(b) Most eyepieces are now made of two or more lenses. What kind of lenses are involved in Huygenian, Ramsden, Periplan, and Kellner eyepiece designs? Which of those eyepieces is the best one to use? Why?

(c) The Dutch naturalist Anton van Leeuwenhoek (1632–1723) is credited as one of the earliest significant contributors to the development of the microscope. However, his microscope consisted of only one lens. How was he able to achieve the high magnifications for which he was known?

Reflecting

4. Estimate the number of times microscope technology has been used to monitor your health in the last two or three years. Justify your estimate and then discuss it with a partner.

11.3 The Telescope

A single lens does not help the normal eye view distant objects. Two or more lenses must be used together to view distant objects such as stars, planets, and the Moon with detail. Images are smaller than the actual objects in space, but the images are much closer so they appear larger.

Opera glasses are conveniently small optical instruments that provide a low magnification, typically three to four times. They are manufactured in many forms, from simple toys to expensive status symbols. Their operation is based on the two-lens system invented by Galileo Galilei in 1609. That system, now called the "Galilean telescope" (**Figure 1**), consists of a converging lens as the objective and a diverging lens as the eyepiece. To produce an upright image, the diverging lens must intercept the light rays from the objective before a real image is formed.

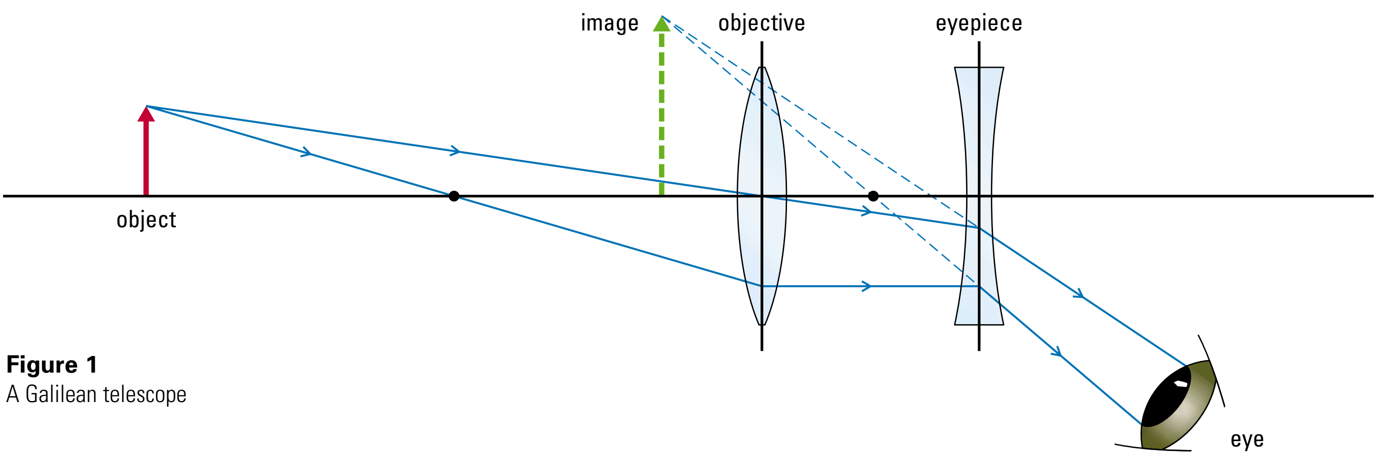

Figure 1
A Galilean telescope

reflecting telescope: telescope that uses a parabolic mirror to focus light

Reflecting Telescopes

Reflecting telescopes use parabolic mirrors to focus light onto the focal plane. The larger the diameter of the mirror, the stronger the concentration of light energy at the focus. This makes it possible for astronomers to see distant stars whose light energy is so low that they cannot be seen otherwise. An eyepiece is used to magnify and focus the image (**Figure 2**).

The first telescope of this type was made by Isaac Newton in 1668. To make it easier to see the image, Newton placed a plane mirror at 45° to the axis of the concave mirror, in front of the principal focus. This reflected the rays to one side, and the image could then be viewed through an eyepiece.

The mirror in the reflecting telescope at the David Dunlap Observatory in Richmond Hill, Ontario, once the largest in the world, has a diameter of 1.8 m.

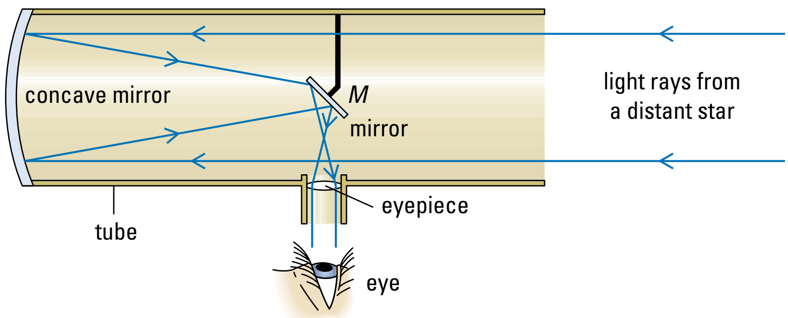

Figure 2
A reflecting telescope

Refracting Telescopes

Refracting telescopes, or refractors, use lenses. **Figure 3** shows how a refractor works: it is constructed from two converging lenses. The objective lens has a long focal length and the eyepiece has a short focal length. When the lens is used to view distant objects, the rays of light are nearly parallel when they enter the objective lens. The objective lens forms a real image (I) just inside the secondary principal focus (F') of the eyepiece. The eyepiece acts as a magnifying glass, producing a greatly magnified virtual image. The image is inverted, but when used for astronomical purposes, for example, this does not matter.

refracting telescope: telescope that uses two converging lenses to focus light

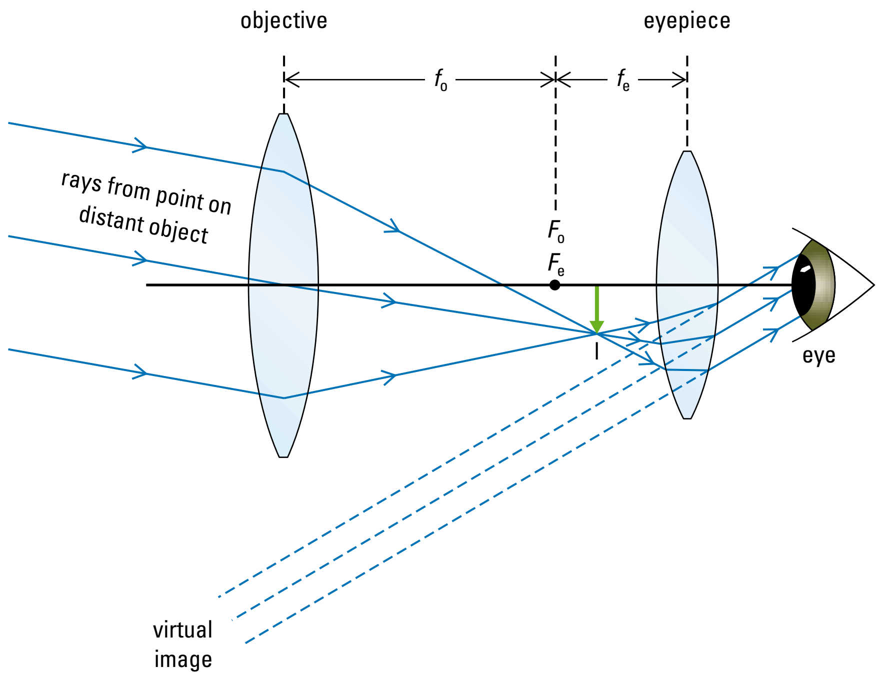

Figure 3
A refracting telescope

Terrestrial Telescopes

terrestrial telescope: telescope that is similar to a refractor, but with the addition of a third lens, the erector lens, to obtain upright images

The **terrestrial telescope** (Figure 4) is similar in construction to the refractor, except for an additional converging lens located between the objective lens and the eyepiece. The third lens is called the erector lens. Its purpose is to invert the image so that it has the same attitude as the object.

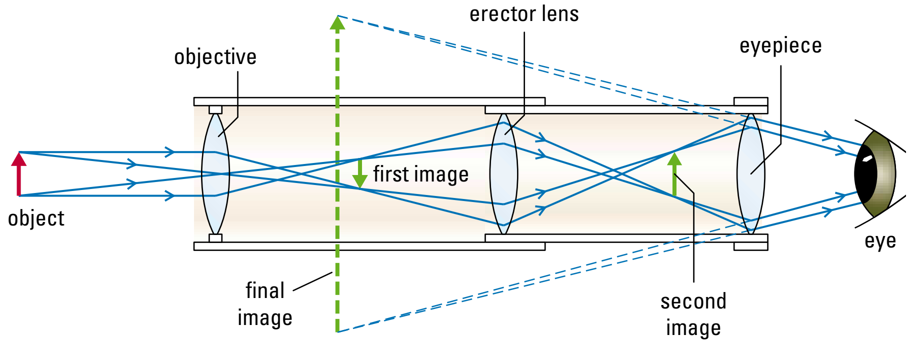

Figure 4
A terrestrial telescope

Practice

Understanding Concepts

1. Describe how a refracting telescope and a microscope are (a) similar and (b) different.
2. State the four characteristics of the final image relative to the original object seen in the terrestrial telescope shown in **Figure 4**. Show your calculation of the magnification, and describe how you can tell whether the final image is real or virtual.

Making Connections

3. Refracting telescopes make distant objects look much closer than opera glasses do. However, at a live theatre performance, opera glasses have advantages over a refracting telescope. What are these advantages?

Answers

2. 7.0 (approx.)

Activity 11.3.1

Model Telescopes

In this activity you will arrange lenses to simulate a refractor and a terrestrial telescope. An objective lens of a telescope should have a large diameter to collect as much light as possible, as well as a large focal length. The greater the focal length, the larger the image of an object located a great distance away.

Materials

various lenses
optical bench
distant target (greater than 5 m)

Procedure

Part 1: The Refractor Telescope

1. Obtain two lenses of different focal lengths and determine the focal length of each. Choose which lens will be the objective and which will be the eyepiece, based on what you've already learned in this chapter.
2. Place the eyepiece in a holder at one end of the optical bench. Place the objective at a distance equal to the sum of the focal lengths away from the eyepiece.
3. Determine the magnification of the telescope by drawing two sets of equally spaced lines on a piece of paper. View the lines from a distance through the telescope as well as with the unaided eye.
4. Try various combinations of lenses to discover which one gives the largest image of the same object. For instance, try objective $f = 5$ cm and eyepiece $f = 10$ cm; objective $f = 5$ cm and eyepiece $f = 5$ cm. Describe your observations.
5. Look through the eyepiece at a distant object and move the lenses and your eye until you obtain the clearest and largest image of the object.

Part 2: The Terrestrial Telescope

6. Choose a third lens, keeping the two lenses that worked well in Part 1. Determine the focal length of the third lens.
7. On the optical bench, arrange the three lenses so that the erector lens is located between the objective and the eyepiece. Use your experience in the previous parts of this experiment to help you decide where to place the lenses.
8. Discover how to obtain a clear, upright, and enlarged image of a distant object. Describe what you discover.

Adaptations of Telescopes

Prism Binoculars

Prism binoculars are really just two refracting telescopes mounted side by side, one for each eye (**Figure 5**). Between each pair of lenses is a pair of prisms that invert the image and reduce the distance between the two lenses. Binoculars are much shorter than a telescope and easier to handle. Note that the distance the light travels between the two lenses in a telescope and between the two lenses on each side of a pair of binoculars is the same, although the telescope is longer.

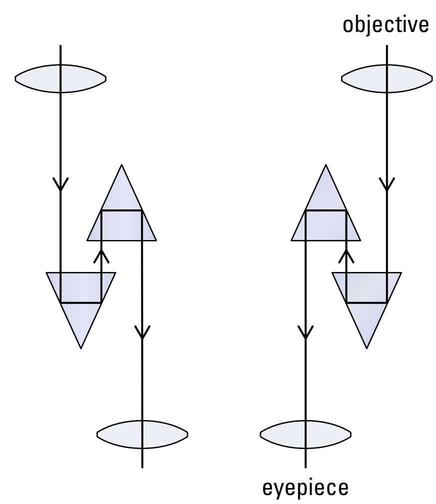

Figure 5
Prism binoculars

Zoom Lens

A zoom lens (**Figure 6**) allows a photographer to adjust the focal length. Lenses with a short focal length (about 25 mm to 35 mm) see a wide-angle view, while those with a long focal length (about 70 mm to 1000 mm) see a small angle but an enlarged image. Essentially, the zoom lens is a telescope mounted on a camera.

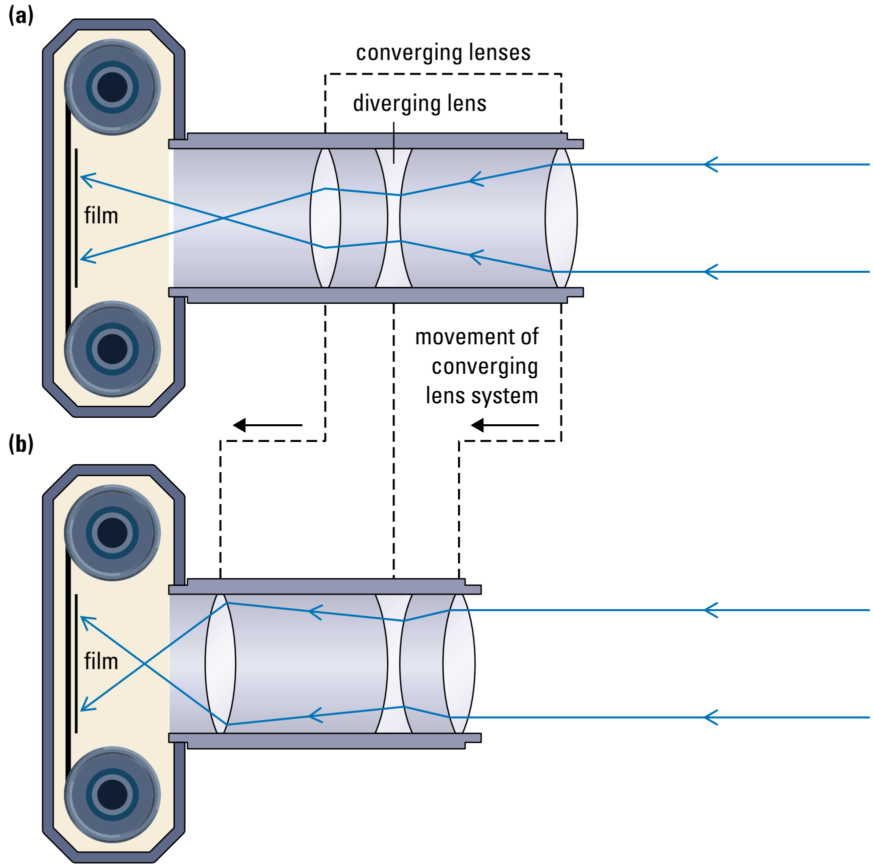

Figure 6
(a) Telephoto setting: longer focal length, larger image, smaller angle of view
(b) Wide-angle setting: shorter focal length, smaller image, larger angle of view

Practice

Understanding Concepts

4. Based on your understanding of zoom lenses, which focal length of binocular lenses provide greater magnification, 35 mm or 50 mm? Which provides a greater angle or field of view? Explain your answers.

SUMMARY Lenses and Telescopes

- A Galilean telescope, also called opera glasses, consists of a converging lens and a diverging lens.
- A reflecting telescope uses a curved mirror to focus light onto the focal plane.
- A refractor consists of two converging lenses.
- A terrestrial telescope is a refractor with an additional lens that ensures that images are upright.
- Binoculars and zoom lens systems are modified telescopes.

Section 11.3 Questions

Understanding Concepts

1. How do the images produced by a Galilean telescope differ from those of a refractor?
2. What is the purpose of the third lens in a terrestrial telescope?
3. (a) Why should a refractor's objective lens have a large diameter?
   (b) How does this limit the usefulness of lenses in telescopes? How have astronomers overcome this limitation?
4. Most single-lens reflex cameras come with a standard lens of focal length 50.0 mm. Suppose the lens is used to focus the image of your friend 10.0 m away.
   (a) Determine the image distance of your friend.
   (b) What is your friend's magnification?
   (c) The lens is replaced with a telephoto lens of focal length 20.0 cm. Determine the image distance and magnification now.
   (d) What is the ratio of the magnification of the 20.0-cm lens to that of the 50.0-mm lens?
   (e) If the 50.0-mm lens is replaced with a 28.0-mm lens, what is the ratio of the magnification of the 28.0-mm lens to that of the 50.0-mm lens? Lenses with focal lengths less than 28.0 mm are called *wide-angle* lenses. Why?

Making Connections

5. You have won a $1000 gift certificate toward the purchase of a telescope and telescope accessories for the essay you entered in the contest entitled "What will our telescopes allow us to see 100 years from now?" sponsored by the Canadian Space Agency. Investigate the current telescopes and accessories available on the market.
   (a) While collecting information, list and describe the criteria that become important in your decision.
   (b) Make your decision. Include a sample order form listing the items to be purchased, their cost, and applicable taxes. Discuss your decision by explaining how you used your list of criteria.
6. Using the Internet and other sources, research the Hubble Space Telescope. Follow the links for Nelson Physics 11, 11.3.
   (a) What is the Hubble Space Telescope?
   (b) Who was Hubble, and why is the space telescope named after him?
   (c) Give a brief description of the Hubble's optics.
   (d) Describe a recent discovery made by the Hubble Space Telescope.

GO TO www.science.nelson.com