Key Terms

- objective lens
- eyepiece
- cornea
- retina
- myopia
- hyperopia
- presbyopia
- astigmatism
- night-vision device

12.3 Lens Technologies and the Human Eye

In 1608 C.E., Galileo Galilei (1564–1642) heard about the invention of telescopes. Within a year, he was designing and building his own. In 1610 C.E., he discovered four of Jupiter's moons using his homemade telescope, similar to the one shown in **Figure 12.15**. He was also able to see craters on the Moon and the phases of Venus (like phases of the Moon). He made these discoveries before the theory of lenses had been fully developed—a remarkable accomplishment.

However, when Galileo increased the magnification, the field of view—the area that he could see—became smaller. For example, when he looked at the Moon, he could not see the entire Moon. His telescope was also affected by spherical and chromatic aberration.

Telescope Modifications

The famous astronomer Johannes Kepler (1571–1630) modified the design of Galileo's telescope to get greater magnification, but his changes also inverted the image. If he had used it to look at objects on Earth, the inverted image would have been very distracting. However, when studying the skies, the inverted image was not a problem.

Galileo's telescope used two lenses—a converging lens and a diverging lens. He used the converging lens for the objective lens. Light enters the telescope through the **objective lens**. He used the diverging lens for the eyepiece. The observer looks into the **eyepiece**, and light leaves the telescope through the eyepiece.

objective lens the lens through which light enters a telescope

eyepiece the lens in a telescope through which the observer views the object and through which light leaves the telescope

Figure 12.15 Galileo made some remarkable discoveries in astronomy using a telescope like this one.

Ray Diagrams for Telescopes

Figure 12.16 shows a ray diagram for a telescope like Galileo's. Notice that F_1 is the focal point of the objective lens and F_2 is the focal point of the eyepiece. The two lenses are positioned so that the focal points to the right of both lenses are at the same place. Rays (shown in red) from a distant star or planet pass through the objective lens. If the eyepiece lens were not present, the objective lens would focus the image to the far right of the diagram. However, the rays reach the eyepiece before an image is formed. The eyepiece lens refracts the rays (shown in green) and creates a virtual, upright image between the two lenses.

Suggested Investigation

Inquiry Investigation 12-C, Make a Simple Telescope, on page 516

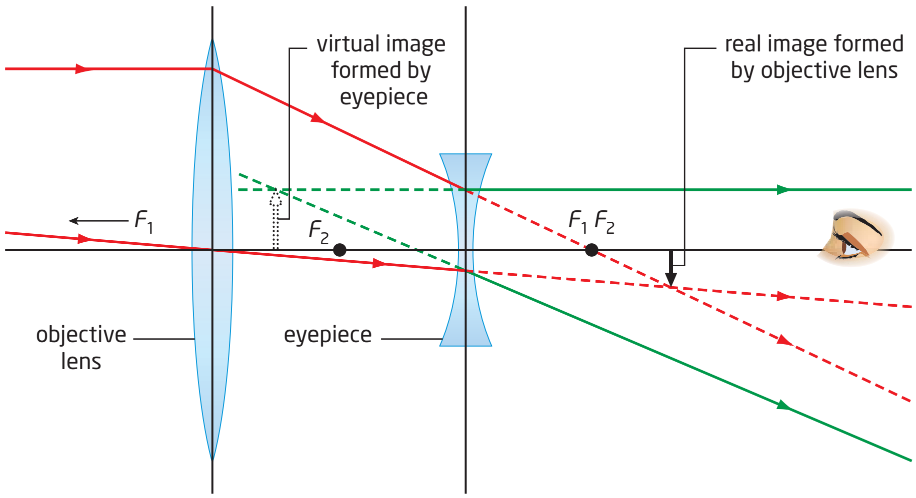


Figure 12.16 In Galileo's telescope, the objective lens alone would produce an inverted image. The eyepiece changes it into an upright image.

A ray diagram of Kepler's telescope is shown in **Figure 12.17**. The two lenses are positioned so that their focal points are at the same point between the lenses. Light from distant stars or planets enters through the objective lens and forms an image between the two lenses. These rays are shown in red. The image formed by the objective lens becomes the object for the eyepiece lens. Light from the first image then passes through the eyepiece lens and forms a virtual image that appears to come from just beyond the objective lens. The rays coming from the first image to the eyepiece are shown in green. The final image is inverted and is larger than the image formed by the objective lens.

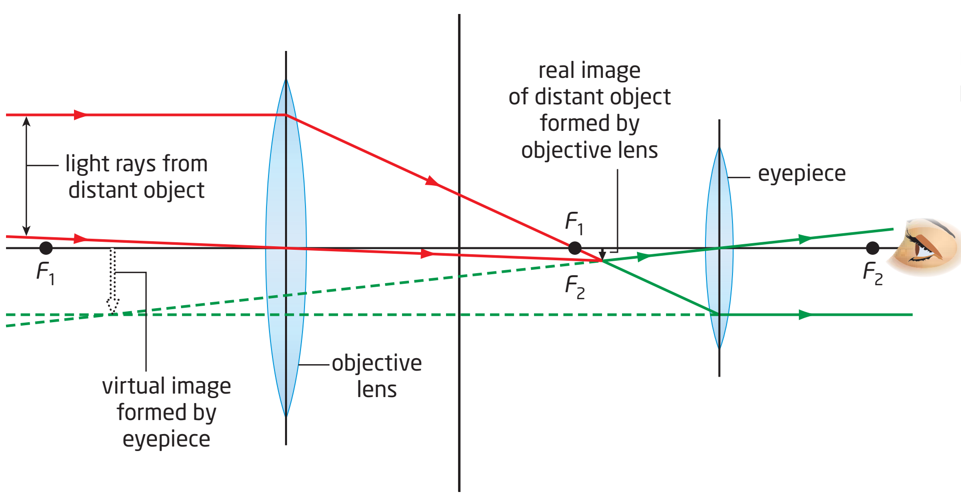


Figure 12.17 Kepler's telescope produces an inverted image.

Sense of Value

Sir Isaac Newton's desire to improve telescope design led him to study optics in more detail. In the 1600s, he made ground-breaking contributions to the study of optics and light.

Newton's Innovation

Sir Isaac Newton (1642–1727) was very distracted by the chromatic aberration in Galileo's and Kepler's telescopes. He was able to significantly reduce the chromatic aberration by using a concave mirror as the objective. A ray diagram for Newton's telescope is shown in **Figure 12.18**. Light enters the telescope and travels to the concave mirror objective. The mirror reflects the light toward focal point F_1. Before the rays reach F_1, a flat mirror reflects them to F_2, the focal point of the eyepiece lens. Rays from F_2 pass through the eyepiece, which magnifies the image.

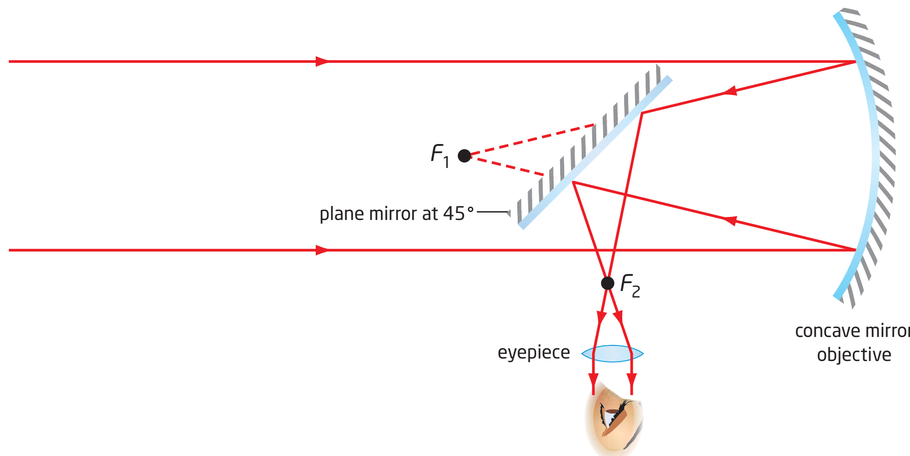


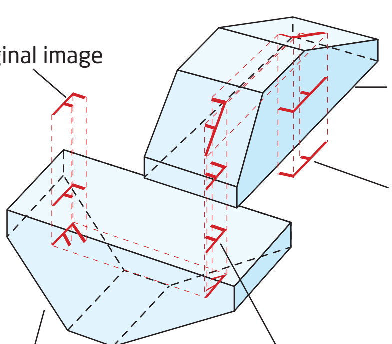
Figure 12.18 The curved mirror in Newton's telescope would form a real image inside the telescope if the flat mirror were not present. The flat mirror reflects the image through a tube to the side of the telescope for viewing.

Modern Telescopes

Although tremendous advances have been made in telescopes, all modern telescopes are based on the designs of Galileo, Kepler, and Newton. Those based on the Galileo and Kepler telescopes are called *refracting telescopes* because they only use lenses. Telescopes based on Newton's design are called *reflecting telescopes* because they also include a mirror.

An important feature of all optical telescopes is the amount of light that they are able to collect. If too little light is collected, a star might be in the field of view but still may not be seen. The only way to allow in more light is to make the objective lens or mirror as large as possible but still maintain a precise shape. A large objective lens is more difficult to make than a large mirror, so most large, modern telescopes are reflecting telescopes.

Figure 12.19 The first prism inverts the image side to side, and the second prism inverts the image up and down.



Binoculars

Binoculars are really just two refracting telescopes based on Kepler's design that are attached so that both eyes see the same image. Recall from Chapter 11 that binoculars have two prisms on each side that use total internal reflection. Reflecting through the prisms makes the light path longer. The longer light path provides better magnification. The prisms are oriented such that the image is upright when it reaches the observer's eye. Carefully follow the path of the image (the letter F) in **Figure 12.19** to see how this inversion of the image is accomplished.

Microscopes

As you may know from previous science classes, the purpose of a microscope is to make a tiny specimen larger. The microscope was invented in 1590 by Johannes and Zacharias Jansen, from the Netherlands. At the time, microscopes were used mainly to study plant and animal specimens. Today, microscopes are used in many more applications, such as studying human cells, animal cells, and minerals. Some doctors and medical researchers use microscopes to investigate diseases and even figure out the cause of a person's death.

Ray Diagrams for Microscopes

If you have used a microscope similar to the one in **Figure 12.20** in your classroom, you may remember the objective lenses and the eyepiece, or ocular lens. **Figure 12.21** is a ray diagram for a microscope, but it has been rotated 90° so that it is horizontal. The figure shows the path of light rays from the specimen to the eye of the observer. Rays from the specimen (shown in red) pass through the objective lens, and the refracted rays form an inverted, real image between the lenses. Rays from the image (shown in green) pass through the eyepiece, which again refracts the rays, and then form the final inverted, virtual image.

Figure 12.20 You have probably used a classroom microscope similar to this one.

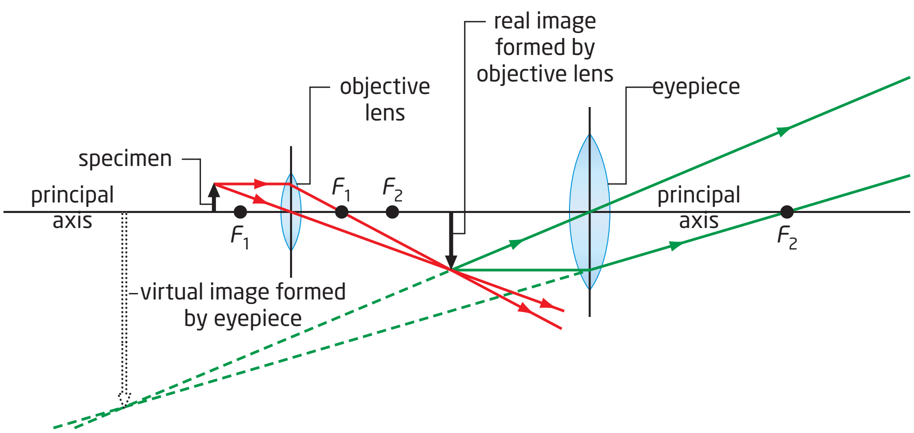


Figure 12.21 You could say that the image produced by the objective lens in a microscope becomes the object for the eyepiece.

Study Toolkit

Making Connections to Prior Knowledge What connections to your prior knowledge can you make about microscopes? A concept map can help show the connections.

Learning Check

1. Newton was disturbed by a characteristic of Galileo and Kepler telescopes. What was the problem, and how did he fix it?
2. Using a Venn diagram, compare refracting and reflecting telescopes.
3. Why are most modern telescopes reflecting rather than refracting telescopes?
4. When you think of telescopes, you usually think of studying the stars and planets. Describe a practical application for using telescopes to see objects on Earth.

Figure 12.22 The eye of a colossal squid is 100 times larger than the human eye.

Sight and the Human Eye

The eye of a colossal squid, shown in **Figure 12.22**, is similar to the human eye except for one characteristic—size. Scientists believe that the eye of a living colossal squid might be as much as 40 cm in diameter, making it larger than a soccer ball. Thus, the squid eye is about 100 times larger than a human eye.

The colossal squid lives in the ocean near Antarctica, at a depth of at least 1000 m. At this depth, there is very little light. A human eye would see total darkness. The size of the eye of the colossal squid allows it to collect much more light, and the squid can therefore see its prey at great depths. In addition, the squid has light organs on each eye that produce light through bioluminescence.

cornea tissue that forms a transparent, curved structure in the front of the eye; refracts light before it enters the eye

retina a layer of rod and cone cells that respond to light and initiate nerve impulses; rod cells are very sensitive to light but cannot distinguish between colours; cone cells detect colour

The Human Eye

Human sight is a marvellous thing. We can focus on objects at different distances, record images, and detect subtle changes in colour and brightness. The focussing happens at the front of the eye, and everything else happens at the back of the eye and in the brain. **Figure 12.23** describes some features of the human eye. Two important parts of the eye that you will learn about in this section are the cornea and retina. The **cornea** is tissue in front of the eye. The cornea refracts light before it enters the eye. The **retina** is a layer of cells that respond to light and initiate nerve impulses.

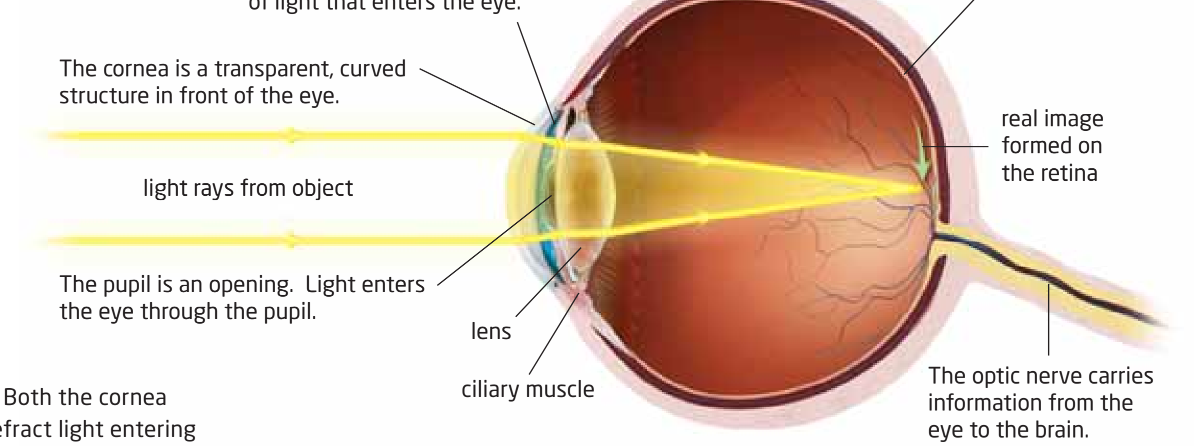


Figure 12.23 Both the cornea and the lens refract light entering the eye and focus an image on the retina. The cornea causes more refraction than the lens.

How the Human Eye Focusses

Recall from your study of lenses that when an object is moved, the image also moves. In the eye, however, the distance between the retina and the lens is always the same. The cornea refracts the light in the same way regardless of the location of the object. The lens in your eye can change shape and thus refract light to a different extent, allowing it to focus light from both nearby and distant objects on the retina. The ciliary muscles make the lens shorter and thicker.

The Changing Lens

Figure 12.24 shows how the shape of a lens affects the position of the focal length. To focus on a nearby object, the curvature of the lens needs to be greater.

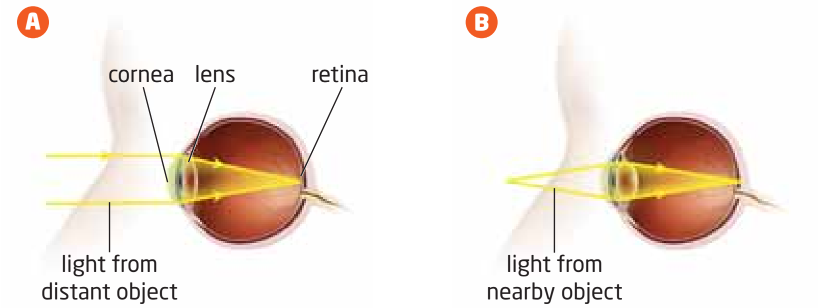


Figure 12.24 In **A**, the relaxed normal eye lens focusses a distant object correctly on the retina. In **B**, the ciliary muscles make the lens shorter and thicker to focus on nearby objects.

Comparing the Eye and the Camera

The camera is designed very much like an eye. **Figure 12.25** compares the human eye to a camera. Both have lenses that focus light on a light-sensitive material. The lens of the eye changes shape in order to focus on objects at different distances. The lens of the camera must be moved in and out to focus on objects at different distances. In the camera, the light-sensitive material is either film or CCDs (charge-coupled devices). In the eye, the retina is the light-sensitive tissue. The camera has an aperture that controls the amount of light that enters the camera. The pupil controls the amount of light that enters the eye.

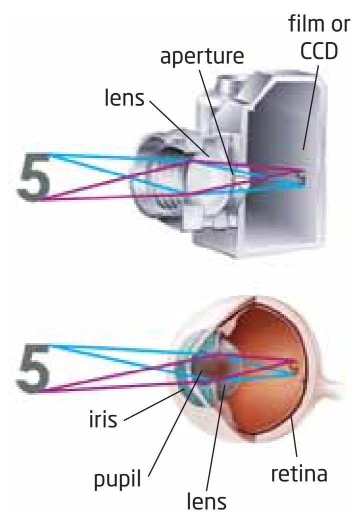


Figure 12.25 Notice that the images in the eye and the camera are upside down. Your brain processes the image it receives from the eye and gives you the sense that it is upright.

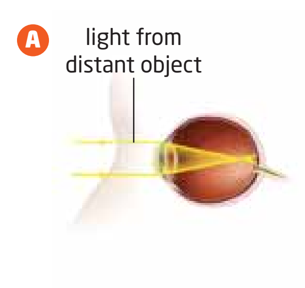
Correcting Vision Using Lenses

Common causes of poor vision are an incorrect shape of the eyeball, an incorrect shape of the cornea, and hardening of the lens. Each condition can be corrected by eyeglasses or contact lenses. Most can be corrected by laser surgery. Four of these conditions are discussed below.

Myopia

Myopia [pronounced my-OPE-ee-ah] is near-sightedness: the eyes cannot focus on distant objects. **Figure 12.26A** shows parallel light rays coming from a distant object. The cornea and eye lens refract the light and bring the rays together. However, the eyeball is too long, and the image forms in front of the retina. When the rays reach the retina, they have begun to spread out again, and the image is blurry. **Figure 12.26B** shows how a diverging lens spreads out the parallel rays before they reach the eye. The rays that are separating from each other appear to be coming from an object that is closer to the eye. When the eye refracts the light, it is focussed on the retina.

myopia near-sightedness; the condition in which the eye cannot focus on distant objects



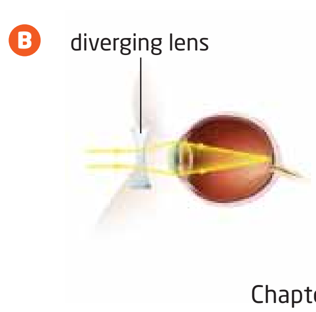


Figure 12.26 Near-sightedness is caused by an eyeball that is too long. In **A**, the focussed image is in front of the retina instead of on the retina. In **B**, the condition is corrected with diverging lenses in eyeglasses or contact lenses.

hyperopia far-sightedness; the condition in which the eye cannot focus on nearby objects

Suggested Investigation

Inquiry Investigation 12-B, I "Speye," on page 514

Hyperopia

Hyperopia [pronounced hi-per-OPE-ee-ah] is far-sightedness. This means that the eyes cannot focus on nearby objects. **Figure 12.27A** shows how light coming from a nearby object is refracted by the cornea and eye lens. In this case, the eyeball is too short. As a result, the rays reach the retina before they meet. The image is so blurry that a far-sighted person cannot read the print on a page. **Figure 12.27B** shows how far-sightedness can be corrected with a converging lens. The corrective lens bends the rays a little, bringing them closer together before they reach the cornea. The lens of the eye then refracts the rays a little more, and the rays are focussed on the retina.

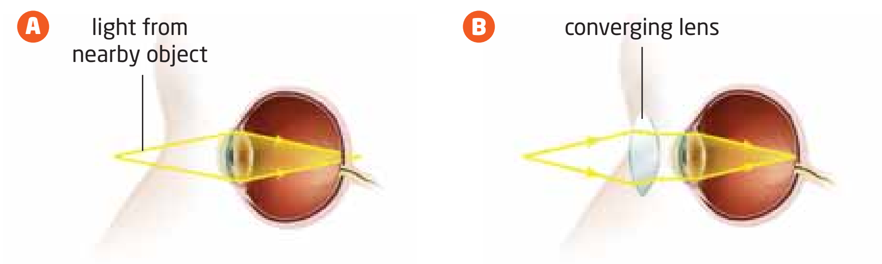


Figure 12.27 In **A**, the eyeball is too short. The person is far-sighted. In **B**, converging lenses, either in eyeglasses or contact lenses, correct hyperopia.

STSE Case Study

Laser Eye Surgery: Shaping Vision

Our ability to see changes over time. As we age, it often deteriorates. Laser eye surgery has revolutionized eye care. It can improve vision, but it is not a risk-free procedure.

Thousands of Canadians have undergone laser eye surgery to correct vision.

In the 1950s, surgeons began to cut the cornea to alter its shape, changing the way light refracts from the cornea onto the lens and then the retina. Later, procedures advanced with the creation of the excimer laser, a form of ultraviolet laser, patented by Mani Lal Bhaumik. The excimer laser is now the cornerstone of laser eye surgery. Rather than burn tissue, the laser ablates (vaporizes) it.

Risks and Benefits

Most people who have laser eye surgery have positive results—improved vision that needs little or no correction with glasses or contact lenses. However, laser surgery is not for everyone, and any surgery involves risks. The risks for laser surgery include

- dry eyes
- oversensitivity to light
- poor perception of contrast
- double vision and
- perception of ghosted images, starbursts, or halos around light sources

Presbyopia

As a person ages, the lenses of the eyes become stiff and the ciliary muscles can no longer make the lenses change shape. The condition is called **presbyopia** [pronounced prez-be-OPE-ee-ah]. Presbyopia is unlike myopia and hyperopia, which are both caused by an incorrect length of the eyeball. People who have presbyopia cannot focus on nearby objects. When people are already near-sighted and they get presbyopia, they cannot focus on either distant or nearby objects. To correct this condition, people wear bifocals, shown in **Figure 12.28.** Bifocals are lenses with two parts. The top part of the lens corrects for near-sightedness, and a small section of the lower part helps the eyes focus on nearby objects. Bifocal contact lenses are also available.

presbyopia the condition in which lenses of the eye become stiff and the ciliary muscles can no longer make the lenses change shape

astigmatism blurred or distorted vision usually caused by an incorrectly shaped cornea

Astigmatism

Astigmatism is blurred or distorted vision that is usually caused by an incorrectly shaped cornea. Instead of being rounded, the cornea is oval. Part of an image might be in focus, but the rest of the image is blurry.

Figure 12.28 The small section at the bottom corrects the near vision, and the rest of the lens corrects for vision at a distance.

People of all ages might think of laser eye surgery as an alternative to wearing glasses or contact lenses. However, a person over age 40 who has laser eye surgery might still need reading glasses afterward—due to presbyopia—and has a higher risk than a younger patient of perceiving starbursts, ghosted images, and halos.

In contrast, a person under age 18 will likely not even be considered for laser eye surgery because eyes have to be stable (unchanging) for at least two years before surgery. There can still be changes in the eye until the age of 18.

One possible risk of laser eye surgery is halos, which are seen in low light.

Laser Eye Surgery

Before surgery, doctors study the shape and thickness of the cornea to identify the tissue that needs to be removed. During most laser eye surgery, an eye surgeon

- cuts a thin flap in the cornea and pulls it back
- ablates the surface to the desired shape
- replaces the flap

Your Turn

1. Do you think the benefits of laser eye surgery outweigh the risks? Explain your answer.
2. Would you enjoy working in a laser eye clinic? Why or why not?
3. Ask some people who have had laser eye surgery what they were told about the procedure and its risks.

Enhancing Human Vision

The human eye can adapt to a wide range of intensities of light. However, as light becomes extremely dim, a point is reached beyond which the human eye can no longer perceive an image. Usually, the dim light does not cause a problem because we have artificial lighting. However, there are some situations in which it is extremely helpful to be able to see without being seen. Military and law enforcement people as well as people studying wildlife benefit tremendously by using night-vision devices that allow them to see in extremely dim light.

Go to **scienceontario** to find out more

Night-Vision Devices

night-vision device an artificial device that allows people to see when only a very small amount of light is available

You may have seen images similar to that in **Figure 12.29A**. This is what a person can see through a **night-vision device**. Night-vision devices use an image-intensifier tube, which is illustrated in **Figure 12.29B**, to enhance vision in dim light.

The front lens of the tube focusses the small amount of light (red dots) available on a plate called a photocathode. The photocathode is sensitive to infrared rays with wavelengths just beyond visible red light. The photocathode emits an electron (yellow dot) at each point that light hits it. A high-voltage power supply attracts the electrons to the next plate, called a microchannel plate. As the name of this plate suggests, there are millions of microscopic holes called microchannels in the plate. As electrons pass through the channels, they collide with the walls, causing the walls to emit more electrons. For every electron that enters the plate, about a thousand leave the plate.

Study Toolkit

Using Graphic Organizers
A cause-and-effect map can help clarify the process that allows a night-vision device to make an object visible in dim light.

A potential difference then attracts the electrons to the next plate, which is coated with a phosphor. When electrons collide with the phosphor, the phosphor emits green light. The human eye is more sensitive to green than any other colour, which is why the designers chose that colour. Finally, the eyepiece focusses the green light onto the eye of the observer. Alternatively, the image can be transferred to a monitor. With this device, dim light as well as some infrared rays can be intensified enough to make the scene visible.

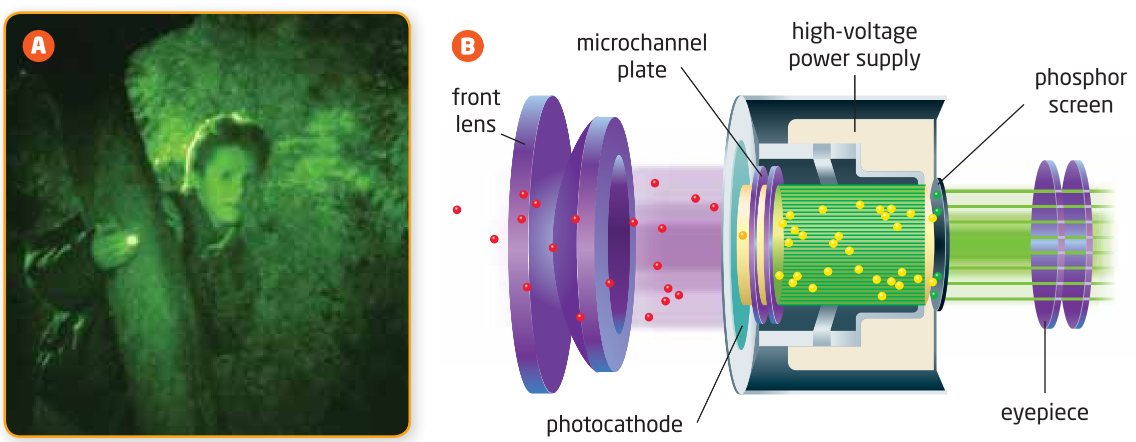


Figure 12.29 **A** Night-vision devices allow you to clearly see images that you could not see with your normal vision. **B** The red dots represent the very small amount of light entering the device. The yellow dots represent electrons.

Section 12.3 Review

Section Summary

- Lenses are used in several technologies. For example, microscopes are used to magnify specimens. Microcsopes are used in many fields.
- The cornea refracts light first. Then the eye lens focusses light once the light enters the eye.
- Myopia (near-sightedness) is caused by an eyeball that is too long. Hyperopia (far-sightedness) is caused by an eyeball that is too short.
- Presbyopia prevents a person from being able to focus up close and is caused by the hardening of the eye lens. Astigmatism causes blurry vision because the cornea is not perfectly round.
- Myopia, hyperopia, presbyopia, and astigmatism can be corrected with eyeglasses, contact lenses, and surgery.
- People in the military and law enforcement and people studying wildlife use night-vision devices to intensify the available light.

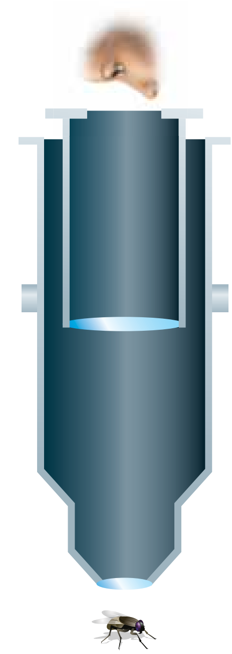
Review Questions

C **1.** Use a Venn diagram to compare a telescope with a microscope.

T/I **2.** Use a Venn diagram to compare the liquid lens in **Figure 12.1**, on page 487, with the human eye in **Figure 12.23**, on page 506.

T/I **3.** Suppose that you are examining a fly under a microscope, as shown in the diagram on the right. Copy the diagram into your notebook, and show the fly's approximate image size and location. Use **Figure 12.21** as a reference.

Show approximately where the image of the fly will be and its size relative to the fly itself.



A **4.** Describe two examples of lens technologies that benefit society.

K/U **5.** In the human eye, the distance between the lens and the retina does not change. Explain how the lens can focus images of both distant objects and nearby objects on the retina.

K/U **6.** The following are components of a camera: aperture, film or CCD, ring that moves the lens in and out. Explain what their function is and what part of the eye carries out a similar function.

C **7.** Explain how night-vision devices amplify the amount of available light. Include a simple diagram.

T/I **8.** The diagrams on the right show two eyes. One eye has normal vision and the other eye has defective vision. Identify the eye that has defective vision. Explain why you chose it, what you think the defect is, and how it can be corrected.