## Section 24.2

## 1 FOCUS

### Section Objectives

**24.4** **Explain** how refracting, reflecting, and radio telescopes work.

**24.5** **Describe** the advantages and disadvantages of each type of telescope.

**24.6** **Explain** the advantages that a space telescope has over an Earth-based telescope.

**Reading Focus**

### Build Vocabulary L2

**Concept Map** Have students make a concept map using the term *telescopes* as the starting point. All the vocabulary terms in this section should be used.

### Reading Strategy L2

**a.** uses a lens to bend and redirect light to a focal point behind a mirror
**b.** uses a concave mirror to focus light to a point in front of a mirror

## 2 INSTRUCT

### Refracting Telescopes

### Build Reading Literacy L1

Refer to **p. 642D** in **Chapter 23**, which provides the guidelines for comparing and contrasting.

**Compare and Contrast** Have students read the section. As they read, they should create lists of how the various types of telescopes are similar and different.
**Verbal**



# 24.2 Tools for Studying Space

**Reading Focus**

### Key Concepts

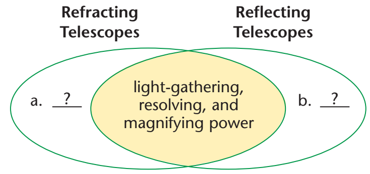
- How does a refracting telescope produce an image?
- Why are most large telescopes reflecting telescopes?
- How does a radio telescope gather data?
- What advantages do space telescopes have over Earth-based telescopes?

### Vocabulary

- refracting telescope
- chromatic aberration
- reflecting telescope
- radio telescope

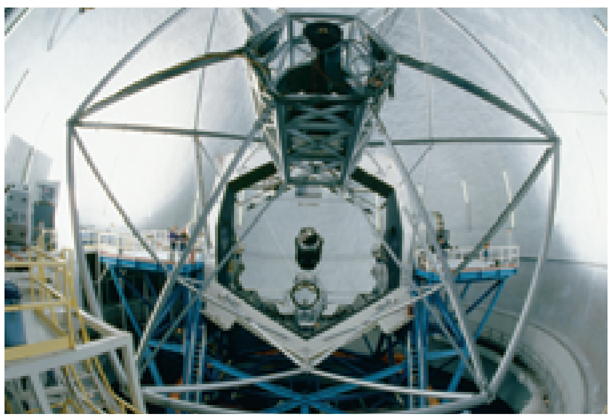
### Reading Strategy

**Comparing and Contrasting** Copy the Venn diagram. As you read, complete it to show the differences between refracting and reflecting telescopes.




Now that we've examined the nature of light, let's turn our attention to the tools astronomers use to intercept and study the energy emitted by distant objects in the universe. Because the basic principles of detecting radiation were originally developed through visual observations, the astronomical tools we'll explore first will be optical telescopes. An example is shown in Figure 5. The 10-meter Keck Telescope, located on Mauna Kea in Hawaii, uses a mosaic of 36 six-sided, 1.8-meter mirrors. The mirrors are carefully positioned by a computer to give the optical effect of a 10-meter mirror. The Keck Telescope is a type of optical telescope. To create an image that is a great distance away, a telescope must collect as much light as possible. Optical telescopes contain mirrors, lenses, or both to accomplish this task.

**Figure 5 Keck Telescope** This optical telescope is located at the summit of Hawaii's Mauna Kea volcano.



## Refracting Telescopes

Galileo is considered to be the first person to have used telescopes for astronomical observations. Having learned about the newly invented instrument, Galileo built one of his own that was capable of magnifying objects 30 times. Because this early instrument, as well as its modern counterparts, used a lens to bend or refract light, it is known as a **refracting telescope.**

**Focus** The most important lens in a refracting telescope, the objective lens, produces an image by bending light from a distant object so that the light converges at an area called the focus** (*focus* = central point). For an object such as a star, the image appears as a point of light. For nearby objects it appears as an inverted replica of the original.

You can easily demonstrate the latter case by holding a lens in one hand and, with the other hand, placing a white card behind the lens. Now vary the distance between them until an image appears on the card. The distance between the focus (where the image appears) and the lens is called the focal length of the lens.

Astronomers usually study an image from a telescope by first photographing the image. However, if a telescope is used to examine an image directly, a second lens, called an eyepiece, is required. The eyepiece magnifies the image produced by the objective lens. In this respect, it is similar to a magnifying glass. The objective lens produces a very small, bright image of an object, and the eyepiece enlarges the image so that details can be seen. Figure 6 shows the parts of a refracting telescope.

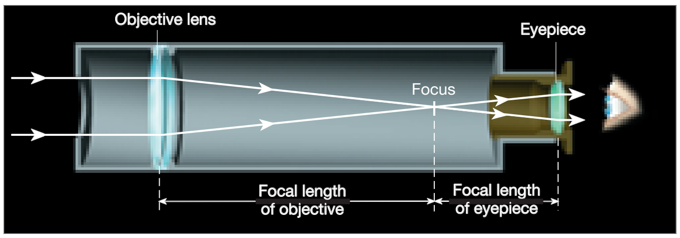



**Figure 6 Simple Refracting Telescope** A refracting telescope uses a lens to bend light.

**Chromatic Aberration** Although used extensively in the nineteenth century, refracting telescopes suffer a major optical defect. As light passes through any lens, the shorter wavelengths of light are bent more than the longer wavelengths. Consequently, when a refracting telescope is in focus for red light, blue and violet light are out of focus. The troublesome effect, known as **chromatic** (*chroma* = color) **aberration** (*aberrare* = to go astray), weakens the image and produces a halo of color around it. When blue light is in focus, a reddish halo appears. When red light is in focus, a bluish halo appears. Although this effect cannot be eliminated completely, it is reduced by using a second lens made of a different type of glass.

Reading Checkpoint *What is chromatic aberration?*



## Use Community Resources L2

Invite an astronomer to talk to your class about telescopes. Ask if he or she could bring small telescopes to use for demonstrations. If possible, see if the astronomer could come at night and have a moon-gazing or star-gazing party.

**Verbal, Interpersonal**

Teacher Demo

## Making a Simple Refracting Telescope L2

**Purpose** Students will observe the simple concepts behind a refracting telescope.

**Materials** 2 magnifying lenses

**Procedure** Observe an object in the distance with one of the magnifying lenses. Move the lens back and forth until you get a sharp image. Place the second magnifying lens in front of your eye. Move the second lens back and forth until you get a clear image. The image should appear larger. Pass the lenses around the classroom to give students an opportunity to view an image.

**Expected Outcome** Students will see that a simple refracting telescope consists of two lenses. In this example, it consists of two convex lenses. A convex lens is thicker in the middle and thinner around the edges.

**Visual, Kinesthetic**

## Customize for Inclusion Students

**Learning Disabled** For students with difficulty absorbing concepts by reading, use Figures 6, 7, and 8 as a visual aid as you describe how each of these telescopes work. Be sure students understand the differences in these telescopes.

### *Answer to . . .*

Reading Checkpoint *Chromatic aberration is a troublesome effect associated with refracting telescopes that weakens an image and produces a halo of color around it.*

**Section 24.2 (continued)**

## Reflecting Telescopes

### Use Visuals

L1

**Figure 7** Have students examine the figure. Ask: **Where is the viewer positioned for each type of reflecting telescope?** *(In A, the viewer is in a viewing cage inside the telescope, positioned at the focal point. In B, the viewer is seated below the telescope at the focal point. In C, the viewer is at the side of the telescope, viewing the image at an angle.)* **Infer why the prime focus method is used only for large telescopes.** *(The telescope has to be large for a person to sit inside the telescope to view the image.)*
**Verbal, Logical**

### Address Misconceptions

L2

Students may think that increasing the magnification of a reflecting telescope will improve the clarity of an image. This is not necessarily true. What can be viewed telescopically is limited by atmospheric conditions and the resolving power of the telescope. Any part of an image that is not clear at low magnification will appear only as a larger blur at higher magnification. Increasing magnification spreads out the light and decreases the brightness of the object. Astronomers describe telescopes not in terms of their magnification, but by the diameter of the objective mirror or lens, because it is this factor that determines both the light-gathering power and the resolving power of a telescope.
A good rule of thumb for amateur astronomers is that for every inch of aperture you can use up to 60 power. A three inch telescope would have a useful magnification of 180×.
**Verbal**

Go Online NSTA SCILINKS

Download a worksheet on telescopes for students to complete, and find additional teacher support from NSTA SciLinks.



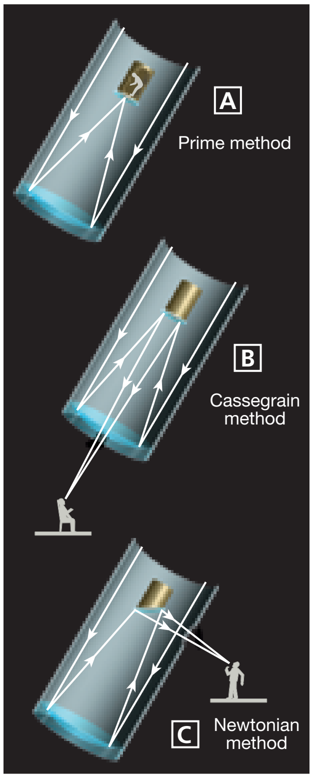



**Figure 7 Viewing Methods with Reflecting Telescopes**
**A** The prime method is only used with very large telescopes.
**B** The Cassegrain method is most commonly used. Note that a small hole in the center of the mirror allows light to pass through.
**C** This figure shows the Newtonian method.

Go Online SCILINKS NSTA

**For:** Links on telescopes
**Visit:** www.SciLinks.org
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## Reflecting Telescopes

Newton was bothered by chromatic aberration so he built telescopes that reflected light from a shiny surface—a mirror. Because reflected light is not dispersed into its component colors, the chromatic aberration is avoided. **Reflecting telescopes** use a concave mirror that focuses the light in front of a mirror, rather than behind it, like a lens. The mirror is generally made of glass that is finely ground and coated with a highly reflective material, usually an aluminum compound.

Because the focus of a reflecting telescope is in front of the mirror, an observer must be able to view the image without blocking too much incoming light. Figure 7A shows a viewing cage for the observer within the telescope. Figures 7B and 7C show that the observer can remain indoors. Most large telescopes employ more than one type.

**Advantages of Reflecting Telescopes** As you might guess, it's a huge task to produce a large piece of high-quality, bubble-free glass for refracting telescopes. **Most large optical telescopes are reflectors. Light does not pass through a mirror so the glass for a reflecting telescope does not have to be of optical quality.** In addition, a lens can be supported only around the edge, so it sags. Mirrors, on the other hand, can be supported fully from behind. One disadvantage of reflecting telescopes is that the secondary mirror blocks some light entering the telescope. Thus, a reflecting telescope with a 10-inch opening will not collect as much light as a 10-inch refractor.

**Properties of Optical Telescopes** Both refracting and reflecting telescopes have three properties that aid astronomers in their work: 1) light-gathering power, 2) resolving power, and 3) magnifying power. Light-gathering power refers to the telescope's ability to intercept more light from distant objects, thereby producing brighter images. Telescopes with large lenses or mirrors "see" farther into space than do those with small ones.

Another advantage of telescopes with large objectives is their greater resolving power, which allows for sharper images and finer detail. For example, with the naked eye, the Milky Way appears as a vague band of light in the night sky. But even a small telescope is capable of resolving, or separating it into, individual stars. Lastly, telescopes have magnifying power, which is the ability to make an object larger. Magnification is calculated by dividing the focal length of the objective by the focal length of the eyepiece. Thus, the magnification of a telescope can be changed by simply changing the eyepiece.

**Reading Checkpoint** *What is light-gathering power?*

## Radio Telescopes

A

B

**Figure 8 A The 43-meter Radio Telescope at Green Bank, West Virginia** The dish acts like the mirror of a reflecting telescope, focusing radio waves onto the antenna. **B The Very Large Array Near Socorro, New Mexico** Twenty-seven identical antennas operate together to form this radio network.
**Identifying** ***What is a network of radio telescopes called?***

## Detecting Invisible Radiation

As you learned earlier, sunlight is made up of more than just the radiation that is visible to our eyes. Gamma rays, X-rays, ultraviolet radiation, infrared radiation, and radio waves are also produced by stars. Photographic film that is sensitive to ultraviolet and infrared radiation has been developed. This extends the limits of our vision. However, most of this radiation cannot penetrate our atmosphere, so balloons, rockets, and satellites must transport cameras "above" the atmosphere to record it.

A narrow band of radio waves is able to penetrate the atmosphere. Measurement of this radiation is important because we can map the galactic distribution of hydrogen. Hydrogen is the main material from which stars are made.

**Radio Telescopes** The detection of radio waves is accomplished by big dishes called **radio telescopes,** shown in Figure 8A. In principle, the dish of one of these telescopes operates in the same manner as the mirror of an optical telescope. **A radio telescope focuses the incoming radio waves on an antenna, which absorbs and transmits these waves to an amplifier, just like a radio antenna.**

Because radio waves are about 100,000 times longer than visible radiation, the surface of the dish doesn't need to be as smooth as a mirror. Except for the shortest radio waves, a wire mesh is a good reflector. However, because radio signals from celestial sources are very weak, large dishes are necessary to intercept an adequate signal.

Radio telescopes have poor resolution, making it difficult to pinpoint the radio source. Pairs or groups of telescopes reduce this problem. When several radio telescopes are wired together, as shown in Figure 8B, the resulting network is called a radio interferometer.



## Detecting Invisible Radiation

### Build Science Skills

L2

**Inferring** Explain to students that radio waves are able to penetrate Earth's atmosphere and are used to map the distribution of hydrogen in the galaxy. Ask: **The largest radio telescope is 300 m (1,000 ft) in diameter. Why is a radio telescope this large an advantage?** *(Radio signals from celestial sources are very weak. This telescope is able to collect a larger number of signals because of its size.)* **This radio telescope was built in a depression in the landscape. Why was this location chosen?** *(This depression blocks human-made radio signals from the telescope.)*
**Verbal, Logical**

## Facts and Figures

The Very Large Array consists of 27 radio antennas set up in a Y-shaped configuration. The site is located on the Plains of San Augustin 50 miles west of Socorro, New Mexico. Each antenna measures 25 m in diameter. When the antennas are combined electronically, they give an equivalent resolution of an antenna 36 km in diameter. The combination of the antennas has the sensitivity of a dish that is 130 m in diameter.

### *Answer to . . .*

**Figure 8** *a radio interferometer*

Reading Checkpoint *Light-gathering power refers to the telescope's ability to intercept more light from distant objects, thereby producing brighter images.*

## Space Telescopes

### Integrate Language Arts

L2

**The Hubble Space Telescope** The Hubble Space Telescope has provided spectacular images of the universe. This program also has experienced failures. Have students in groups research the Hubble Space Telescope project and create a computer presentation to share with their classmates. The Internet contains many photographs that can be included in the presentation.
**Verbal, Interpersonal**

Q & A

**Q** *Why do astronomers build observatories on mountaintops?*

**A** Observatories are most often located on mountaintops because sites above the densest part of the atmosphere provide better conditions for "seeing."

**Advantages of Radio Telescopes** Radio telescopes have some advantages over optical telescopes. They are much less affected by turbulence in the atmosphere, clouds, and the weather. No protective dome is required, which reduces the cost of construction. "Viewing" is possible 24 hours a day. More important, radio telescopes can "see" through interstellar dust clouds that obscure visible wavelengths. Radio signals from distant points in the universe pass unhindered through the dust, giving us an unobstructed view. Furthermore, radio telescopes can detect clouds of gases too cool to emit visible light. These cold gas clouds are important because they are the sites of star formation.

Radio telescopes are, however, hindered by human-made radio interference. While optical telescopes are placed on remote mountaintops to reduce interference from city lights, radio telescopes are often hidden in valleys to block human-made radio interference.

Radio telescopes have revealed such spectacular events as the collision of two galaxies. They led to the important discovery of quasars and pulsars.

Reading Checkpoint *Why can radio telescopes be used 24 hours a day?*

## Space Telescopes

Have you ever seen a blurring effect caused by the movement of air on a hot summer day? That blurring effect also distorts the images produced by most telescopes on Earth. On a night when the stars twinkle, viewing is difficult because the air is moving rapidly. This causes the image to move about and blur.

Observatories are most often located on mountaintops. This is because sites above the densest part of the atmosphere provide better conditions for "seeing." At high elevations, there is less air to scatter and dim the incoming light. Also, there is less water vapor to absorb infrared radiation. Further, the thin air on mountaintops causes less distortion of the images being observed.

There is one other way to get around the distorting effects of Earth's atmosphere—send telescopes into space. **Space telescopes orbit above Earth's atmosphere and thus produce clearer images than Earth-based telescopes.**

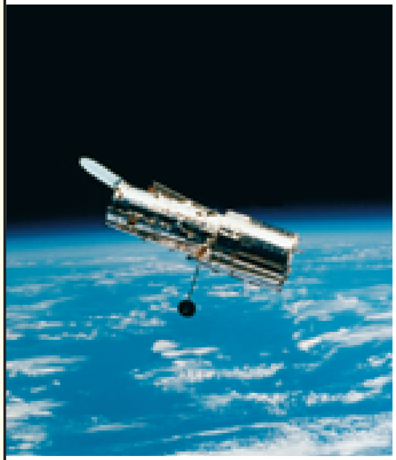

**Figure 9 Hubble Space Telescope** Hubble was deployed into Earth orbit by the space shuttle *Discovery.*

**Hubble Space Telescope** The first space telescope, built by NASA, was the Hubble Space Telescope, shown in Figure 9. Hubble was put into orbit around Earth in April 1990. This 2.4-meter space telescope has 10 billion times more light-gathering power than the human eye. Hubble has given us many spectacular images. For example, the



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Hubble Space Telescope has provided images that clearly resolve the separation between Pluto and its moon, Charon. It has also provided data about planets that orbit other stars, the birth of stars, black holes, the age of the universe, and the expansion of the universe.

### Other Space Telescopes

Other types of radiation are also affected by Earth's atmosphere. To study X-rays, NASA uses the Chandra X-Ray Observatory. This space telescope was launched in 1999. One of its main missions is to gather data about black holes—objects whose gravity is so strong that visible light cannot escape them. Another space telescope, the Compton Gamma-Ray Observatory, was used to study both visible light and gamma rays. In 2011, NASA plans to launch the James Webb Space Telescope to study infrared radiation. As Figure 10 shows, images obtained by different telescopes offer different information about the same object in space—in this case, the Milky Way galaxy. By studying all the images together, astronomers obtain a more thorough understanding of the galaxy.

**Figure 10 Images of the Milky Way Galaxy** These images were taken by different types of telescopes, including visible light, X-ray, gamma ray, and infrared.

## Section 24.2 Assessment

### Reviewing Concepts

1. How does a refracting telescope work?
2. How does a reflecting telescope differ from a refracting telescope?
3. Why are most large telescopes reflecting telescopes?
4. How do radio telescopes gather data?
5. Why do space telescopes obtain clearer images than Earth-based telescopes?

### Critical Thinking

6. **Calculating** If a telescope has an objective with a focal length of 50 centimeters and an eyepiece with a focal length of 25 millimeter, what will be the magnification?
7. **Applying Concepts** Using the numbers from the previous question, would an eyepiece with a greater focal length increase or decrease magnification? Explain.

**Connecting Concepts**

**Electromagnetic Radiation** Recall the different types of electromagnetic radiation. Based on what you've learned in this section, would you recommend sending a telescope into space to study radio waves? Why or why not?



## 3 ASSESS

### Evaluate Understanding L2

Have students write down the following types of telescopes: refracting, reflecting, and radio. Then, have students write down three facts about each telescope. Have students share their facts with the class.

### Reteach L1

Use Figures 6, 7, and 8 to review how each of the these telescopes works.

**Connecting Concepts**

Sample answer: Radio waves can easily pass through Earth's atmosphere. Therefore, there is little advantage in sending a radio telescope into space.

**Answer to . . .**

*They do not need visible light to obtain images.*

## Section 24.2 Assessment

**1.** The objective lens produces an image by bending light from a distant object so that the light converges at an area called the focus.
**2.** A reflecting telescope uses a concave mirror to produce an image. A refracting telescope uses a lens to bend or refract light.
**3.** Because light does not pass through a mirror, the glass for a reflecting telescope does not have to be of optical quality. In addition, a lens can be supported only around the edge, so it sags. Mirrors, on the other hand, can be supported fully from behind.
**4.** A radio telescope focuses the incoming radio waves on an antenna, which absorbs and transmits the waves to an amplifier.
**5.** Space telescopes orbit above Earth's atmosphere and thus produce clearer images than Earth-based telescopes.
**6.** Magnification is calculated by dividing the focal length of the objective by the focal length of the eyepiece. In this example, 500 mm ÷ 25 mm = 20; magnification would be 20 times.
**7.** An eyepiece with a greater focal length, such as 50 mm, would decrease magnification because 500 mm ÷ 50 mm = 10 times magnification.