8 page book. At the top of each full page, write one of the following.
Convex Lenses and Ray Diagrams
Concave Lenses and Ray Diagrams
Lenses and Human Vision
Modern Optical Technologies



Read and Write As you read this chapter, fill your journal with notes and diagrams on the appropriate page.

6.1 Concave and Convex Lenses

A lens is piece of transparent material that can bend, or refract, light rays to help form a well-focussed image. Lenses have two focal points, one on each side of the lens. Convex lenses are thicker in the middle than at the edge and they cause light rays to converge, or move toward each other. Convex lenses are often used as magnifying glasses because the image of an object that is within twice the focal length from the lens will be larger than the object. Concave lenses are thinner in the middle than at the edge and they cause light rays to spread out, or diverge. Images produced by concave lenses are always smaller than their objects.

Key Terms

concave lens
convex lens
focal length
lens
optical centre

A **lens** is a curved piece of transparent material, such as glass or plastic, that refracts light in a predictable way. Lenses come in a wide variety of sizes and shapes and are made of different types of materials. For example, in Figure 6.1, you see a camera with a very large lens and another camera with a very small lens. These lenses are made of glass. The last picture in the figure is of someone inserting a contact lens. This lens is made of a soft plastic. Regardless of the type of material or the size of the lens, they all work on the same basic principle—the refraction of light.

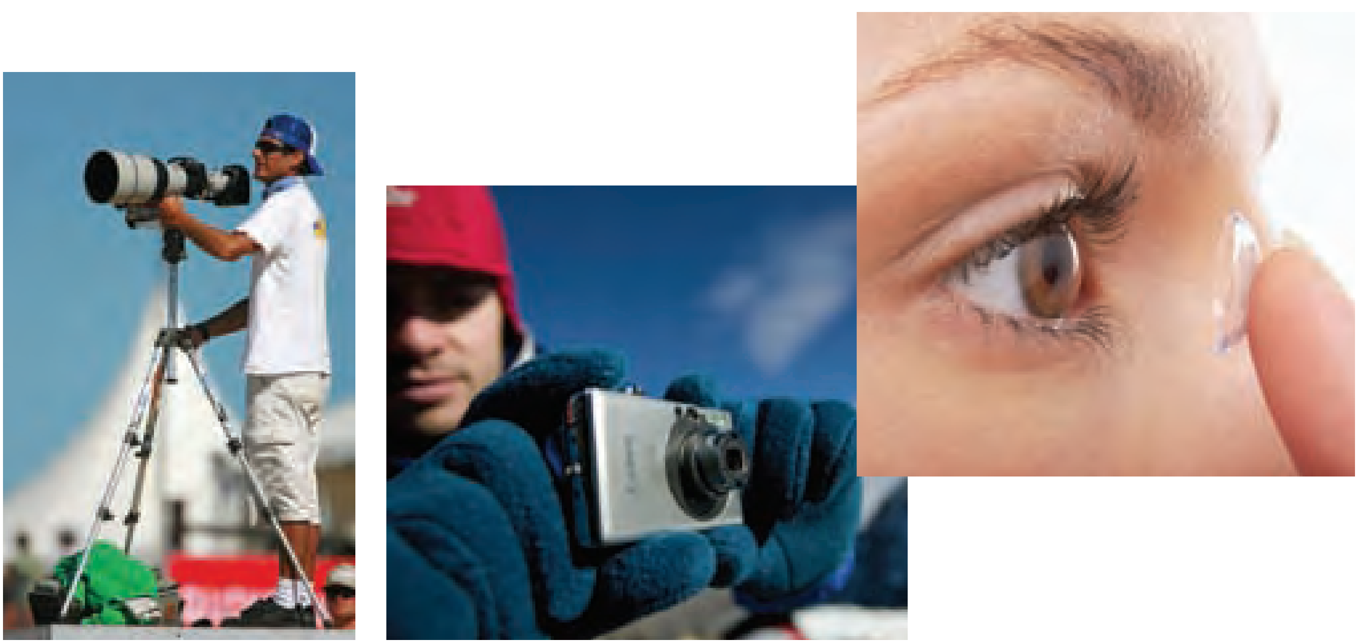


Figure 6.1 Cameras come with many sizes and types of lenses. Some lenses are for distant objects and some are for close up objects. A large lens collects more light so the photographer can take pictures without extra lighting. Contact lenses correct a person's vision.

6-1A Lenses and Light Rays

Find Out ACTIVITY

When a light ray passes through a lens, it refracts twice—once when the ray passes into the lens and once when the ray passes out of the lens. What is the overall effect of a light ray passing through a lens?

Materials

- ray box
- concave lens
- printed page
- convex lens

What to Do

1. Shine the ray box at a concave lens. Observe how the rays are affected. Make a sketch of your observations.
2. Look through the concave lens at some printed text. Observe the appearance of the print. Make a sketch of your observations.
3. Shine the ray box at a convex lens. Observe how the rays are affected. Make a sketch of your observations.
4. Look through the convex lens at some printed text. Observe the appearance of the print. Make a sketch of your observations.

What Did You Find Out?

1. Compare what you observed about the appearance of the text with each of the two lenses.
2. Which type of lens would be best used as a magnifying glass? Explain why.
3. What might the other kind of lens be used for?

Refraction of Light Through Lenses

You know that light bends when it passes from one medium to another. What happens when a light ray passes into a medium such as glass or plastic and then passes out of that medium on the opposite side? This is what happens when you are looking at an object through a lens (Figure 6.2).

The curved surfaces on lenses are named in the same way as curved surfaces on mirrors. When the centre of the lens bulges out, it is called convex. When the centre of the lens is caved in, it is called concave.

Figure 6.2 A curved lens changes the appearance of objects on the other side.

A **convex lens** causes light rays to bend toward each other, or converge (Figure 6.3). A **concave lens** causes light rays to bend away from each other, or diverge (Figure 6.4). To understand why this happens, remember what you learned about refraction in Chapter 5. As light rays travel from a less dense medium, such as air, into a more dense medium, such as glass or plastic, they bend toward the normal. As the rays exit the other side of the lens, travelling from a more dense to a less dense medium, they bend away from the normal.

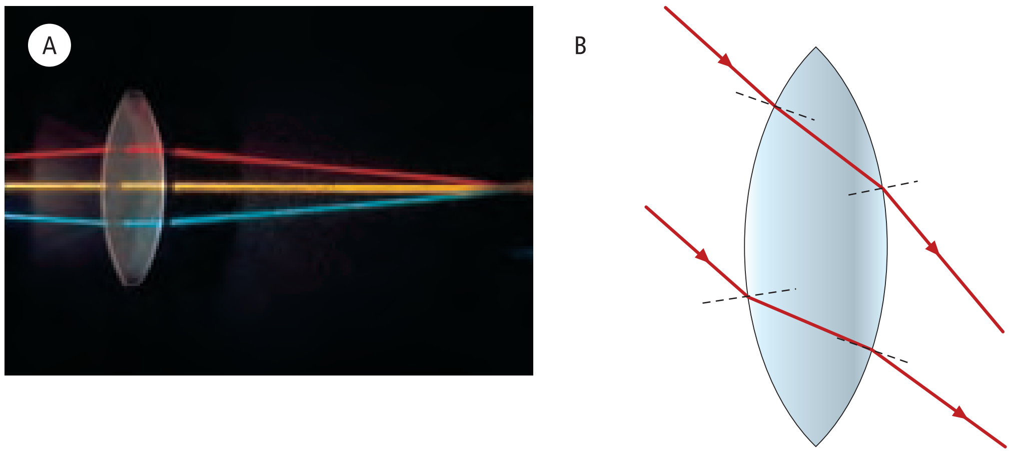


Figure 6.3 (A) Light rays converge when they pass through a convex lens. (B) Rays bend toward the normal (shown by dotted lines) as they enter the lens, and away from the normal as they exit the lens.

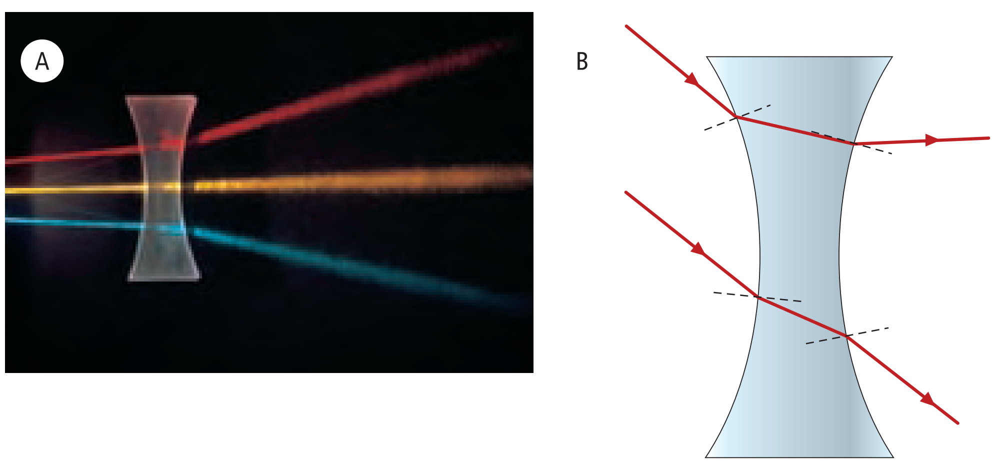


Figure 6.4 (A) Light rays diverge when they pass through a concave lens. (B) Rays bend toward the normal (shown by dotted lines) as they enter the lens, and away from the normal as they exit the lens.

Reading Check

1. Sketch a convex lens and a concave lens.
2. Explain why two parallel rays bend at different angles when they pass from air into a concave lens.
3. What type of lens can make parallel rays spread apart?

Convex Lenses

If you completed Find Out Activity 6-1A, you probably discovered that convex lenses can act as magnifying lenses. They are often found in magnifying glasses such as the one in Figure 6.5. You will be able to demonstrate how convex lenses can magnify an object when you learn to draw ray diagrams for convex lenses.

Many of the terms that you learned while studying mirrors are also applied to lenses. Convex lenses have a focal point where light rays meet after passing through the lens. The **focal length** of the lens is the distance from the centre of the lens to the focal point (Figure 6.6).

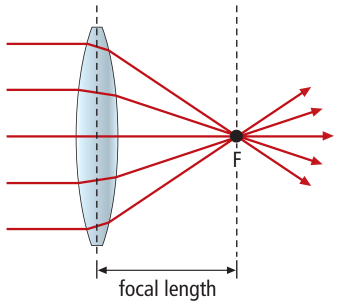


Figure 6.6 The focal point (F) of a convex lens is the point at which parallel rays meet after passing through the lens. The distance between the centre of the lens and the focal point is called the focal length.

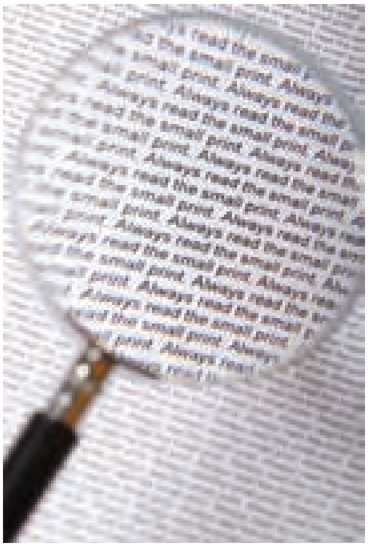


Figure 6.5 The lenses in magnifying glasses are convex lenses.

Each lens has its own focal length, which is determined by the curvature of the lens. As shown in Figure 6.6, lenses with greater curvature have shorter focal lengths. Recall from Chapter 4 that, centuries ago, Anton van Leeuwenhoek experimented with lens curvature. What did he discover about the relationship between lens curvature and magnifying power?

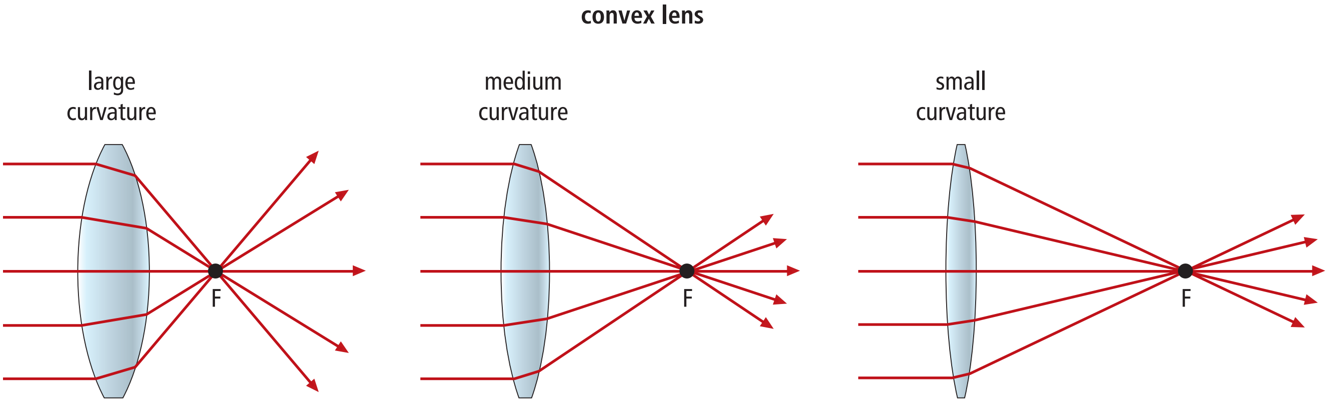


Figure 6.7 The amount of curvature on a convex lens determines how much the lens bends the light passing through it. This also determines the focal length of the lens.

Unlike mirrors, you can shine light on either side of a lens. As a result, a lens has a focal point on both sides. When you draw ray diagrams for lenses, you will put a focal point on each side of the lens as shown in Figure 6.8. Note that the line through the centre of the lens is called the principal axis. The point where the principal axis intersects the centre of the lens is known as the **optical centre** (O).

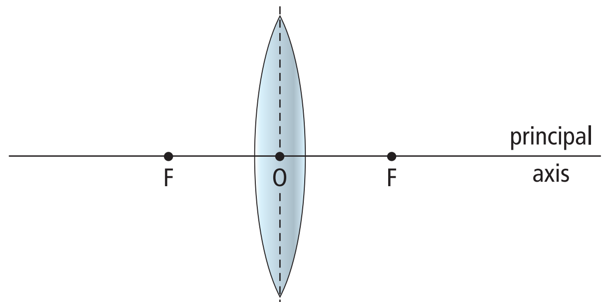


Figure 6.8 All lenses have two focal points—one on each side of the lens. They are always the same distance from the lens.

6-1B The Focal Length of a Convex Lens

Find Out ACTIVITY

You can use the Sun to find the focal length of a convex lens.

Materials

- convex lens
- ruler
- masking tape
- stiff white paper

What to Do

1. Tape the lens near the end of a ruler as shown.

2. Go to a window where there is direct sunlight. Hold the lens and ruler up so the sunlight is coming directly through the lens. **Caution: Do not look directly at the Sun through the lens.**
3. Hold the piece of stiff white paper behind the lens and move it back and forth along the ruler until you get the smallest possible point of sunlight on the paper.
4. Observe and record the distance between the lens and the paper.

What Did You Find Out?

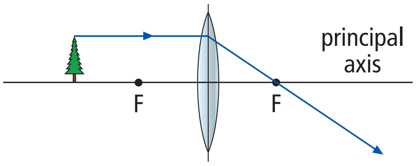
1. What was the distance between the lens and paper when the spot of sunlight was as small as possible?
2. How do you know that the distance that you measured is the focal length of the lens?
3. If you turned the lens around, would your results be the same or different? Why?

Drawing Ray Diagrams for Convex Lenses

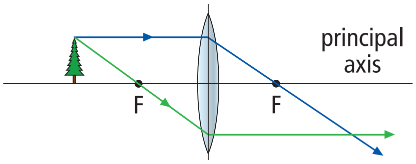
You might think that, when drawing a ray diagram for lenses, you would have to draw refracted rays for each surface of the lens. However, this is not necessary. If you examine the incident and final refracted rays, the process can be simplified. You draw diagrams for lenses as though rays refract only at the centre of the lens rather than at both surfaces.

To draw ray diagrams for lenses, you follow the same basic steps that you followed for curved mirrors. If you place the bottom of the object on the principal axis, the bottom of the image will sit on the principal axis. Drawing three rays from the top of the object will allow you to predict the location of the top of the image:

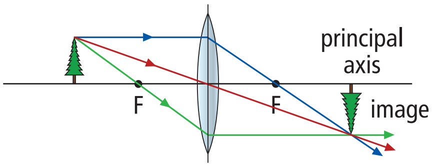
1. Draw a ray parallel to the principal axis. It will refract, passing through the focal point on the opposite side of the lens. (Draw the ray so that it begins to refract at the centre of the lens.)



2. Draw a ray that passes through the near focal point (on the same side of the lens as the object). This ray will refract at the centre of the lens and then run parallel to the principal axis.



3. Draw a ray that travels through the optical centre. No refraction takes place, so the ray will travel straight through.



The top of the image is located at the point where these three rays meet.

Did You Know?

Don't forget that the rays from the bottom of the object pass straight through the lens with no refraction. This is why we know that the bottom of the image will be on the principal axis.

Suggested Activity

Find Out Activity 6-1C on page 224
Conduct an Investigation 6-1D on page 225

Predicting Image Characteristics Using Ray Diagrams

You have seen that convex lenses can act as magnifying glasses. Do convex lenses always magnify the object? You can predict the image characteristics—size, position, orientation, and type—by drawing ray diagrams. All you need to do is position the image in a location and repeat the three-ray process (see page 219). Depending on where the object is located, you may get a very different image. Ray diagrams for some locations are shown in Figure 6.9, below.

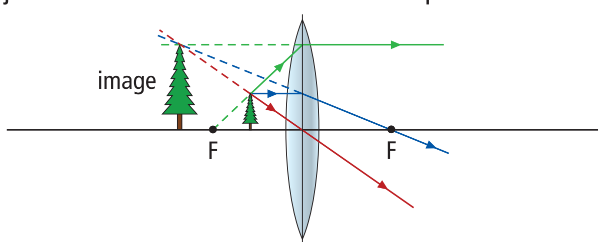
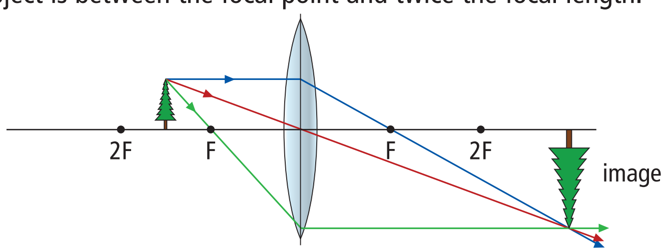
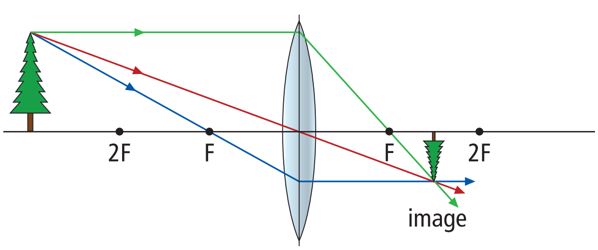
Ray Diagram	Characteristics of Image
The object is between the lens and the focal point. 	• larger than object • farther from lens than object • upright • virtual
The object is between the focal point and twice the focal length. 	• larger than object • farther from lens than object • inverted • real
The object is more than twice as far from the lens as the focal point. 	• smaller than object • closer to lens than object • inverted • real

Figure 6.9 Study each diagram and be sure that you understand how each ray was drawn. Notice that in the first diagram, the refracted rays do not meet. You must extend these rays backward from the lens to find the location of the image.

Figure 6.9 shows that the characteristics of an image in a convex lens depend on the distance of the object from the lens. When the object is between the focal point and the lens, the image is magnified. This is the situation that you saw in Figure 6.5 on page 217, in which the lens was being used as a magnifying glass. When the object is between the focal point and twice the distance to the lens as the focal point, the image is magnified but it is inverted. When the object is farther from the lens than twice the distance to the focal point, the image is smaller than the object and it is inverted.

Notice in Figure 6.9 that when the object is between the focal point and the convex lens, the image is virtual. A virtual image is formed when the refracted rays do not actually meet—only the extended rays meet. A virtual image is located on the same side of the lens as the object, while a real image is located on the opposite side of the lens.

internet connect

There are many simulations of lenses on the Internet. To find one and observe objects and images in many different cases, go to **www.discoveringscience8.ca** to find out where to go next.

Reading Check

1. Explain how you would find the focal point of a convex lens.
2. Explain how the curvature of a convex lens affects the location of the focal point.
3. Why do lenses have two focal points?
4. Draw a ray diagram for an object that is exactly two focal lengths from a convex mirror. Predict the image characteristics.

Concave Lenses

You saw in Figure 6.4 on page 216, that when parallel light passes through a concave lens, the rays spread out. How do you define the focal point for a concave lens if the refracted rays do not meet? The method for finding the focal point for a concave lens is similar to the method that you used for a convex mirror. After drawing the refracted rays, you extend the rays backward as dotted lines (Figure 6.10). The focal point is the point at which the dotted lines meet. Similar to convex lenses, each concave lens has its own focal length, which is determined by the curvature of the lens. As shown in Figure 6.10, lenses with greater curvature have shorter focal lengths.

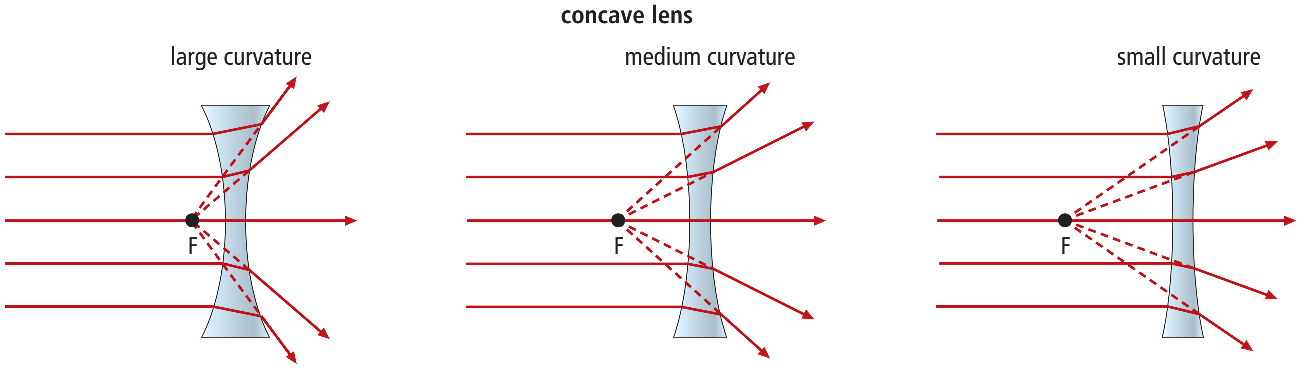
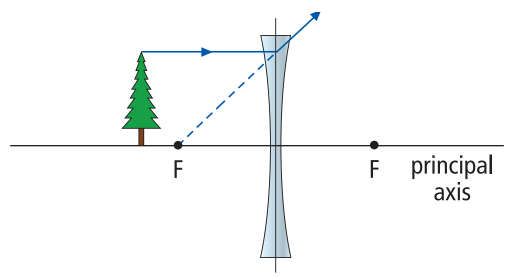


Figure 6.10 The curvature of a concave lens determines the location of the focal point.

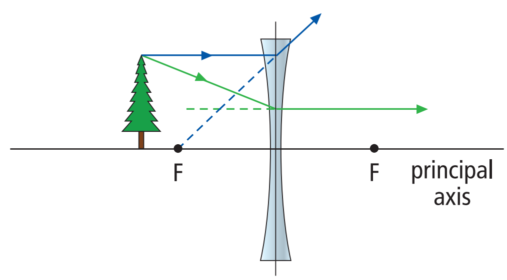
Drawing Ray Diagrams for Concave Lenses

Concave lenses, like convex lenses, have two focal points, one on each side of the lens and the same distance from the lens. Drawing ray diagrams for concave lenses is very similar to drawing ray diagrams for convex lenses. By placing the bottom of the object on the principal axis, you know that the bottom of the image will also lie on the principal axis. If you draw three rays from the top of the object, you will be able to predict the image. The three rays are the same as the ones you have drawn in ray diagrams for curved mirrors and convex lenses, but you will need to extend the rays back toward the object to find the image.

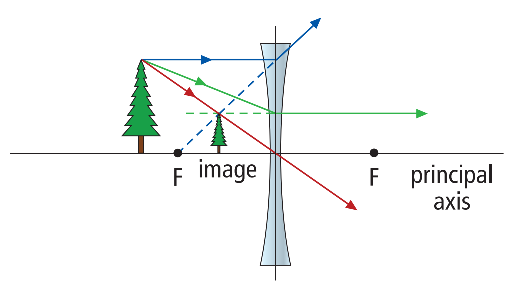
1. Draw a ray parallel to the principal axis. It will refract such that the extension of the refracted ray will pass through the focal point on the same side of the lens as the object.



2. Draw a ray toward the focal point on the opposite side of the lens. This ray will refract parallel to the principal axis. Extend the refracted ray back toward the object.



3. Draw a ray that travels through the optical centre. No refraction takes place, so the ray will travel straight through.



The top of the image is located at the point where two extended rays and one real ray meet.

Image Characteristics for Concave Lenses

Just as you did with convex lenses, you can repeat the three-ray process with concave lenses to determine the images for objects in different positions (Figure 6.11). Recall that the characteristics of an image produced by a convex lens changed depending on the position of the object. Concave lenses produce images that have a lot in common, regardless of the object's position. In all cases, the image formed by a concave lens has the following characteristics:

- The image is smaller than the object.
- The image distance is smaller than the object distance.
- The image is upright.
- The image is virtual.

As the object moves farther from the lens, the image becomes smaller. An example of an image seen through a concave lens is shown in Figure 6.12.

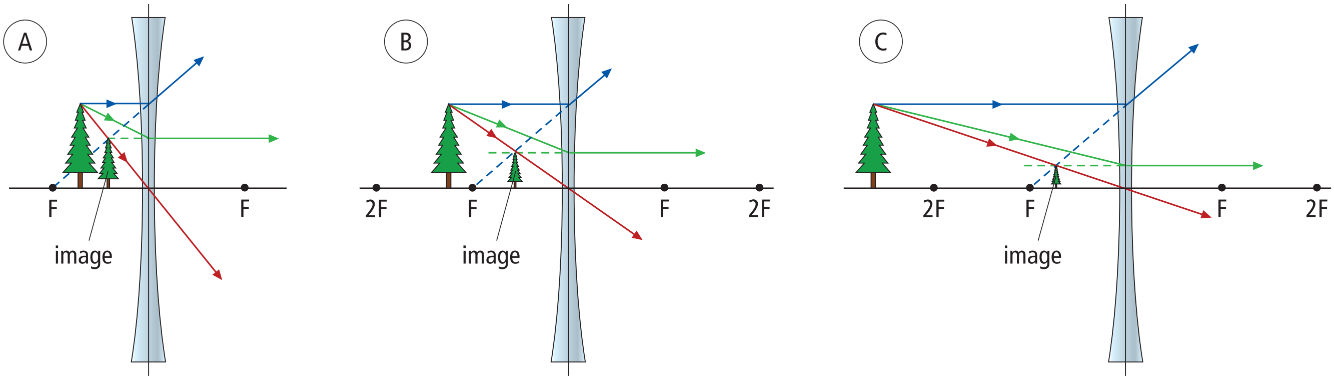
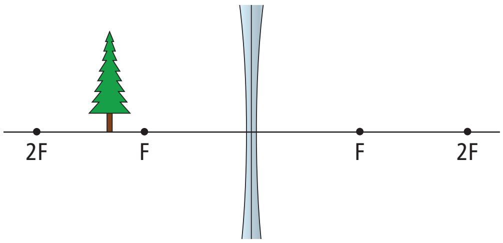


Figure 6.11 The only differences between images created by a concave lens when objects are in different locations are the size of the image and its distance from the concave lens. The images are all upright and virtual.

Reading Check

1. Explain how you would find the focal point of a concave lens.
2. How does the curvature of a concave lens affect the location of the focal point?
3. Draw the figure below. Use three rays to find the image. Describe the characteristics of the image, including size, orientation, distance from lens relative to the object, and whether the image is real or virtual.



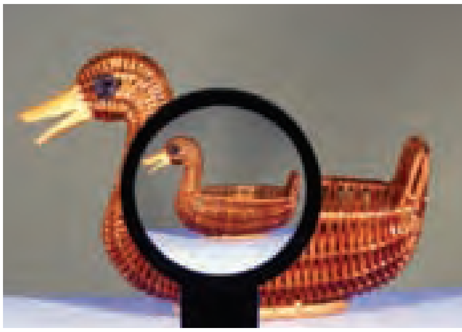


Figure 6.12 A concave lens never produces an image that is as large as or larger than the object.

6-1C Make a Model of a Projector

Find Out ACTIVITY

In this activity, you will examine how an image is affected when seen through a beaker full of water. You will also use a lens to project the image of a light filament onto a screen. A light filament is the twisted wire inside a light bulb.

Safety

- Make sure the electrical cord does not get wet.
- Be careful not to burn yourself with the light bulb.

Materials

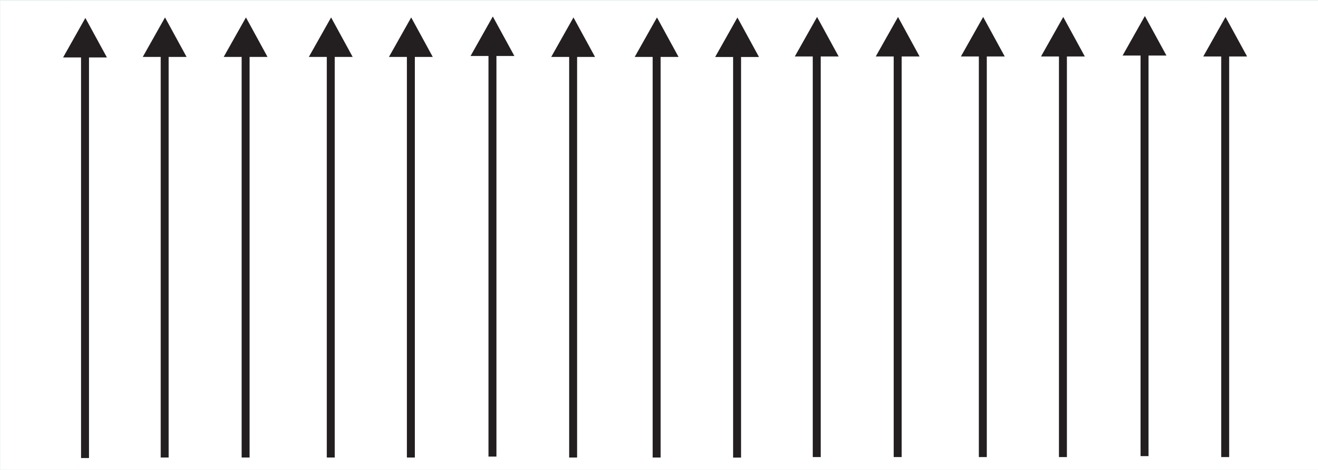
- sheet of paper
- felt pen
- beaker
- water
- convex lens
- unfrosted light bulb

What to Do

1. Draw a series of arrows on a sheet of paper, as shown, and then view the arrows through a beaker full of water. Move the paper left and right and then compare this to the movement of arrows seen through the beaker.
2. Darken the room and turn the light bulb on. Hold the convex lens between the unfrosted light bulb and a plain piece of paper.
3. Move the lens back and forth between the light bulb and the piece of paper. Keep adjusting the distance until you see a sharp image of the filament. Note the size of the image compared to the actual size of the filament.

What Did You Find Out?

1. In step 1:
   (a) How did the orientation of the projected image of the arrows compare with the actual arrows side to side, and up and down?
   (b) How did the projected image of the arrows compare with the actual arrows in terms of size?
2. In step 3:
   (a) How did the orientation of the projected image of the filament compare with the actual filament side to side, and up and down?
   (b) How did the projected image of the filament compare with the actual filament in terms of size?
3. How is the beaker of water like a double convex lens?



6-1D Pinhole Camera

Conduct an INVESTIGATION

Inquiry Focus

SkillCheck

- Observing
- Classifying
- Modelling
- Explaining systems

Safety

- Never look directly at the Sun with any camera, including the one constructed in this activity.

Materials

- 2 tubes of different diameters (from wrapping paper, paper towels, aluminum foil or plastic wrap) or make 2 tubes using tape and paper
- adhesive tape (with frosty appearance, not clear)
- scissors
- aluminum foil
- pushpin

A tiny hole can act like a lens.

Question

Can a pinhole camera be used to make an image of a bright object such as a light filament or a television screen?

Procedure

1. Obtain two tubes of different diameters so one can slide inside the other.
2. Completely cover one end of the smaller diameter tube with adhesive tape by placing overlapping strips of tape together. The tape is the screen that the image will be projected on.
3. Completely cover one end of the larger diameter tube with aluminum foil and use tape to hold it in place. Use a pushpin to poke a hole in the foil. The hole in the foil acts like a lens.
4. Slide the smaller tube into the larger tube, keeping the tape screen and the aluminum foil on the same side. Begin by sliding the tape right up against the foil.
5. You have just made a camera! Point your camera at a bright object such as a bare light bulb or a television that is turned on. CAUTION: Never look directly at the Sun through any camera, including this one.
6. Slide the smaller tube away from the foil until the image comes into focus. A darkened room may be helpful for this. Is the image in the same orientation as the object or is it inverted?
7. Rotate the camera as you view an image. Does the image rotate with the camera?
8. Clean up and put away the equipment you have used.

Analyze

1. How would the letter d appear if viewed through your camera?
2. Explain, using a ray diagram, why the image formed in the camera is inverted.

Conclude and Apply

1. Passing through a forest on a bright day, you notice that on the ground, right under some leaves, there are many tiny images of the Sun. Explain how these images form.

Wild, Weird, Wonderful

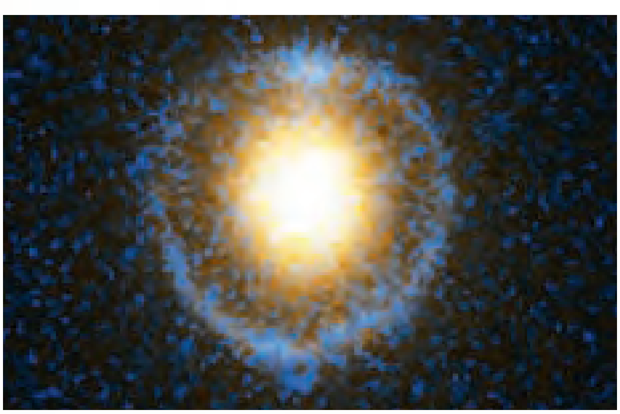
www Science

Gravitational Lenses

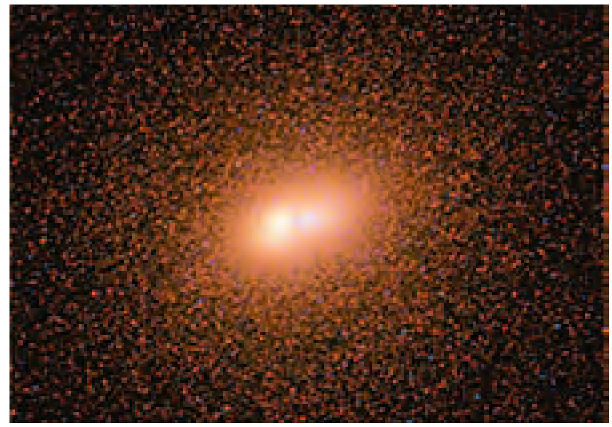
Imagine that there is a region deep in space that you would like to explore with your telescope, but the distance is just too great to see anything. What if you discovered that halfway between you and the object there was a huge magnifying glass that focussed the light from the distant object right at Earth?

All objects have mass, and where there is mass there is gravity. Gravity not only holds you to Earth and keeps the Moon from flying out of its orbit, it also attracts light. The effect is small for small objects like humans, planets, and individual stars. But gravity can refract light rays passing by a galaxy by a huge amount. When gravity causes many light rays to come together at one point, then we have a lens—a gravitational lens.

The photograph at the bottom left shows an Einstein ring. The gravitational lens is the bright galaxy in the centre. The blue ring is the distorted image of another galaxy that is on the far side of the lens. The lens is actually in front of the distant blue-coloured galaxy. Light from the blue galaxy passes on all sides of the lens and is pulled together again as it arrives at Earth.

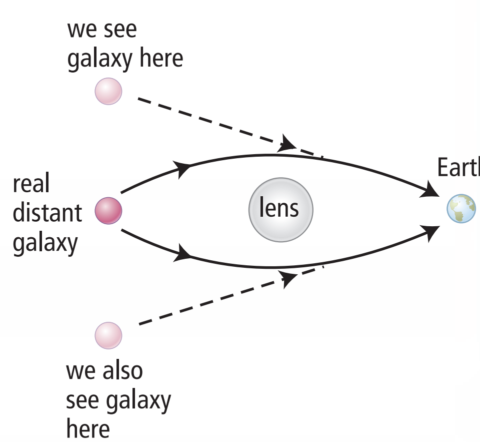


An Einstein ring



A white galaxy

The photograph above shows what appear to be two smaller white galaxies on either side of the lens. Actually, it is one galaxy that is as far behind the lens as we are in front of it. It may seem strange that we get two images, but some light travels above the lens and other light from the same source travels below the lens. The light from the white galaxy has been travelling through space for a very long time. It took two billion years to reach the lens, and another two billion years to reach Earth.

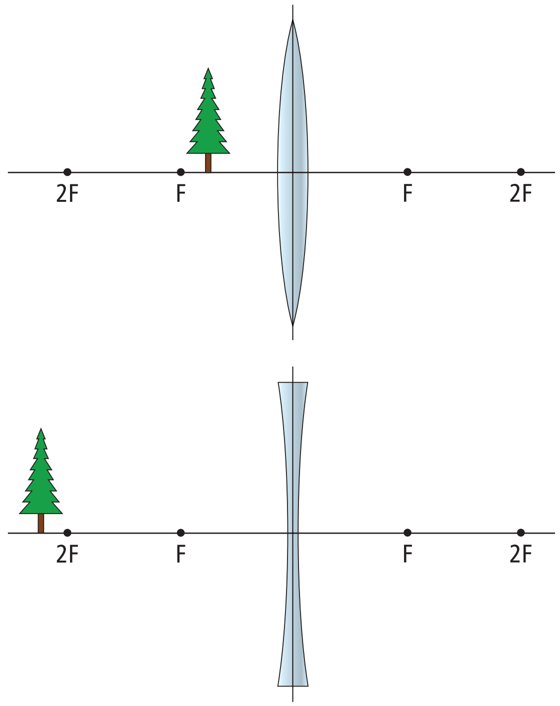


What appears to be two galaxies is actually only one galaxy.

Check Your Understanding

Checking Concepts

1. Make a sketch of the cross section of a convex lens and of a concave lens.
2. What happens to parallel light rays when they pass through a concave lens?
3. Why do lenses have two focal points?
4. Would you use a concave lens or a convex lens for a magnifying glass? Explain why.
5. How does the curvature of a convex lens affect its focal point?
6. Copy the following diagrams. For each diagram, complete a ray diagram, using three rays, to find the image. Describe the characteristics of each of the images, including size, orientation, distance from lens relative to the object, and whether the image is real or virtual.

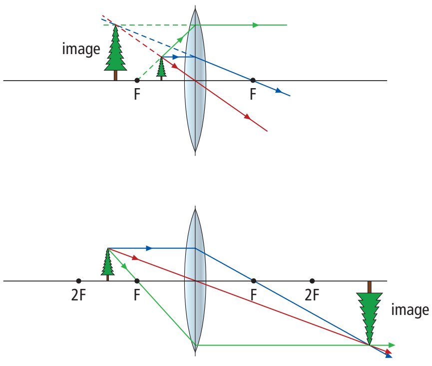


Understanding Key Ideas

7. Does a concave lens affect light more like a concave mirror or a convex mirror? Explain your answer.
8. Describe each of the three rays that you use to make a ray diagram for a convex lens. Explain how you know where the refracted ray will go.
9. Under what conditions will a convex lens not give you a magnified image of the object?
10. On which side of a concave lens do you find the image? Is it on the same side as the object or on the side of the lens opposite the object?

Pause and Reflect

If the image of an object between F and 2F of a convex lens is real and inverted, and the image of an object between the lens and F of the same lens is upright and virtual, what do you think would happen if the object was exactly on the focal point, F? Draw a ray diagram to support your answer.



6.2 Human Vision

The cornea-lens-retina system focusses light at the back of the eye. Special cells in the retina called rod cells and cone cells convert light into electrical signals that are sent to the brain. Light does not always fall on the retina in perfect focus. Near-sightedness results when the eye cannot form a sharp image of distant objects. Near-sightedness can be corrected by placing a concave lens in front of the eye. Far-sightedness results when the lens of the eye cannot form a sharp image of nearby objects. Far-sightedness can be corrected by placing a convex lens in front of the eye.

Key Terms

astigmatism
blindness
blind spot
colour blindness
cone cells
cornea
far-sighted
iris
near-sighted
night blindness
optic nerve
pupil
retina
rod cells
sclera
snow blindness

Your eyes allow you to read the text on this page, to see colourful illustrations, and to focus on moving objects. How is all of this possible? In fact, you have already learned three important facts about light that will help you understand how human vision works:

1. Light travels in straight lines.
2. Light bends as it travels from one medium to another of different density.
3. A lens can be used to focus light by bending it in a specific way.

This knowledge will help you understand how the specialized structure of the human eye allows you to see.

6-2A Changing Colours

Find Out ACTIVITY

In this activity, you can observe how your colour vision adapts to changing lighting conditions.

What to Do

1. Look at the image of the flag of Canada, which is printed in a greenish tint. Stare at the image of the flag for 25 s, making sure not to move your eyes around.
2. Immediately switch your gaze to a white space on the page, and wait a few seconds. What do you see? Achieving this effect may take a few tries.

What Did You Find Out?

1. (a) What did you see when you stared at the white page?
   (b) Why do you think you saw this?
2. How might this adaptability of your colour vision help you as you walk through a forest in bright sunlight and at twilight?

Flag of Canada

How Light Enters the Eye

Light enters your eye through the **pupil** (see Figure 6.13). The pupil is an opening that appears dark because light passes through it without reflecting back. The iris is the coloured circle of muscle surrounding the pupil. The **iris** is the structure we refer to when we speak about the colour of someone's eyes being grey, brown, blue, or hazel. The iris controls the amount of light entering the eye. In dim light, the iris dilates, or expands, the pupil to allow more light to enter (see Figure 6.14A). In bright light, the iris contracts the pupil to reduce the amount of light entering the eye (see Figure 6.14B).

Covering the iris and pupil is a transparent tissue called the **cornea**. The cornea is made of cells that are transparent enough to let light pass through, yet tough enough to hold the eye together. Surrounding the cornea is an opaque tissue called the **sclera**. We see the sclera as the white region surrounding the iris.

Behind the pupil is a flexible convex lens. The light rays pass through the lens and are focussed on a screen at the back of the eye called the **retina**, where an image is formed. Special light-sensitive cells in the retina detect the image. Other cells in the retina convert the light rays into electrical signals that are sent to the brain through a thick nerve called the **optic nerve**.

Did You Know?

The human eye is more sensitive to green light than to any other colour. If you look at a green light and a red light of the same intensity, the green light appears to be brighter.

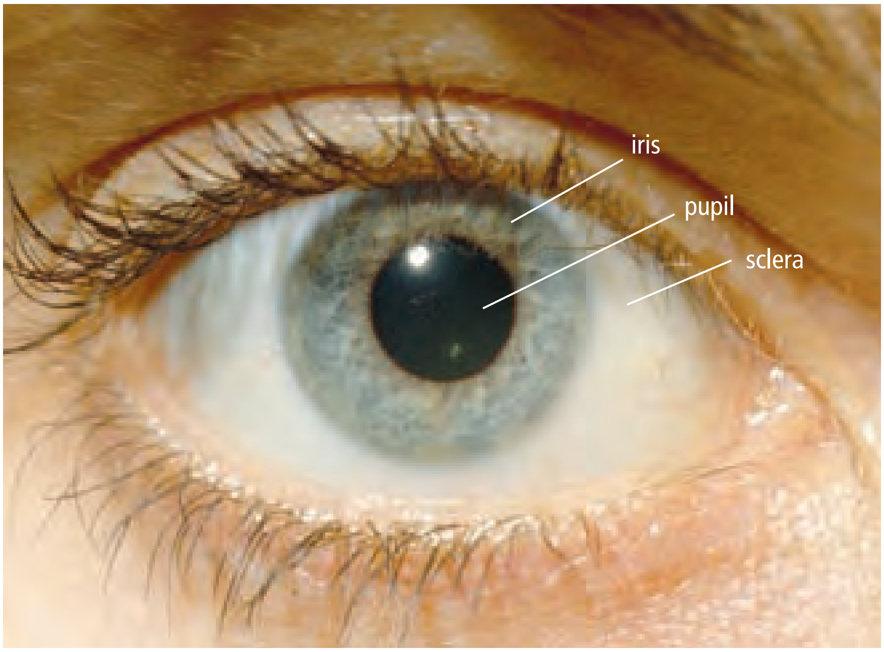


Figure 6.13 Light enters the eye through a transparent opening called the pupil.

Figure 6.14A A dilated pupil

Figure 6.14B A contracted pupil

Word Connect

The term "cornea" comes from the Latin word for horn, the front part of an animal's head. The cornea is the most forward part of the eye.

The Cornea-Lens-Retina System

Light rays pass through a focussing system involving the cornea, the lens, and spaces in the eye filled with a watery fluid (see Figure 6.15). The fluid between the lens and the cornea supports both the cornea and the lens, and provides nutrients to the cornea, which does not have any blood vessels. The fluid behind the lens gives shape to the eye and supports the lens.

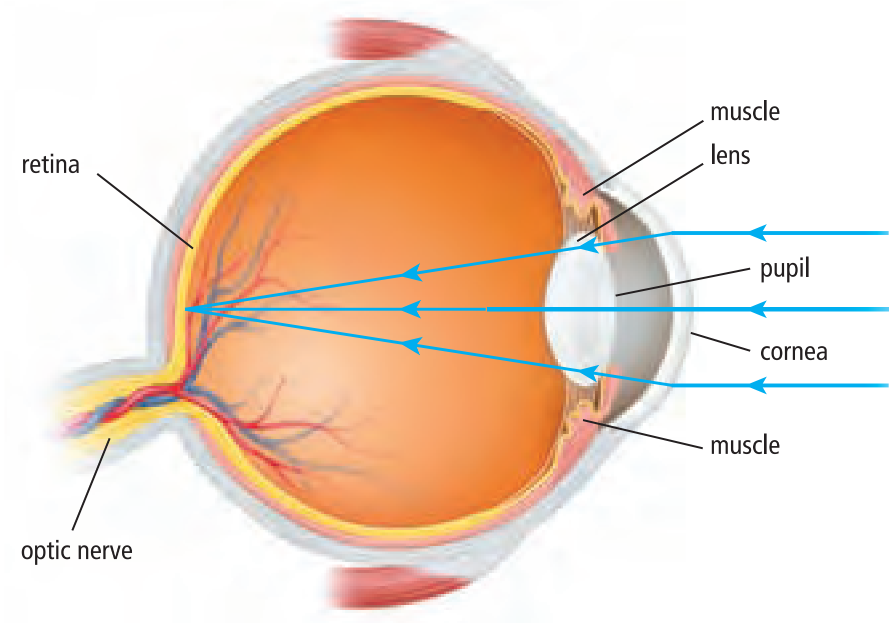


Figure 6.15 The eye in cross section

Light rays begin to be focussed as soon as they pass into the cornea. The cornea refracts incoming light rays so that they converge toward the retina. The cornea provides most of the focussing done by our eyes. The lens does the remaining focussing. This may be a surprise to you because we usually think of the lens as doing the focussing. Perhaps it is because we do not notice the amount of focussing done by the cornea that we tend not to think about its function in forming the image.

The lens has the ability to fine-tune our focus by automatically changing its shape. When certain muscles in the eye contract, there is less tension on the lens, allowing the lens to become thicker. A thicker lens can focus on near objects. When you look at distant objects, these same muscles relax, increasing tension on the lens and making it thinner. You can feel your eyes working hard to focus if you hold a finger up very close and try to see it clearly.

Did You Know?

In some species of animals, such as the octopus, the lens and the retina can move closer together.

Forming an image

All the light rays that enter the eye from one spot on the base of an object come together again in one place at the top of the retina. Similarly, all the light rays that enter the eye from a spot at the top of an object come together at one place at the bottom of the retina. As shown in Figure 6.16 the image formed by the lens is inverted. However, you do not have to stand on your head to see upright. Your brain interprets the image as being upright.

Suggested Activity

Conduct an Investigation 6-2D, on page 238

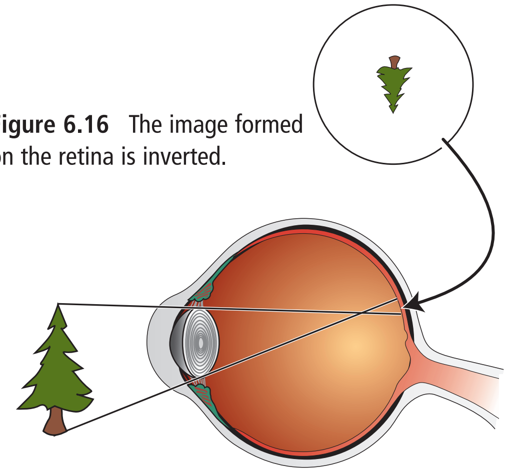


Figure 6.16 The image formed on the retina is inverted.

Blind Spot

The area where the optic nerve enters the retina does not have any light-sensing cells. This area is known as the **blind spot**. You can easily demonstrate the presence of your blind spot by following the steps outlined in Figure 6.17. Note that each eye sees what the other misses because the blind spots are not in the same place.

internet connect

An optical or visual illusion tricks the eye and brain into perceiving something unlike what actually exists. Check out examples of optical illusions and find out what they reveal about the way we see. Start your search at **www.discoveringscience8.ca.**

Figure 6.17 To locate your blind spot, hold this book at arm's length. Cover your right eye with your hand. Stare at the X while you move the book slowly toward yourself. The dot should disappear and then reappear as its image moves onto your blind spot and then off again.

Reading Check

1. What happens to light rays after they enter the eye through the pupil?
2. Where does most of the focussing in the eye occur?
3. How does the lens change to focus on objects that are close?
4. How does the lens change to focus on objects that are distant?
5. Why is the image of an object inverted when it strikes the retina?

Black-and-White Vision and Colour Vision

Once the light rays are focussed correctly on the retina, the cells that absorb the light begin their job. Some cells in your retina specialize in detecting low levels of light. Other cells detect bright light. The cells in your retina that absorb light come in two basic shapes: longer cylindrical ones called rod cells and rounder ones called cone cells (see Figure 6.18).

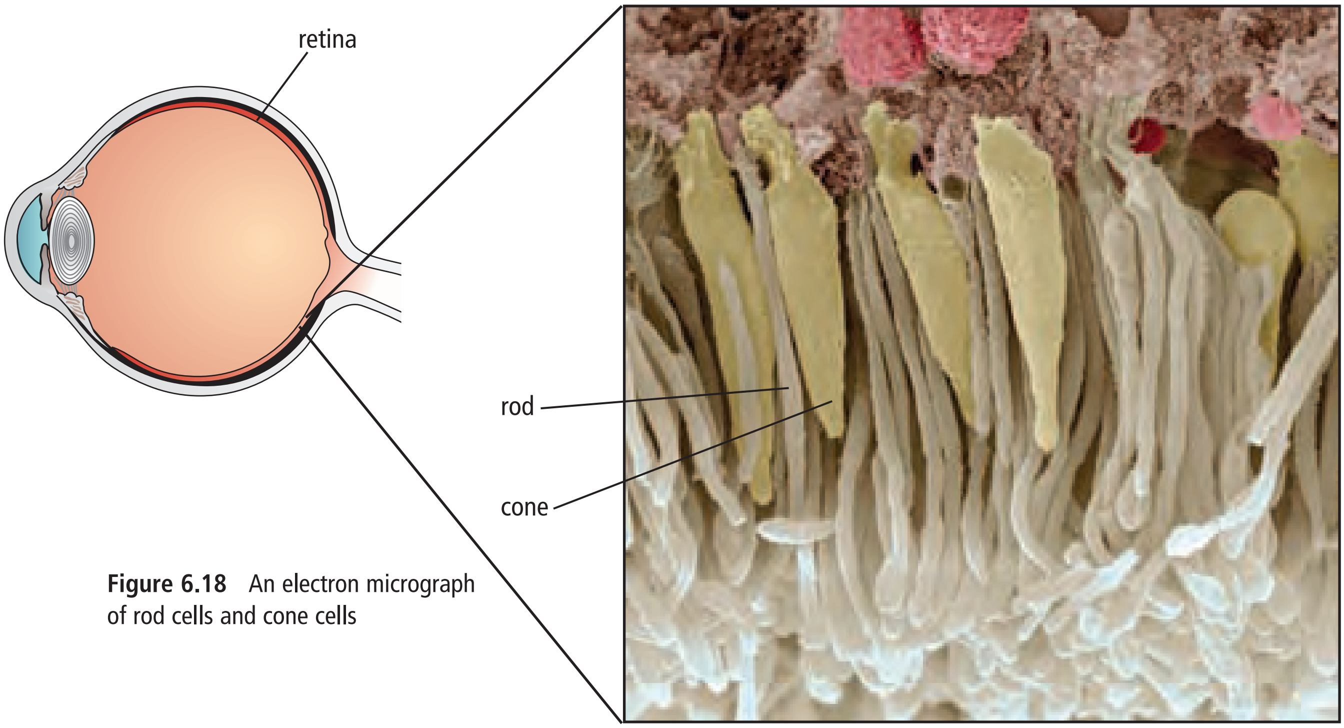


Figure 6.18 An electron micrograph of rod cells and cone cells

Rod cells—shapes, movement, and shades of grey

Rod cells can absorb almost any colour of light, but they absorb green light particularly well. Even so, our brain does not use any of the signals from rod cells to determine colour—just shades of light and dark. This is called our black-and-white vision system, and in low-light conditions it helps us see shapes and movement.

Did You Know?

We sometimes forget we see in black and white at night because we know what the colours should be.

Cone cells—seeing the rainbow

Cone cells allow us to detect colour. We have three kinds of cone cells, each possessing a slightly different kind of pigment. Recall that by using only red, green, and blue it is possible to see all the colours of the rainbow. If our brain receives an equal amount of all three colours, then we see the object as white. The human brain can combine and balance the different colour signals that it receives. This is why the white page of a book can appear white to us under varying amounts of daylight.

6-2B What Colours Do Rod and Cone Cells Detect?

Think About It

In Part 1 of this activity, you will use the information in a table to answer questions about rod cells and cone cells. In Part 2 of this activity, you will use the information in a graph to determine which colours rod cells and cone cells detect.

What to Do

Part 1

1. Use the table below to help you answer the questions that follow. Pigment is the colouring matter in a cellular tissue.

Functions of Rod Cells and Cone Cells

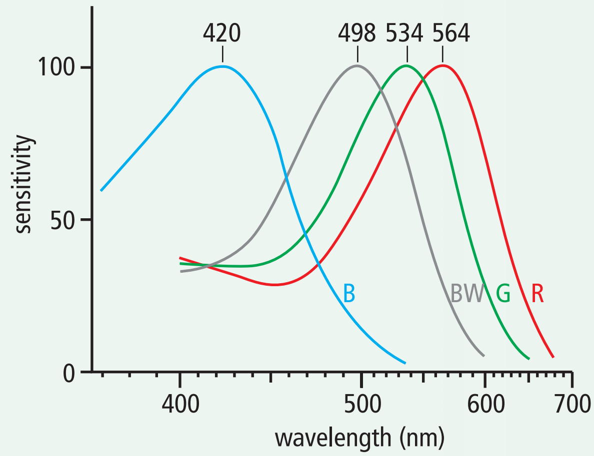
Rod Cells	Cone Cells
Used for night vision	Used for bright illumination vision
Very light sensitive	Not very light sensitive
One type of light-sensitive pigment	Three types of light-sensitive pigment
Have more pigment than cones, so can detect images in low light conditions	Have less pigment than rods, so require more light to detect images
Slow response to light	Fast response to light
Smaller than cone cells	Larger than rod cells
About 100 million in the human eye	About 6 million in the human eye
Mostly found on the outer edges of the retina	Mostly found in the centre of the retina

2. Why are rod cells more useful for night vision?
3. Why are cone cells more useful for colour vision?

Part 2

4. Use this graph to help you answer the questions that follow.

B blue-sensitive cone cells
G green-sensitive cone cells
R red-sensitive cone cells
BW black- and white-sensitive rod cells



A graph of the ability of cone cells and rod cells to absorb light of differing wavelengths

5. Consider the line labelled "R," for red-sensitive cone cells.
   (a) At what wavelength, in nanometres, are these cells most effective at detecting light?
   (b) What colour does the wavelength in (a) correspond to?
   (c) Which colour are the red-sensitive cells able to detect more easily—green or red?
   (d) Suggest a reason why these cells are called red-sensitive cells even though they can detect many other colours as well.
6. (a) At what wavelength do the black- and white-sensitive rod cells absorb light most efficiently?
   (b) What colour does the wavelength (a) correspond to?
7. Examine the graph and explain why humans are able to detect faint amounts of green light.

Correcting Focus Problems

Most people have trouble focussing clearly at some time in their lives. As children grow, especially in their teen years, the shape of their eye changes. The change of shape can affect their ability to focus and may require the temporary use of eyeglasses. As adults age, the flexibility of the eyes' lenses often decreases, making it harder to focus on nearby objects.

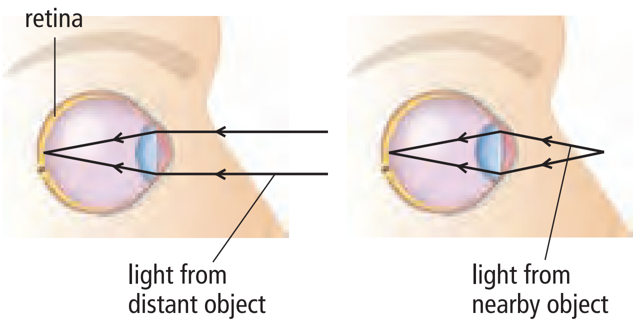
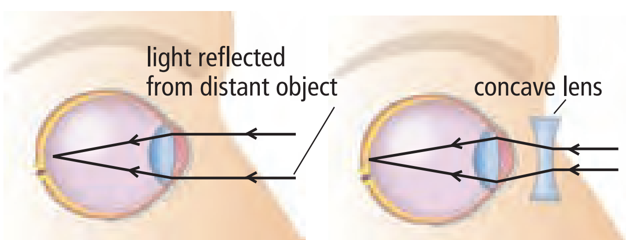


Figure 6.19 How the lens in a normal human eye focusses light rays onto the retina

Normal vision

When light rays from a distant object enter the eye, the rays are nearly parallel (Figure 6.19). The lens, which is convex, causes the rays to converge at the retina, producing a sharp image. Light rays from a nearby object are diverging when they enter the eye, so muscles in the eye cause the lens to change shape, making the lens thicker. This gives the lens a greater ability to converge the light rays to form a clear image.



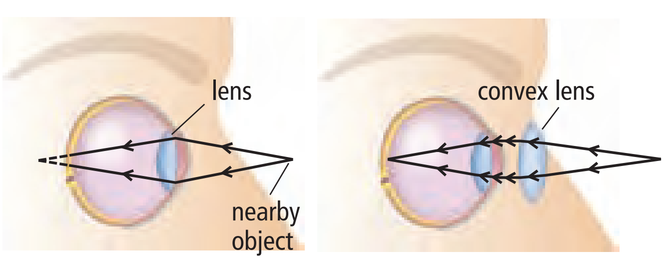
Near-sighted vision: image falls short of retina (eye has longer shape than normal eye)

Vision corrected with concave lens: lens allows image to fall on retina

Figure 6.20 How a concave lens in eyeglasses corrects near-sightedness

Correcting near-sighted vision

People who can see nearby objects clearly but who cannot bring distant objects into focus are **near-sighted** (Figure 6.20). This condition occurs because the lens converges the light rays to form an image in front of the retina. By the time the light rays actually strike the retina they have begun to spread out again, causing the person to see a fuzzy image. A concave lens is used to diverge the parallel rays slightly so that the image forms farther back, on the retina.



Far-sighted vision: image falls behind retina (eye has shorter shape than normal eye)

Vision corrected with convex lens: lens allows image to fall on retina

Figure 6.21 How a convex lens in eyeglasses corrects far-sightedness

Correcting far-sighted vision

Some people can see distant objects clearly but find that nearby objects remain fuzzy no matter how hard they try to focus on them, a condition known as **far-sighted** vision (Figure 6.21). Light rays from distant objects are nearly parallel, and require less refraction to converge them than light from nearby objects. However, light rays from nearby objects are diverging as they enter the eye. A convex lens is needed for the light rays to come into focus exactly on the retina.

Correcting astigmatism

Some people need vision correction because their cornea has a distorted shape, a condition known as **astigmatism**. A normal cornea is shaped spherically, like a soccer ball, while an astigmatic eye has an irregularly-shaped cornea. This condition causes an image to focus on more than one point on the retina, resulting in blurred vision (see Figure 6.22). Astigmatism can be corrected using eyeglasses or contact lenses (see Figure 6.23) or with laser surgery to reshape the cornea.

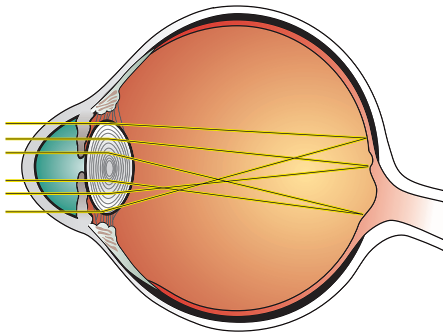


Figure 6.22 In astigmatism, the shape of the cornea causes the image to focus on more than one point of the retina.

Figure 6.23 Contact lenses are small plastic lenses that float on the cornea. Almost any correction that can be made using prescription eyeglasses can also be made using contact lenses.

Blindness

Blindness can be any vision impairment that keeps people from doing important life activities such as riding a bike, reading, or recognizing their friends through sight. In very rare cases, a blind person may not be able to detect any light whatsoever. Most people who are legally blind can perceive some light or even have a limited amount of vision.

In some types of blindness a person can see only a tiny part of the middle of a whole scene. Other people who are blind have the opposite situation: they can see on the edges of their vision, but not directly ahead. Others can detect light and darkness, but no amount of visual aids can help them to see clearly.

In developing countries, blindness is most often a result of disease or malnutrition. Children in poorer communities are more likely to be affected by blindness caused by disease than are children in more affluent communities. Of the approximately 40 million people who are blind in the world today, about 80 percent could have some or all of their sight restored through treatment. However, many people in developing countries cannot afford even basic vision aids such as eyeglasses.

Suggested Activity

Think About It 6-2C on page 237

Figure 6.24 Inuit snow goggles of caribou antler.

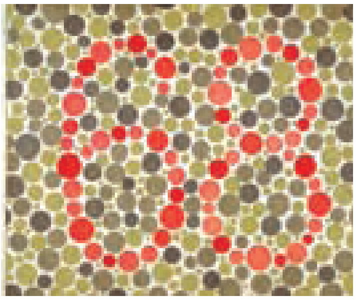


Figure 6.25 Those who do not have red-green colour vision deficiency should see the number 68 here.

Other Types of Blindness

Snow blindness is a painful condition of temporary partial or complete blindness caused by overexposure to the glare of sunlight, such as on snow fields at high altitudes. Treatment includes resting the eyes in a dark room for several days to allow the inflammation to decrease. The Inuit traditionally wore goggles with thin slits to help prevent snow blindness (see Figure 6.24).

Night blindness is a condition in which it is difficult or impossible to see in dim light. The most common cause is the rod cells losing their ability to respond to light. A person might be born with night blindness, or it could develop due to injury or malnutrition.

Colour blindness is the ability to see only in shades of grey, and occurs in about one person in every 40 000. Colour blindness is usually considered a disability, but there are situations in which a person who is colour-blind has an advantage over a person who sees colour. For example, a person who is colour-blind may find it easier to pick out an object from a confusing background.

Although colour blindness is rare, colour vision deficiency is quite common, occurring in about 8 percent of males and 1 percent of females. Colour vision deficiency is an inability to distinguish certain colours. There are many kinds of colour vision deficiency because one, two, or all three kinds of cone cells may be involved. The most common kind of colour vision deficiency involves the inability to tell red and green apart. For many affected people, both colours appear to be shades of yellow. A simple test for colour vision deficiency is shown in Figure 6.25.

Explore More

There are many kinds of vision problems related to focussing, colour perception, and size of field. Other vision problems involve high pressure in the eye, degeneration of parts of the eye or optic nerve, detachment of the retina, or hardening of the lens. Find out more about vision problems. Start your search at **www.discoveringscience8.ca.**

Reading Check

1. What can cause focussing problems as children grow? As adults age?
2. Explain why a person who is near-sighted can see a close object clearly, but not a distant one.
3. Explain why a person who is far-sighted can see a distant object clearly, but not a close one.
4. How does an irregularly-shaped cornea cause astigmatism?
5. What are three examples of what a person who is blind might be able to see?
6. Why are children in developing countries at a greater risk of becoming blind?
7. How can snow blindness be prevented?

6-2C Being Blind

In this activity, you will learn about the life of a blind student.

What to Do

1. Read the letter and answer the questions that follow.

Hello, my name is Sean, and I am blind. Although I was born blind, I have learned how to understand the world around me. I can read Braille and I really love reading books in the same way sighted kids learn how to enjoy reading print. The only difference is that I read with my fingers instead of my eyes.

I also enjoy listening to "talking books" on my iPod®. You might think it strange, but I talk about "reading" books, even though I read through my fingers or listen through my ears. I like to do all the things people with sight like to do, like playing with my dog, going swimming, listening to music, or just hanging out with my friends.

I go to school with kids who can see. My favourite subjects are math and English. I use a computer with a Braille keyboard and voice output, so I can check what I have done. The best part of school is the friends I have made. They help me "see" things I cannot see, and I help them with things that are not so visible.

The Braille alphabet allows a blind person to read by touch.

A Braille keyboard

What Did You Find Out?

1. (a) Based on Sean's writing, or on friendships you have with people who are blind or visually impaired, do you think you should use expressions when you talk to them like, "See you later" or "Did you watch the TV show last night?" Explain your answer.
   (b) What about expressions like "The book is over there" or "Come here"? Explain your answer.
2. How could you help a student who is visually impaired who was new to your classroom?
3. How could your classroom be improved to make it easier for a student who is visually impaired to learn?

6-2D Dissecting a Sheep Eye

SkillCheck

- Observing
- Classifying
- Communicating
- Explaining systems

Safety

- The sheep eye is raw meat. Make sure you wash your hands with soap after completing the dissection to ensure that all bacteria have been washed off.
- Keep your hands away from your eyes and mouth when handling the sheep eye.
- Ensure that all of the animal parts are cleaned up and discarded according to your teacher's instructions.
- Sharp edges can cut. Be careful with scissors and prods.

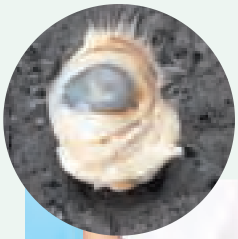
Materials

- preserved sheep eye
- scissors
- prod
- dissection tray
- protective gloves
- paper towel
- plastic disposal bag
- 10 percent bleach solution
- Wear protective gloves. Follow your teacher's instructions for removing and disposing of them.

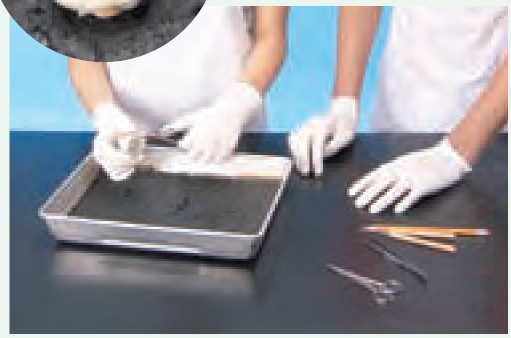
A sheep eye and a human eye have many things in common—as well as a few important differences. Examining a sheep eye will help you better understand how your own eyes function.

Question

How does a sheep eye function?



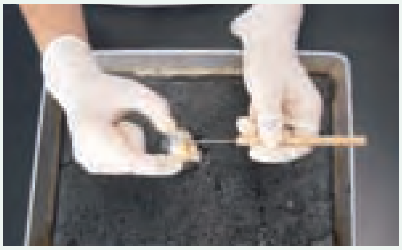
Exterior view of a sheep eye



Trim away fat and muscle.

Procedure

1. Put on your gloves. Examine the outside of the sheep eye. Notice that it is covered in a layer of fat and muscle. The fat is yellow tissue, and the muscle may appear grey.
   - The fat protects the eye, while the muscle helps the eye to move in its socket. A sheep eye has four large muscles to move the eye up, down, left, and right.
   - Humans have six muscles, which allow us to roll our eyes.
2. Use scissors to trim away the excess fat and muscle.
3. Look at the front of the eye and note the outer layer, called the cornea. The cornea is clear in the living eye, but may have become cloudy in the preserved eye. The cornea is curved, which means light passing through it is focussed.
4. Examine the rest of the outside of the eye. Note that an opaque layer, the sclera, covers the eye.
   - The sclera has a dark layer that prevents the passage of light into the eye from the side. This keeps out stray light.
   - The optic nerve enters the eye at the back.
5. Use the prod to poke a hole in the eye halfway between the cornea and the optic nerve. Some liquid will come out when you do this. Use scissors to cut all the way around the eye, separating it into front and back halves. Try not to disturb the internal parts of the eye as you cut.



Poke a hole into the sclera so that scissors can be used to cut the eye in half.

6. Separate the eye into two halves. Taking the front half of the eye, try to look through it. It may be possible to see right through the lens and cornea. See if you can read text through the eye. If you can see an image through the eye, note whether it appears upright or upside down.
7. Use the prod again to poke a hole at the junction of the cornea and the sclera. Use the scissors to cut a circle around the cornea in order to remove it.
   - Under the cornea is more jelly-like substance that is liquid in the living eye. The jelly-like substance supports the cornea and helps to give it shape.
   - Under the cornea is the iris, which is a ring of tissue. In a sheep, the iris is oval-shaped. In humans, it is circular. The pupil is seen to be simply a hole in the iris.

Cut a circle around the cornea in order to remove it.

8. Remove the lens from the eye and, using a paper towel, wipe all the jelly from it. The lens will probably be yellow, but it is colourless and clear in the living eye. See if you can see an image through the lens. The lens will be hard, but in the living eye it is soft and can change shape in order to focus.
9. Examine the inside of the back half of the eye. Note where the optic nerve comes into the eye. There are no rod or cone cells here, and this is the sheep's blind spot. Humans have a similar blind spot.
   - The retina is a network of nerves that flow into the optic nerve. The retina may be found against the inside back of the eye. If the retina has come off it will likely be attached to the eye at a single spot (the blind spot).
   - The back of the eye may appear black or blue. In sheep, there is also a shiny or iridescent layer that helps the sheep to see in low-light conditions.
   - Humans do not have this layer, and the layer under the retina in our eyes is black, to absorb stray light.
10. Place all of the eye parts in a plastic disposal bag. Clean up all equipment and work areas with a 10 percent bleach solution. Remove and dispose of your gloves as your teacher instructs.
11. Wash your hands thoroughly with warm soapy water.

Analyze

1. List four differences between the anatomy of a sheep eye and a human eye.
2. Is the image that is cast on the retina at the back of the eye upright or inverted? Draw a ray diagram to explain your observations.
3. Describe the appearance, colour, shape, and feel of the lens from the sheep eye.

Conclude and Apply

1. Make a labelled diagram of a cross section of the sheep eye that includes all of the structures you studied.
2. You may have observed that the retina seemed to be continuous with the optic nerve. Do you think the retina is part of the brain? Explain.

Wild, Weird, Wonderful

www Science

Can You See What I Hear?

Bats, dolphins, and whales all use natural sonar systems to perceive the world around them. Do you? You may be surprised. If you have normal hearing, then you might want to try this experiment. Have 10 people stand in a line. Face away from them and then have one person make a sound. You are likely to be able to turn and face the exact person who made the sound.

There are some interesting reasons for this. The sound reaches each ear at different times, and your brain can detect the difference in the arrival times of the sound signals. Another reason is that you have an awareness of the space around you, and when you hear your friend make the sound, you locate him or her in this space. You can even keep track of this as you turn around to face your friend. In other words, you can "see" what you just heard.

Echolocation involves producing sounds and then interpreting the environment based on the echo. Bats emit high-pitched chirps. They can use the echoes of the chirps to avoid wires and find insects to eat. Some people who are blind make their own clicking sounds when walking. Then they interpret the echoes to find out about objects close by.

This ability has inspired a number of researchers to construct devices that produce sounds that people who are blind can use to find out about the location, size, shape, and even texture of objects around them. For example, a loud, clear echo might represent a close, hard object. We all have an inborn ability to interpret sounds in a visual way, and those who practise it get much better at it .

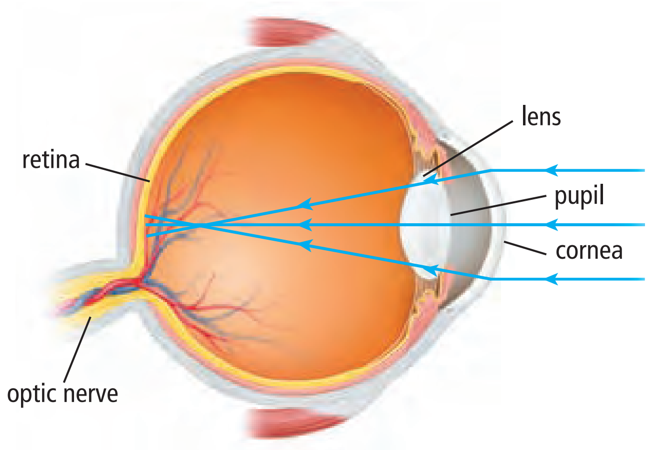
The woman above is wearing a video camera. The camera is mounted in her sunglasses, as is the digital equipment that creates an audio signal of every object she faces. The woman listens to the sounds and converts the "sound scape" into a mental image of her environment.

The use of these devices is very experimental. With the current technology, bright objects are made to produce a loud sound. Black objects are silent. As objects get closer to you they look bigger. This translates as a higher pitch. A car driving away from you sounds like a falling tone. Although we are still a long way from getting to "I can see what you see," we may be only a big step away from "I can hear what you see."

Check Your Understanding

Checking Concepts

1. Make a table that lists the parts of the eye in one column and the function of each part in the other.
2. (a) Which parts of your eye are involved in focussing an image?
   (b) What is the role of each part?
3. (a) Describe the vision problem shown by the illustration below.
   (b) What could be done to correct this problem?



4. Why can the human eye see colours better in bright light than in dim light?
5. Write a definition of blindness in your own words.

Understanding Key Ideas

6. What would happen to a person's vision if the eye's lens was unable to change shape?
7. Why is it necessary to have three kinds of cone cells operating in order to have full colour vision?
8. Describe how the eye adapts to the following changes in conditions:
   (a) sudden increase in brightness
   (b) gradual dimming of light until it is almost dark
   (c) looking at a kite, then down at your hand to let out string
9. Most mammals, including dogs and cats, cannot see colours. Infer how the retina of a cat's eye might be different from the retina of a human eye.

Pause and Reflect

After years of work in the field of vision and community service, you have been selected to become the high commissioner for the Elimination of Preventable Vision Disabilities. You have a budget of $1 billion. Your commission is responsible for defining four goals that will improve vision in the developing world. Reflect on this problem and then list your four goals along with the portion of the budget that each should receive. Briefly explain your choices.

6.3 Extending Human Vision

Microscopes and refracting telescopes use lenses to capture and focus light. Reflecting telescopes use both mirrors and lenses to gather light. The Hubble Space Telescope can obtain clearer images than ground-based telescopes because there is no atmosphere to interfere with images from the Hubble Space Telescope. Camera design and human vision have a number of similarities and differences.

Key Terms

aperture
charge-coupled device (CCD)
diaphragm
refracting telescope
reflecting telescope

Human knowledge about our planet and the universe was very limited until we developed tools to extend our vision. We now have the ability to peer into the tiny world of micro-organisms and out into the vast reaches of outer space. The tools we use for these inquiries may seem quite different from each other, but they are based on the same understanding of light, mirrors, and lenses.

Ray diagrams demonstrate how light behaves when it strikes a mirror or passes through a lens. Microscopes, telescopes, and other optical instruments use multiple lenses and/or mirrors to magnify images. You could use ray diagrams to determine the images these instruments produce, but the diagrams would be rather complicated. Scientists often use simplified diagrams to help explain how optical instruments work.

6-3A Experimenting with a Simple Lens — Find Out ACTIVITY

In this activity, you will observe some properties of a test tube lens.

Materials

- glass test tube with stopper
- water
- paper or note card

What to Do

1. Fill a glass test tube with water and seal it with the stopper.
2. Print the name of your favourite scientist in capital letters on a piece of paper or a note card.
3. Lay the test tube flat on the note card, running left to right over the words you have written.
4. Observe whether the letters are magnified, whether the letters are in focus, and whether the image is upright or inverted. Record your observations.
5. Hold the tube about 1 cm above the card and observe the letters. Record your observations.
6. Repeat, holding the tube at several other heights above the words.

What Did You Find Out?

1. Describe what happens to the images of the letters as the lens is gradually moved away from the note card.
2. Draw and label a ray diagram showing the situation when the image appeared to be inverted and magnified.

How to Bring an Image into Focus

In order for the light rays passing through a lens to form a clear image, the screen that is receiving the image must be the correct distance from the lens. The screen must be at the place where all the light rays from a given point on the object converge. If the screen is placed too close to the lens, then the light rays do not fully converge by the time they strike the screen. There will be an image formed, but it will appear blurred. On the other hand, if the screen is too far away, then the light rays converge and then begin to diverge before they strike the screen, resulting in a blurred image. Adjusting the distance between the screen and the lens to make a clear image is called focussing. Focussing is an important step in using optical devices such as microscopes, telescopes, binoculars, and cameras.

Microscopes

A compound light microscope uses two convex lenses with relatively short focal lengths to magnify small, close objects. To *magnify* means to cause to look larger than the real size.

Figure 6.26 shows a microscope. The object to be viewed is placed on a transparent slide and 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. Recall that if the distance from an object to a convex lens is between one and two focal lengths, it forms an enlarged image of the object. The eyepiece lens, which is another convex lens, then magnifies the image again. This final image can be hundreds of times larger than the actual object, depending on the focal lengths of the two lenses.

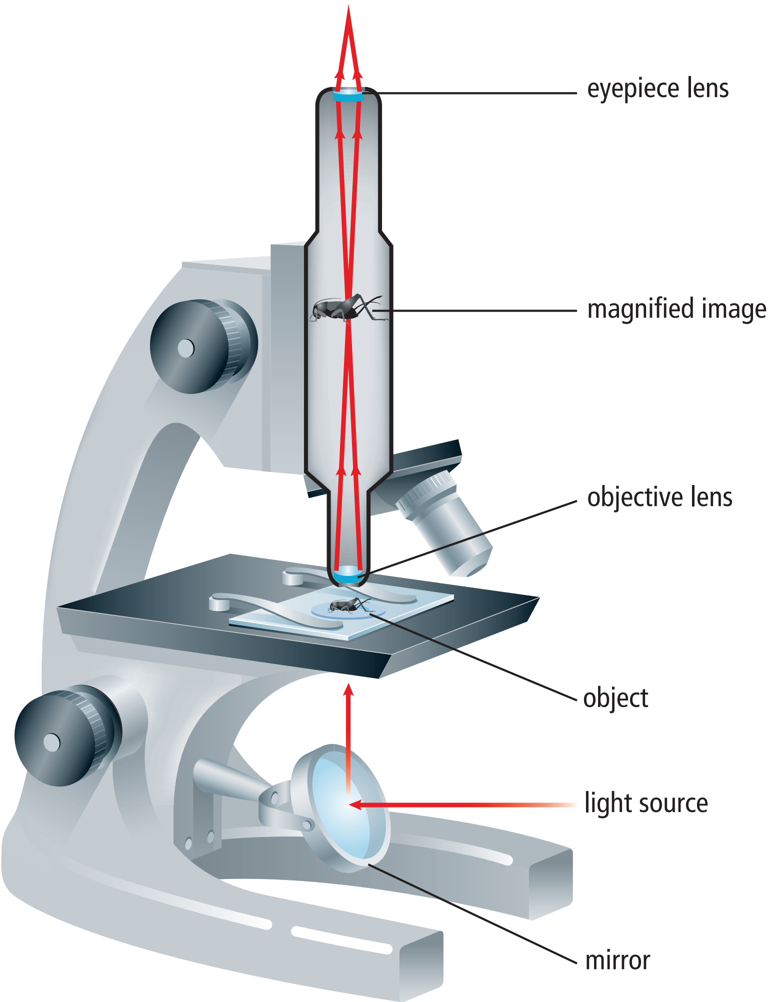


Figure 6.26 This microscope uses two convex lenses to magnify small objects. To focus the image, you have to move the object you are studying closer to or farther from the objective lens.

6-3B Microscopes on the Job

In previous studies, you may have seen how biologists use microscopes. However, biologists are not the only people who need microscopes in their daily work. In this activity, you will find out how microscopes are used in other occupations. You will share your information in a brief presentation.

What to Do

1. Work in groups of two or three. In your group, select an occupation in which a microscope is used, for example:
   - medical laboratory technician
   - mineralogist (someone who studies minerals)
   - forensic laboratory technician (someone who studies evidence related to crimes)
   - gemologist (someone who studies precious stones)
   - metallurgist (someone who studies the properties of metals)
   - petrologist (a geologist who studies the origin and composition of rocks)
2. Research the type of work done by a person in the occupation you have selected. You can find information in the library or on the Internet, or by interviewing people in the occupation. Start your search at www.discoveringscience8.ca. Find answers to the following questions.
   (a) For what purpose does the person use the microscope?
   (b) What type of microscope does the person use?

A forensic scientist uses a microscope to examine a beetle found on a corpse.

   (c) What can be seen through the microscope? (In your presentation, include a typical view. Show this in a circle to represent the field of view of the microscope. Include the magnification, if possible.)
   (d) What does the person do with the information obtained by using the microscope?
   (e) How does using a microscope assist the person at work?
3. Create a presentation based on the occupation you have selected. Make sure you include information on all the questions that you researched. Use appropriate support materials, for example, a pamphlet, poster, overhead transparencies, video, computer, or web site. If possible, produce a multimedia presentation.

What Did You Find Out?

Based on the information in the presentations:

1. List those occupations that make similar uses of the microscope.
2. Identify which occupation uses the microscope in the greatest number of different ways.
3. (a) Which of these occupations is the most interesting to you?
   (b) What do you find interesting about the occupation?
4. Describe how your group's presentation could be improved.

An electron microscope image displayed on a computer screen

Telescopes

You know from experience that it is difficult to see faraway objects clearly. When you look at an object, only some of the light reflected from its surface enters your eye. As the object moves farther away, the amount of light entering your eye decreases, and so the object appears to be dimmer. Scientists have been designing and constructing telescopes for more than 400 years to gather and focus light from faraway stars (Figure 6.27).

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 over 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, the image can be magnified to a greater extent to reveal more detail.

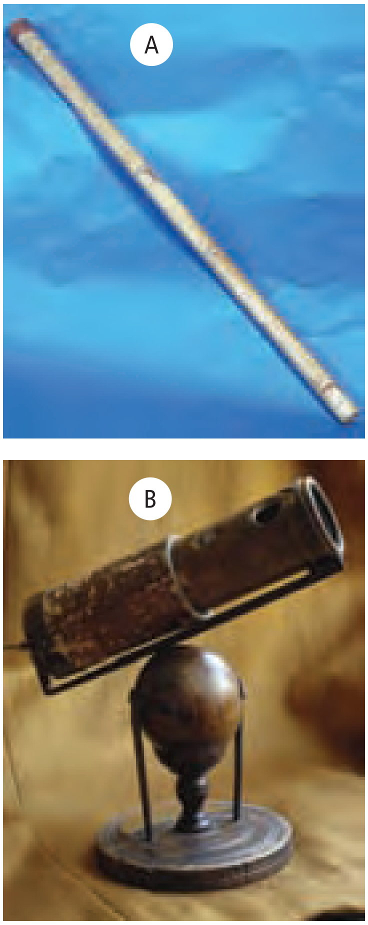


Figure 6.27 (A) Galileo used lenses to build simple telescopes that he used to make discoveries about the Universe. (B) Isaac Newton improved on Galileo's design by using a mirror to collect and begin to focus the light from the stars. This is now known as a reflecting telescope.

Refracting telescopes have similarities to microscopes

A telescope, like a microscope, has an objective lens and an eyepiece lens. However, the objective lens in a telescope has a longer focal length than in a microscope because the objects viewed are far from the lens. The simplest microscopes and telescopes use only two lenses. The lenses bend the light to focus it, which is why a telescope with this design is called a **refracting telescope** (see Figure 6.28).

In both the microscope and the refracting telescope, an objective lens collects light and focusses it into an image (see Figure 6.29). This image is formed inside the microscope or telescope and is never seen directly. Instead, the image is magnified by the eyepiece lens, and directed into the eye of the operator or into a camera.

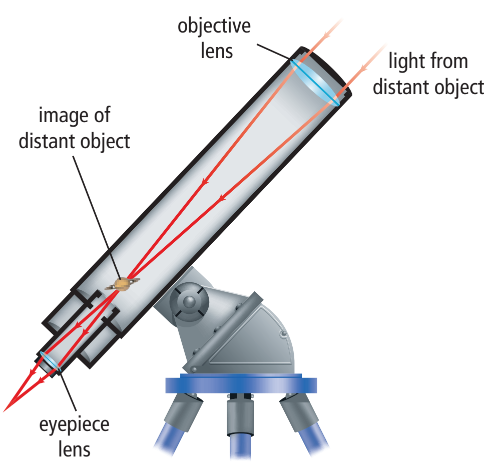


Figure 6.28 Light from a distant object passes though an objective lens and an eyepiece in a refracting telescope. The two lenses produce a large image.

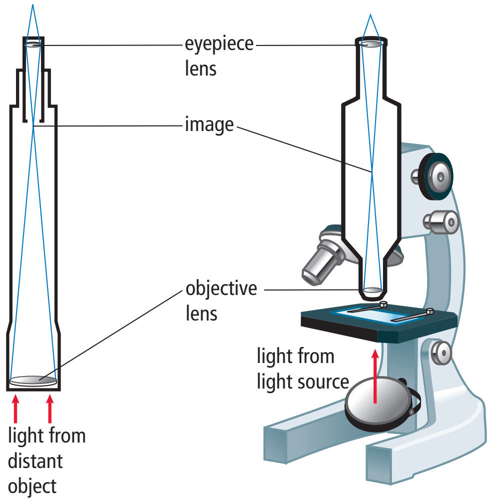


Figure 6.29 In order to focus with a microscope, the object being viewed is moved. In order to focus with a telescope, its eyepiece and the observer are moved.

Figure 6.30 The 102 cm refracting telescope at the Yerkes Observatory in Wisconsin is the largest refracting telescope ever used.

Problems with refracting telescopes

In order to form a detailed image of distant objects, such as planets or galaxies, the objective lens must be as large as possible (Figure 6.30). A large lens is heavy and can be supported in the telescope tube only around its edge. The lens can sag or flex due to its own weight, distorting the image it forms. Also, heavy glass lenses are costly and difficult to make, and even when the highest quality of glass is used, the lens absorbs some of the light.

Reflecting telescopes

Due to the problems with making large lenses, most large telescopes today are **reflecting telescopes**. A reflecting telescope uses a concave mirror, a plane mirror, and a convex lens to collect and focus light from distant objects. Figure 6.31 shows a 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 strikes a plane mirror that is placed at an angle within the telescope tube. The light is reflected from the plane mirror toward the telescope's eyepiece. The light rays converge, creating an image of the distant object. Just as in a refracting telescope, a convex lens in the eyepiece then magnifies this image.

Some telescopes used to study distant galaxies collect the light rays from several mirrors and then combine the rays into a single image. One such telescope is the Keck telescope located in Hawaii (see Figure 6.32).

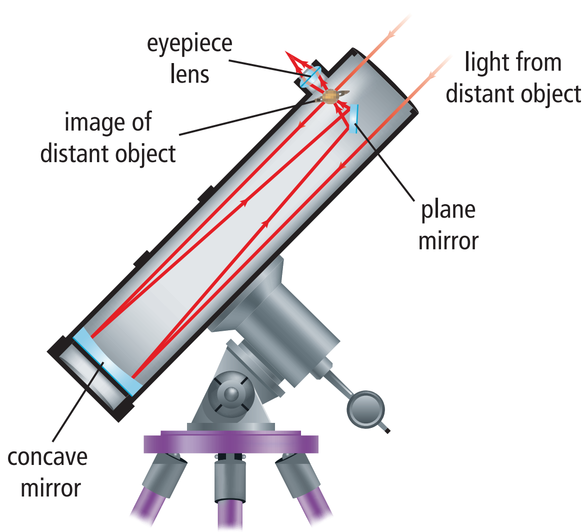


Figure 6.31 Reflecting telescopes use two mirrors to create an image, which is then magnified by a convex lens. In order to focus an image on a reflecting telescope, the eyepiece (convex lens) is moved.

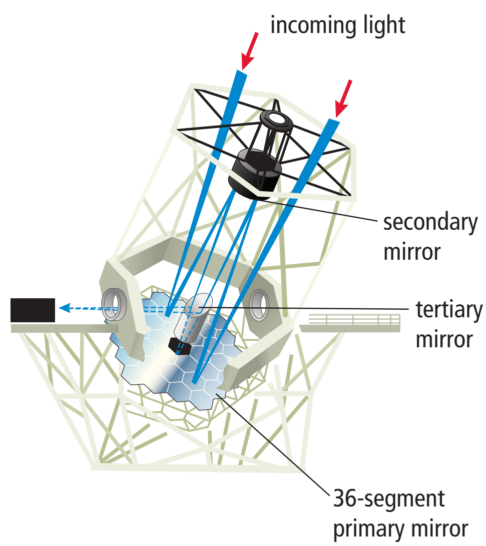


Figure 6.32 The Keck telescope combines light from two mirror systems like the one in the diagram to make a single image that is many times clearer than an image produced by one mirror.

The Hubble Space Telescope

Imagine being at the bottom of a swimming pool and trying to read a sign by the pool's edge. The water in the pool would distort your view of any object beyond the water's surface. In a similar way, Earth's atmosphere blurs the view of objects in space. To overcome the blurriness of our view into space, the Hubble Space Telescope was launched in 1990. The Hubble Space 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 and can collect visible light—as well as other types of electromagnetic radiation—from planets, stars, and distant galaxies. Freed from the distortion caused by Earth's atmosphere, the Hubble Space Telescope has produced images much sharper and more detailed than the largest ground-based telescopes (see Figure 6.33).

internet connect

Find out more about the Hubble Space Telescope, the images it has produced, and Canada's role in servicing the telescope. Start your search at **www.discoveringscience8.ca.**

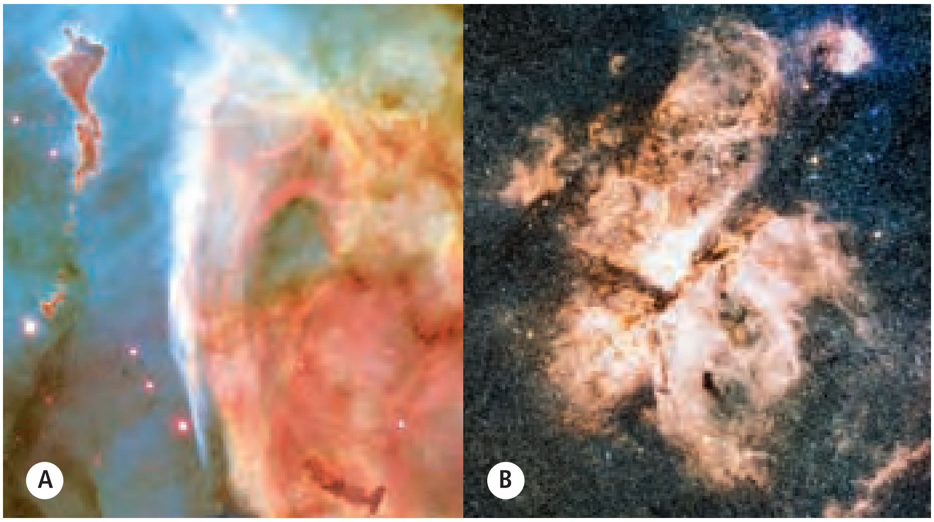


Figure 6.33 The image from the Hubble Space Telescope is clear (A), not blurred by Earth's atmosphere (B).

Binoculars

Binoculars are actually two refracting telescopes mounted side by side. You can imagine how difficult it would be to hold up two long telescopes. The telescopes in binoculars are shortened by placing prisms inside that serve as plane mirrors. Rather than travelling down the long tube of a telescope, the prisms reflect the light in binoculars back and forth inside a shorter tube (see Figure 6.34).

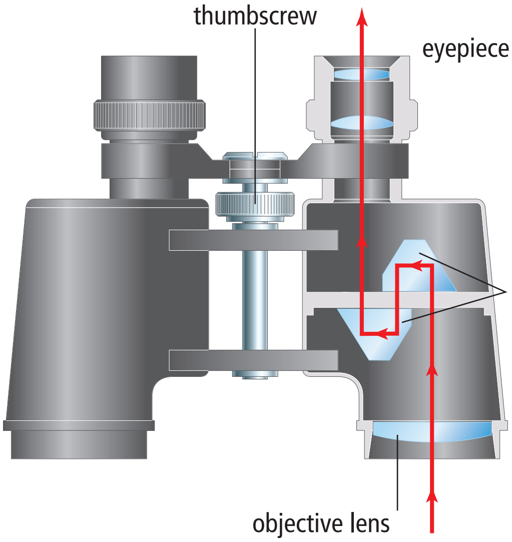


Figure 6.34 The thumbscrew on binoculars is used to change the focal length in order to focus on the objects being viewed.

Cameras

A digital camera works by gathering and bending light with a convex lens. The lens then projects an image onto a light detector to record a digital image of a scene. When you take a photograph, a shutter opens to allow light to enter the camera for a specific length of time. The light reflected off your subject enters the camera through an opening called the **aperture**. The light then passes through the lens, which focusses the image on the light detector. Because a convex lens is used, the image is inverted and smaller than the actual object.

Wide-angle lenses

Suppose you and a friend use two different cameras to photograph the same object at the same distance. If the cameras have different lenses, your pictures might look different. For example, some lenses have short focal lengths that produce a relatively small image of the object but have a wide field of view (see Figure 6.35). These lenses are called wide-angle lenses. Wide-angle lenses must be placed close to the light detector to form a sharp image.

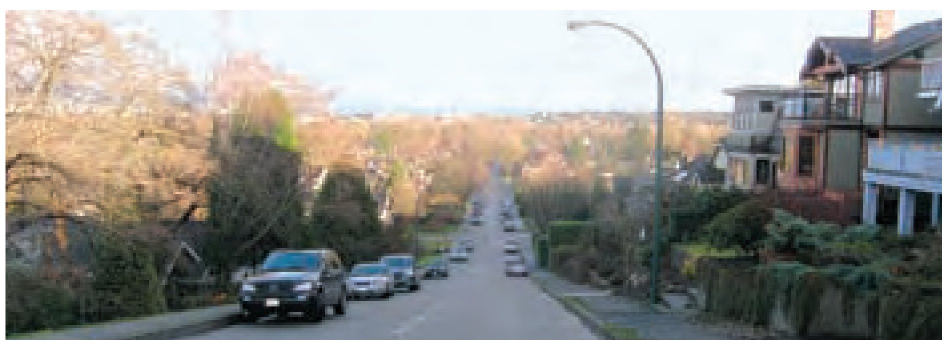


Figure 6.35 A photograph taken with a wide-angle lens

Telephoto lenses

Telephoto lenses have longer focal lengths. The image through a telephoto lens seems enlarged and closer than it actually is (see Figure 6.36). Telephoto lenses are easy to recognize because they usually protrude from the camera to increase the distance between the lens and the light detector (see Figure 6.37).

Figure 6.36 A photograph of the same scene as Figure 6.35 taken with a telephoto lens

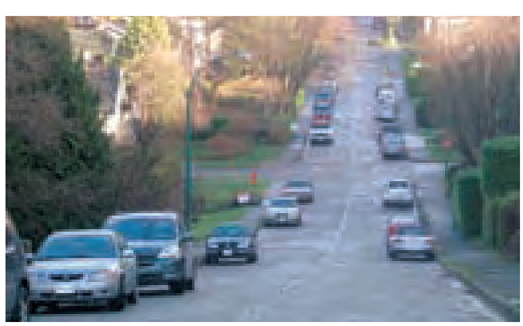


Figure 6.37 A telephoto lens

Cameras Have Similarities to Human Eyes

There are many structural similarities between a camera and the human eye (see Figure 6.38). For example, compare the lens cap for a camera to the human eyelid. Both reduce the chance of accidental damage. An iris limits the amount of light entering the eye. In cameras, this function is accomplished using a device called a **diaphragm**. The diaphragm is made of a number of opaque circles that are arranged in a circle. The circles can be moved to make the central hole larger or smaller. Light passes through the lens and forms an inverted image in both the camera and the eye.

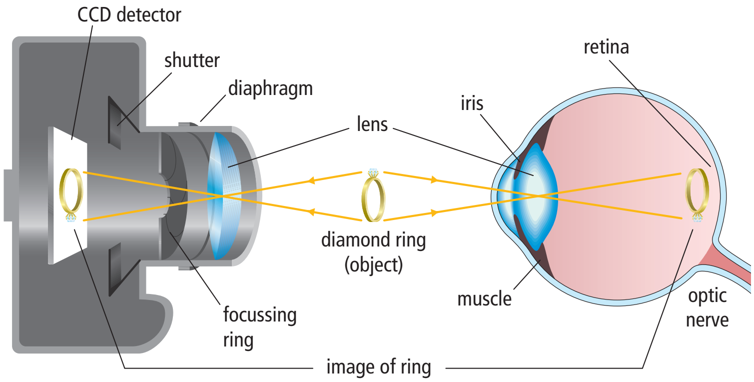


Figure 6.38 A comparison of the camera and the human eye

Not all structures in a camera work the same way as in the human eye. For example, changing the distance between the lens and the detector does the focussing in a camera. Recall that in humans, the lens changes shape, rather than moving closer to the retina.

At the back of the camera is a detector called a **charge-coupled device (CCD)**, which absorbs light and provides the electrical signals needed to produce a digital image. The CCD has many tiny regions, called pixels, each of which is capable of recording a tiny part of the whole image. The pixels correspond to the rods and cones that detect light in our eyes. Research is currently being done to try to connect the electrical signals from a digital camera directly to human optic nerves. This may one day provide a working vision system that will allow people who are blind to see.

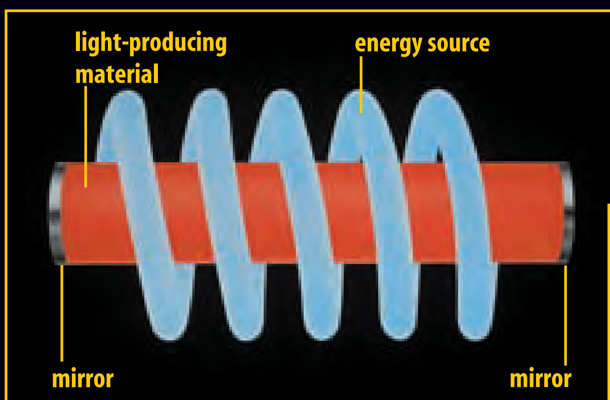
Reading Check

1. How does a microscope magnify an image?
2. How is a reflecting telescope similar to a microscope?
3. How is a reflecting telescope different from a refracting telescope?
4. Why is the Hubble Space Telescope able to produce clearer images than telescopes on Earth?
5. What is the function of prisms in binoculars?
6. How does the focal length of a telephoto lens compare to the focal length of a wide-angle lens?
7. What are two ways in which a camera is similar to a human eye?
8. What are two ways in which a camera is different from a human eye?

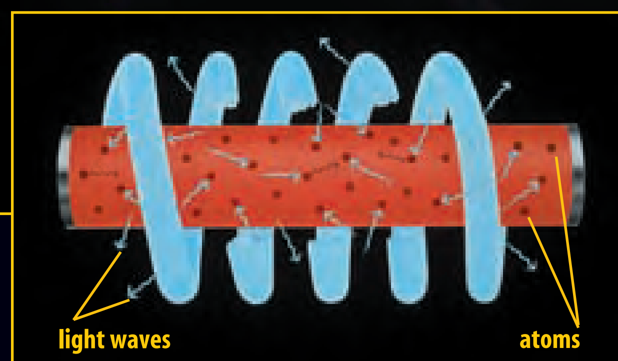
NATIONAL GEOGRAPHIC

VISUALIZING LASERS

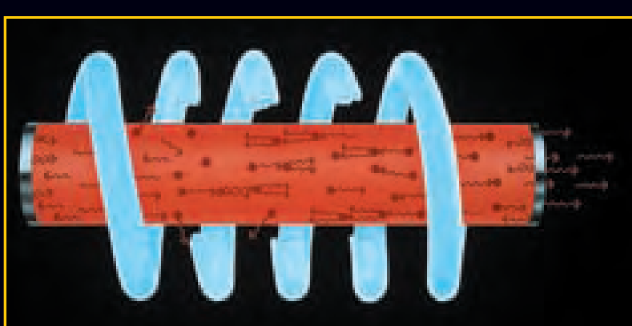
Lasers produce light waves that have the same wavelength. Almost all of these waves travel in the same direction. As a result, beams of laser light can be made more intense than ordinary light. In modern eye surgery, shown at the right, lasers are often used instead of a traditional scalpel.



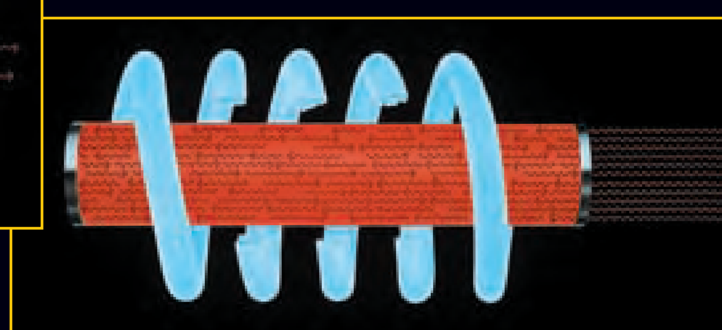
A The key parts of a laser include a material that can be stimulated to produce light, such as a ruby rod, and an energy source. In this example, the energy source is a light bulb that spirals around the ruby rod and emits an intense light.



B When the light bulb is turned on, energy is absorbed by the particles in the rod. These particles then re-emit that energy as light waves that all have the same wavelength. As well, all of the crests and troughs of the waves are aligned.



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



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

Will & Deni McIntyre/Photo Researchers

Check Your Understanding

Checking Concepts

1. Make a table that lists the parts of a camera in one column and the function of each part in the other.
2. (a) Make a labelled diagram to show the arrangement of lenses in a refracting telescope.
   (b) Show how light rays pass from a distant object to the eye of a person looking through the eyepiece.
3. (a) Which lens in a microscope is responsible for producing a magnified image on the inside of the microscope that is not seen directly by the person using the microscope?
   (b) Why is this image produced?
4. Explain the difference(s) between a reflecting telescope and a refracting telescope.
5. Compare the focal length, image size, and field of view for wide-angle lenses and telephoto lenses.

Understanding Key Ideas

6. (a) Explain why telescopes used to study distant galaxies need to have such large mirrors.
   (b) Give two reasons why a large lens is inferior to a large mirror in a telescope.
7. Is the image produced by a microscope real or virtual? Draw a ray diagram to support your answer.
8. Why do you think that modern research telescopes are so large?
9. Centuries ago, Galileo and Isaac Newton worked independently to construct refracting and reflecting telescopes. Why do you think it is necessary for large groups of scientists and engineers to work together to design and build modern telescopes, such as the Hubble Space Telescope?

Pause and Reflect

Below are two photographs, one taken through a telescope and the other through a microscope. One is of Earth, taken from above the Moon. The other is of common bacteria called *E. coli*, which are found in the mouth of every healthy person on Earth. These two viewpoints were unknown to humans only three generations ago. Reflect on each, select one, and explain why being able to see this scene might be important to how humans see the world.

Chapter Review

Prepare Your Own Summary

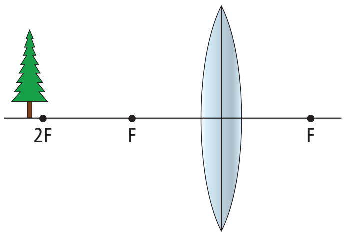
In this chapter, you investigated how lenses work, how we see, and how human vision can be extended using optical systems. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. Use the following headings to organize your notes:

1. Ray Diagrams for Convex and Concave Lenses
2. How We See
3. Correcting Focus Problems
4. Using Optical Systems to Magnify Close Objects
5. Using Optical Systems to See Distant Objects

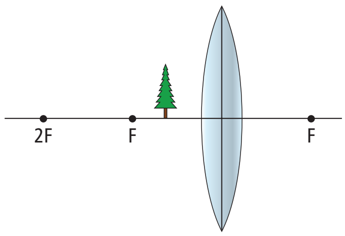
Checking Concepts

1. What type of lens can make parallel rays converge, or come together?
2. What type of lens always makes parallel rays diverge, or spread out?
3. Copy the following diagrams of convex lenses in your notebook. For each, complete a ray diagram using three rays. Describe the characteristics of the image.

(a)



(b)

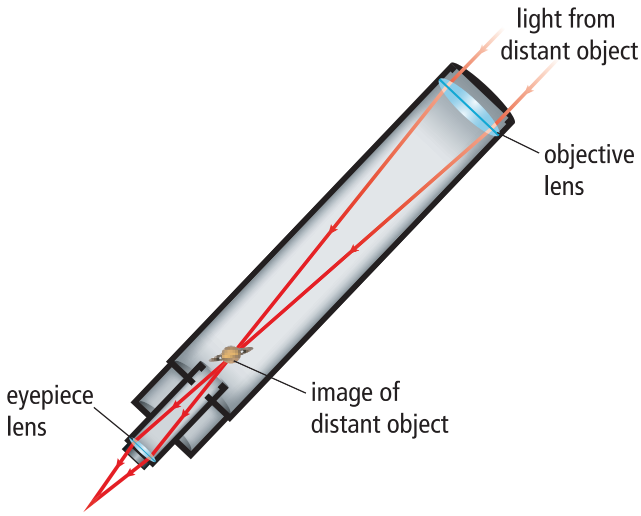


4. (a) Which type of lens, convex or concave, should a person who is near-sighted use? Explain.
   (b) Which type of lens, convex or concave, should a person who is far-sighted use? Explain.
5. What is astigmatism?
6. Draw a diagram showing the mirror and lens arrangement in a reflecting telescope.
7. (a) Explain how focussing occurs in a microscope.
   (b) Explain why this type of focussing would not work for a telescope.
8. Binoculars are similar to two telescopes mounted in parallel, except that they are not very long. How is this shortening accomplished?

Understanding Key Ideas

9. Many people over 50 years old wear reading glasses. Why do you think this is the case?
10. Explain why it takes a few minutes to be able to see when you walk from full daylight into a darkened room. List the adaptations that happen in the eye to adjust to low-light vision.
11. Explain why mirrors have one focal point but lenses have two focal points. Describe the relationship between the two focal points of a lens.
12. When a nearsighted person looks at an object without wearing glasses or contact lenses, the image is blurry. Explain the cause of this blurriness.

13. One type of lens can produce an image that is inverted, real, larger than the object, and farther from the lens than the object. Is this lens convex or concave? Where is the object relative to the focal point? Sketch a ray diagram that verifies your answer.
14. State the function in a telescope of:
    (a) objective lens or mirror
    (b) eyepiece lens



15. Why is the image that you observe in a refracting telescope inverted?
16. Suppose your camera is focussed on a person who is 2 m away. You now want to focus on a tree that is farther away. Should you move the lens closer to the CCD or farther away? Explain your answer.
17. When you use the highest magnification on a microscope, the image is much darker than it is at lower magnifications.
    (a) What are some possible reasons for the darker image?
    (b) What could you do to obtain a brighter image?

Pause and Reflect

Eyeglasses were first developed in Italy in the 13th century and were used mainly by nobles and the clergy. Then, in 1456, Johannes Gutenberg invented the printing press. What effect do you think the availability of eyeglasses had on the number of books printed? What effect do you think the number of books printed had on the production of eyeglasses? If eyeglasses were not available, would books have become an important source of information? Explain your ideas.

Unit Summary

4 Many properties of light can be understood using a wave model of light.

- Humans built telescopes and microscopes before they understood the nature of light. (4.1)
- Waves are disturbances that transmit energy from one place to another. (4.2)
- Waves have amplitude, wavelength, and frequency. (4.2)
- As wavelength decreases, frequency increases. (4.2)
- Different colours of light have different wavelengths. (4.3)
- White light is a mixture of many wavelengths of light. (4.3)
- A prism can separate and recombine different colours of light (4.3)
- The electromagnetic spectrum is made up of waves that are similar to light waves that have much longer or shorter wavelengths. (4.4)
- Radio waves, microwaves, and infrared waves have longer wavelengths than visible light. (4.4)
- Ultraviolet waves, X rays, and gamma rays have shorter wavelengths than visible light. (4.4)

5 The law of reflection allows mirrors to form images.

- The angle of reflection is equal to the angle of incidence. (5.1)
- Reflection can be either specular or diffuse, depending on the reflecting surface. (5.1)
- An image in a plane mirror is virtual and is the same size, orientation, and distance from the mirror as the object. (5.2)
- A concave mirror curves in at the centre and a convex mirror curves out. (5.3)
- Images in concave mirrors can be real or virtual, upright or inverted, larger or smaller than the object, depending on the distance between the object and the mirror. (5.3)
- Images in a convex mirror are virtual, upright, and smaller than the object. (5.3)
- Ray diagrams allow you to predict the characteristics of images in mirrors. (5.3)

6 Lenses refract light to form images.

- The characteristics of images produced by convex lenses depend on the distance of the object from the lens. (6.1)
- Images produced by concave lenses are always upright, virtual, closer to the lens, and smaller than the object. (6.1)
- Light is detected by the eye using the cornea-lens-retina system. (6.2)
- Rod cells detect dim light but are not sensitive to colour. (6.2)
- Cone cells dominate in bright light and distinguish between colours. (6.2)
- Vision deficiencies include near-sightedness, far-sightedness, astigmatism, and deficiencies in distinguishing between different colours. (6.2)
- Eyes, cameras, microscopes, and telescopes have some similarities in the way they operate. (6.3)
- Microscopes and refracting telescopes use only lenses to magnify objects, while reflecting telescopes use both mirrors and lenses. (6.3)

Key Terms

- amplitude
- compression wave
- crest
- electromagnetic radiation
- energy
- force
- frequency
- gamma rays
- hertz
- infrared waves
- medium
- microscope
- microwaves
- Pythagoras
- radiant energy
- radio waves
- reflection
- refraction
- spectrum
- telescope
- transverse wave
- trough
- ultraviolet waves
- visible light
- wave
- wave model of light
- wavelength
- X rays

Key Terms

- angle of incidence
- angle of reflection
- angle of refraction
- concave mirror
- convex mirror
- diffuse reflection
- extended rays
- focal point
- image
- image distance
- incident ray
- inverted
- law of reflection
- normal
- object distance
- opaque
- particle model of light
- plane mirror
- principal axis
- ray diagram
- ray model of light
- real image
- rectilinear propagation
- reflected ray
- refracted ray
- specular reflection
- translucent
- transparent
- upright
- vertex
- virtual image

Key Terms

- aperture
- astigmatism
- blind spot
- blindness
- charge-coupled device (CCD)
- colour blindness
- concave lens
- cone cells
- convex lens
- cornea
- diaphragm
- far-sighted
- focal length
- iris
- lens
- near-sighted
- night blindness
- optical centre
- optic nerve
- pupil
- reflecting telescope
- refracting telescope
- retina
- rod cells
- sclera
- snow blindness

Building an Optical Device

Modern optical technologies make use of combinations of lenses, mirrors, prisms, and other optical elements. In this project, you will design, build, and test a device that uses both mirrors and lenses.

Problem

Design an optical device that uses at least three stages. You must use at least one mirror and at least one lens. You can use more if you choose. You will use the device to see behind you or around corners and to see distant objects clearly.

Safety

- use care when handling sharp glass objects and scissors.

Materials

- variety of lenses (convex and concave)
- plane mirrors (one or more)
- cardboard
- tape
- scissors
- glue
- ruler
- pencil

Criteria

- In a small group, design and build an optical device.
- The device must use both mirrors and lenses.
- The device must allow you to magnify tiny or distant objects, or to see behind you, over a barrier, or around a corner.
- The image must be clear.

Procedure

1. With your group, brainstorm ideas about what you will build. The toy periscope shown here might give you some ideas.

2. Make a sketch of the device with specifications including dimensions. List the materials that you will need.
3. Collect the materials that you will need.
4. Show your plans to your teacher and get approval before you begin to build your device.
5. Assemble and test your device. If it does not work the way you intended for it to work, discuss what modifications you could make.
6. If necessary, make modifications until your device functions properly.

Report Out

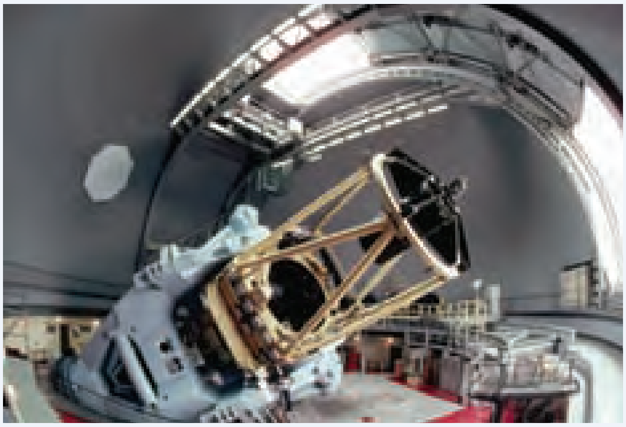
1. In your small group, plan a presentation that you can report to your class.
   - Include the materials that you used.
   - Explain and demonstrate how your device works.
   - Discuss the problems that you encountered and how you solved them.
2. Evaluate your device. Discuss how well it met your original expectations.

Mirrors for Reflecting Telescopes

You have learned a lot about mirrors and lenses and how they are used. In this investigation, you will do research to learn more about one specific application of mirrors for astronomical telescopes.

Background

Galileo designed and built refracting telescopes. Isaac Newton designed and built the first reflecting telescope in 1668. These early telescopes were used to make important discoveries, such as the moons of Jupiter. Astronomers today, however, are building "bigger and better" telescopes. Most large astronomical telescopes are reflecting telescopes. Some, like the one shown here, do not even look like telescopes.



All modern reflecting telescopes have very large mirrors. Some are as large as 10 m in diameter. Other telescopes have several different mirrors that work together. Some institutions are developing liquid mirrors like the one in the photograph on the right for use in telescopes.

Find Out More

Use print resources and the Internet, starting at **www.discoveringscience8.ca**, to learn more about mirrors for large astronomical telescopes. The following questions provide a starting point.

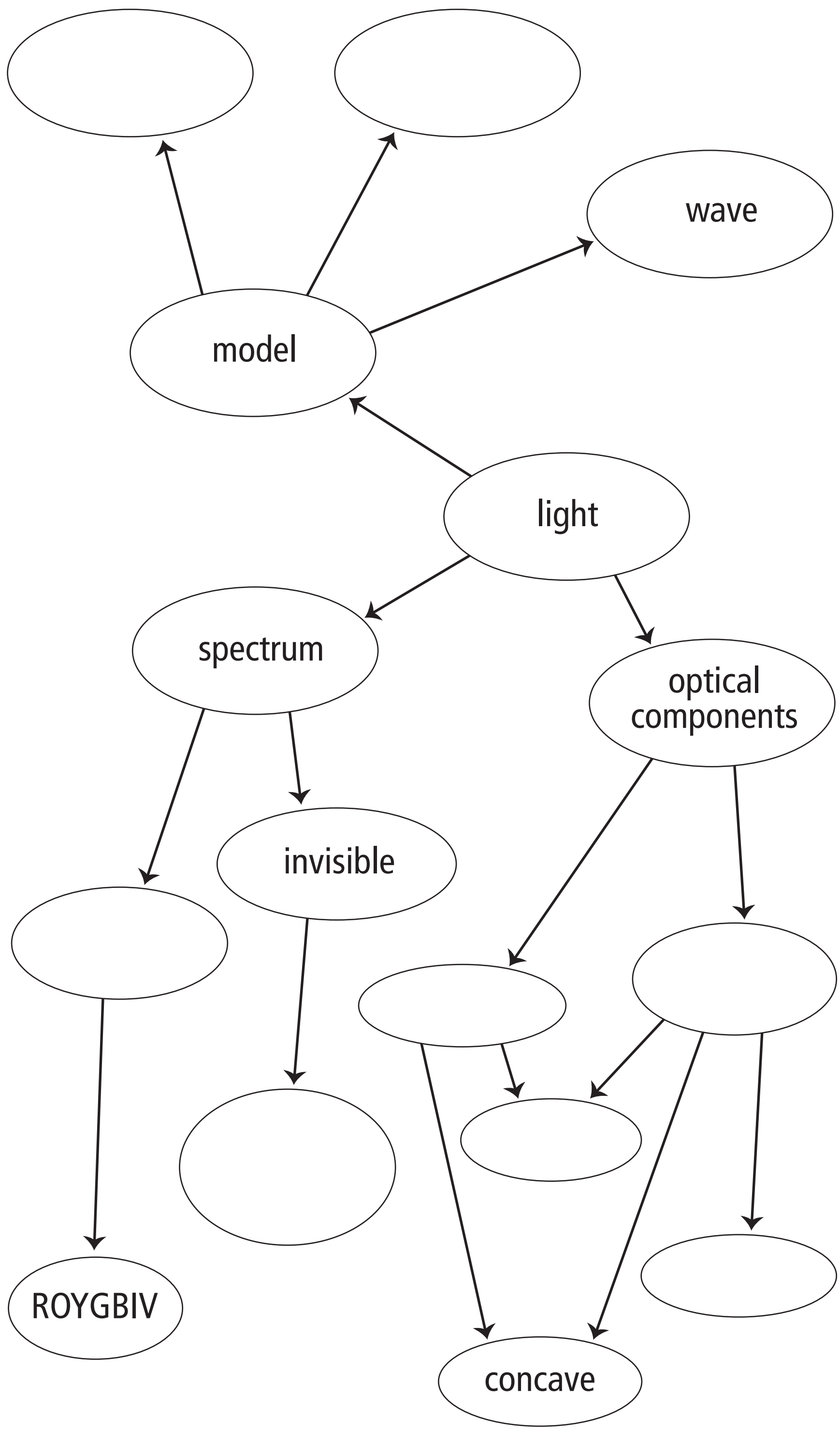
- Why are telescope mirrors so large? What can astronomers learn by using these extremely large mirrors that they cannot learn with smaller telescopes?
- What is a liquid mirror? How can a liquid have a curved surface necessary for collecting and focussing light?
- How big is the largest mirror for a telescope?
- How heavy are the large mirrors?

Report Out

Prepare a poster, brochure, or electronic presentation that you could use to provide information to your classmates. Include photographs, a discussion, and a summary or the things that you learned through your research. If possible, give an oral presentation to your class.

Visualizing Key Ideas

1. Copy the concept map about light into your notebook. Complete the concept map to help review Unit 2.



Using Key Terms

2. Indicate whether the following statements are true or false. If a statement is false, rewrite it to make it true.
   (a) The amplitude of a wave is the distance from a crest to a tough.
   (b) Infrared waves transfer heat.
   (c) Translucent materials prevent light from penetrating the object.
   (d) Refraction is the bending of the direction of a wave when it passes from one medium to another.
   (e) Specular reflection scatters light, preventing the formation of an image.
   (f) The angle of reflection is the angle between a reflected wave and the reflecting surface.
   (g) A real image can be seen if you place a screen where the image is focussed.
   (h) When parallel rays are reflected from a convex mirror, they travel toward each other and pass through the focal point.
   (i) Concave mirrors always spread light out, and therefore cannot form images.
   (j) When a ray passes from a less dense medium to a more dense medium, the ray bends away from the normal.
   (k) Far-sighted vision results when light rays produce an image before they reach the retina.
   (l) Convex lenses always form virtual images.
   (m) Microscopes have objective lenses but telescopes do not.
   (n) A refracting telescope is made of a combination of lenses and mirrors.

Checking Concepts

4

3. Describe one situation in which early technologies involving light made new scientific discoveries possible.
4. Draw a light wave. Label amplitude, wavelength, trough, and crest.
5. Explain how a prism affects white light that passes through it.
6. How do transparent and translucent materials differ when light strikes them?
7. Explain why light, but not sound, can travel through a vacuum.
8. Describe one application of microwaves and one application of X rays.

5

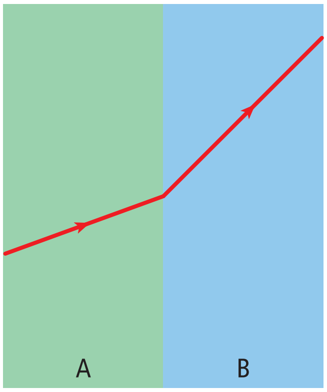
9. State the law of reflection.
10. How can light rays that are involved in both specular and diffuse reflection all follow the law of reflection?
11. Explain how a change in the speed of a wave can cause a change in the direction of a wave.
12. Describe the characteristics of images formed by plane mirrors.
13. When drawing a ray diagram for a concave mirror, one of the rays that you draw goes from the top of the object through the focal point to the mirror. How will you draw the reflected ray?
14. What will be the characteristics of the image of an object that is between the focal point and twice the distance to the focal point from a concave mirror? If you need to, draw a ray diagram to analyze the image.
15. Make a sketch to show how you would find the focal point for a convex mirror.
16. Explain the difference between real and virtual images.

6

17. When you are drawing a ray diagram for convex lenses, one of the rays you draw goes from the top of the object, parallel to the principle axis, to the lens. How do you draw the refracted ray?
18. Where must the object be located in order for a convex lens to produce an image that is real, inverted, smaller than the object, and closer to the lens than the object? If you need to, sketch a ray diagram to find an answer.
19. How does the distance of the object from a concave lens affect the image? For example, as the object moves farther from the lens, what happens to the characteristics of the image?
20. Describe how the shape of the lens in your eye changes when you look at a nearby object, and then at a distant object.
21. What type of lens can correct nearsightedness? Use a diagram to demonstrate why your answer is correct.
22. List and describe four common defects in human vision.
23. Draw a labelled diagram showing how binoculars work.
24. Compare and contrast a refracting telescope and a microscope.

Understanding Key Ideas

25. Summarize two uses of the invisible spectrum in producing medical images of the human body.
26. Describe two properties of light and one other type of electromagnetic wave that support the idea that they are two different types of the same general kind of wave.
27. Explain the properties of light and reflection that make it possible to read black print on a white piece of paper.
28. Explain why you can see your image in a mirror but when you look at a piece of very smooth white paper, you do not see an image even though the paper reflects the light according to the law of reflection.
29. Defend the statement: A concave mirror could be used to form an image on a screen, but a convex mirror could not.
30. Compare how colour vision works with how black-and-white vision works.
31. Explain the functions of the objective and eyepiece lenses in a microscope.
32. Examine the ray diagram below in which the green and the blue regions represent different media. Which medium is more dense? Explain.



33. Explain how you would determine the focal length of a convex lens.
34. Why do mirrors have only one focal point but lenses have two?

Thinking Critically

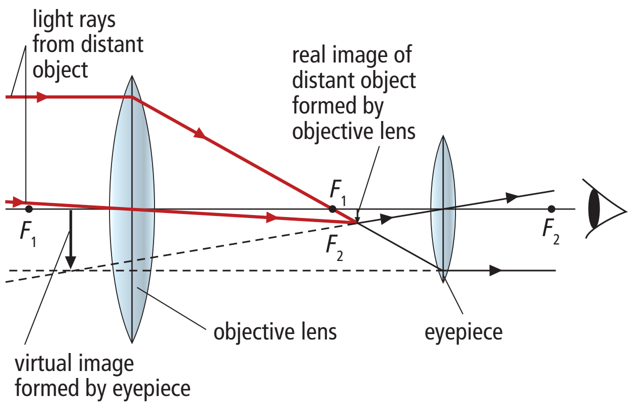
35. A lens made of plastic is placed in a liquid. Light rays travelling in the liquid are not refracted when they pass through the lens. Compare the speed of light in the plastic and in the liquid.

36. A person takes a photograph of an image in a plane mirror. If the camera is 2 m in front of the mirror, at what distance should the camera lens be focussed?

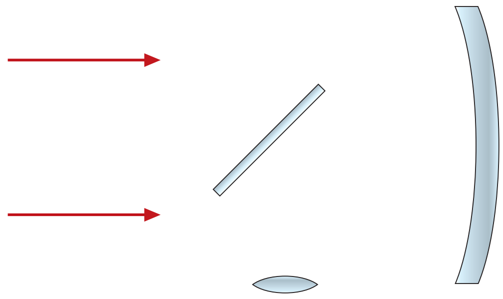
37. What would happen to an image made by projecting light through a lens onto a screen if you cover the left half of the lens with your hand?

Developing Skills

38. The diagram below is a ray diagram for a refracting telescope. Follow each ray. Explain why each ray was drawn as it was according to the rules for drawing ray diagrams.



39. The diagram below shows the elements in a reflecting telescope. There is a concave mirror, a flat mirror, and a convex lens. The arrows represent light rays coming from a distant star. Copy the diagram and show where the rays go and how they reach the observers eye.



Pause and Reflect

As people age, the lenses of the eyes stiffen and the muscles cannot make the lenses change shape. This makes it difficult to focus on nearby objects. Some people wear reading glasses to correct for this problem. Others need bifocal glasses, which have a small section in the lower part of the lens that corrects for reading. Do you think bifocals would be worn by near-sighted or far-sighted individuals?