CHAPTER

24 Studying the Sun

CONCEPTS in Action

Exploration Lab
Tracking Sunspots

Earth as a System
Solar Activity and Climatic Change

Discovery Channel School **Video Field Trip**

Fireball

Take a solar field trip with Discovery Channel and learn about the inner core and the outer surface of our sun. Answer the following questions after watching the video.

1. How did scientists discover the activity of the sun's core?
2. How do auroras occur?

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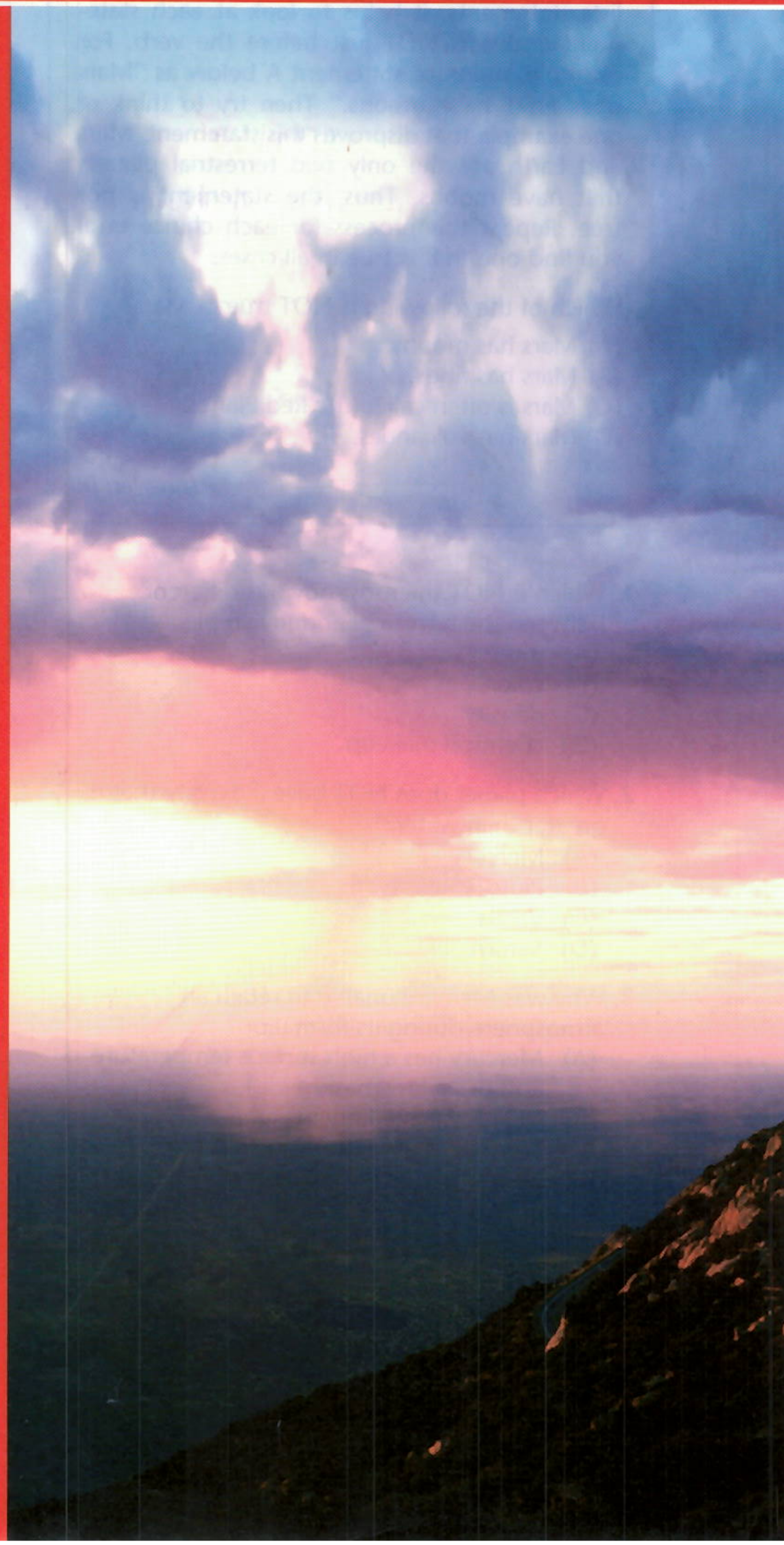
This photograph shows Kitt Peak National Observatory near Tucson, Arizona. ▶



Chapter Preview

Inquiry Activity

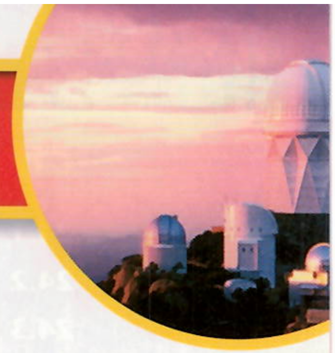
How Does the Position of the Setting Sun Change?

Procedure

1. Several minutes before sunset, estimate where the sun will set on the western horizon. Draw prominent features, such as buildings and trees, to the north and south of the sun's setting position.
2. As the sun sets, draw its position relative to the fixed features on the horizon. **CAUTION** *Never look directly at the sun; eye damage may result.*
3. Note the date and time of your observation.
4. Return to the same position several days later. Repeat the activity and record the results. Wait several more days then do the activity one more time.

Think About It

1. **Observing** How did the sun's position at sunset change over the course of your observations?
2. **Predicting** Based on your observations, predict where the sun might set in several weeks time. Sketch the sun on your drawing relative to the fixed features on the horizon.



24.1 The Study of Light

Reading Focus

Key Concepts

- What types of radiation make up the electromagnetic spectrum?
- What can scientists learn about a star by studying its spectrum?
- How can astronomers determine whether a star is moving toward or away from Earth?

Vocabulary

- electromagnetic spectrum
- photon
- spectroscopy
- continuous spectrum
- absorption spectrum
- emission spectrum
- Doppler effect

Reading Strategy

Predicting Copy the table. Before you read, predict the meaning of the term *electromagnetic spectrum*. After you read, revise your definition if it was incorrect.

Vocabulary Term	Before You Read	After You Read
electromagnetic spectrum	a. ___?___	b. ___?___

Astronomers are in the business of gathering and studying light. Almost everything that is known about the universe beyond Earth comes by analyzing light from distant sources. Consequently, an understanding of the nature of light is basic to modern astronomy. This chapter deals with the study of light and the tools used by astronomers to gather light in order to probe the universe. In addition, we will examine the nearest source of light, our sun. By understanding how the sun works, astronomers can better grasp the nature of more distant objects in space.

Electromagnetic Radiation

The vast majority of our information about the universe is obtained from the study of the light emitted from stars and other bodies in space. Although visible light is most familiar to us, it makes up only a small part of the different types of energy known as electromagnetic radiation. **Electromagnetic radiation includes gamma rays, X-rays, ultraviolet light, visible light, infrared radiation, microwaves, and radio waves.** The arrangement of these waves according to their wavelengths and frequencies is called the **electromagnetic spectrum.** Figure 1 shows the electromagnetic spectrum. All energy, regardless of wavelength, travels through the vacuum of space at the speed of light, or 300,000 kilometers per second. Over a 24-hour day, this equals a staggering 26 billion kilometers.

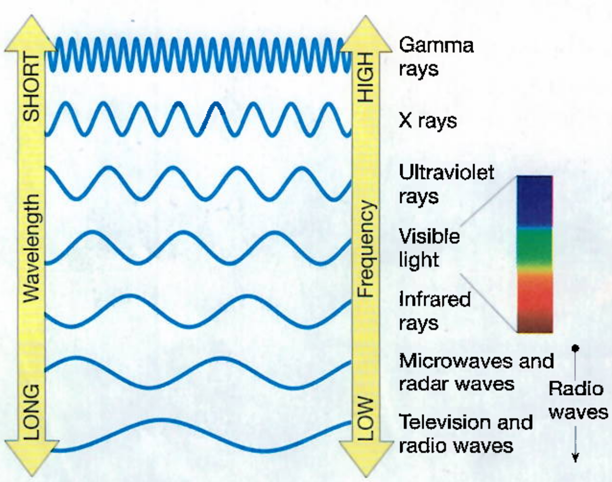


Figure 1 Electromagnetic Spectrum The electromagnetic spectrum classifies radiation according to wavelength and frequency.
Interpreting Diagrams ***Which type of radiation has the shortest wavelength?***

Nature of Light Experiments have shown that light can be described in two ways. In some instances light behaves like waves, and in others like particles. In the wave sense, light can be thought of as swells in the ocean. This motion is characterized by a property known as wavelength, which is the distance from one wave crest to the next. Wavelengths vary from several kilometers for radio waves to less than a billionth of a centimeter for gamma rays, as shown in Figure 1. Most of these waves are either too long or too short for our eyes to see.

The narrow band of electromagnetic radiation we can see is sometimes called visible light. However, visible light consists of a range of waves with various wavelengths. This fact is easily demonstrated with a prism, as shown in Figure 2. As visible light passes through a prism, the color with the shortest wavelength, violet, is bent more than blue, which is bent more than green, and so forth. Thus, visible light can be separated into its component colors in the order of their wavelengths, producing the familiar rainbow of colors.

Table 1 Colors and Corresponding Wavelengths

Color	Wavelength (nanometers*)
Violet	380–440
Blue	440–500
Green	500–560
Yellow	560–590
Orange	590–640
Red	640–750

**One nanometer is 10^{-9} meter.*

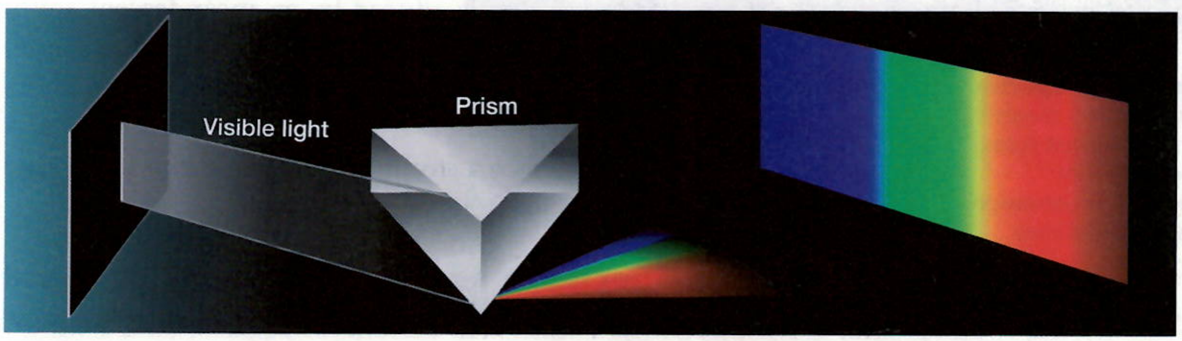


Figure 2 Spectrum A spectrum is produced when sunlight or visible light is passed through a prism, which bends each wavelength at different angles.

Photons Wave theory, however, cannot explain some effects of light. In some cases, light acts like a stream of particles called **photons.** Photons can be thought of as extremely small bullets fired from a machine gun. They can push on matter. The force they exert is called radiation pressure. Photons from the sun are responsible for pushing material away from a comet to produce its tail. Each photon has a specific amount of energy, which is related to its wavelength in a simple way: Shorter wavelengths have more energetic photons. Thus, blue light has more energetic photons than does red light.

Which theory of light—the wave theory or the particle theory—is correct? Both, because each will predict the behavior of light for certain phenomena. As George Abell, a well-known astronomer, stated about all scientific laws, "The mistake is only to apply them to situations that are outside their range of validity."

Reading Checkpoint ***What are photons?***

Go Online SCI LINKS NSTA

For: Links on the electromagnetic spectrum
Visit: www.SciLinks.org
Web Code: cjn-7441

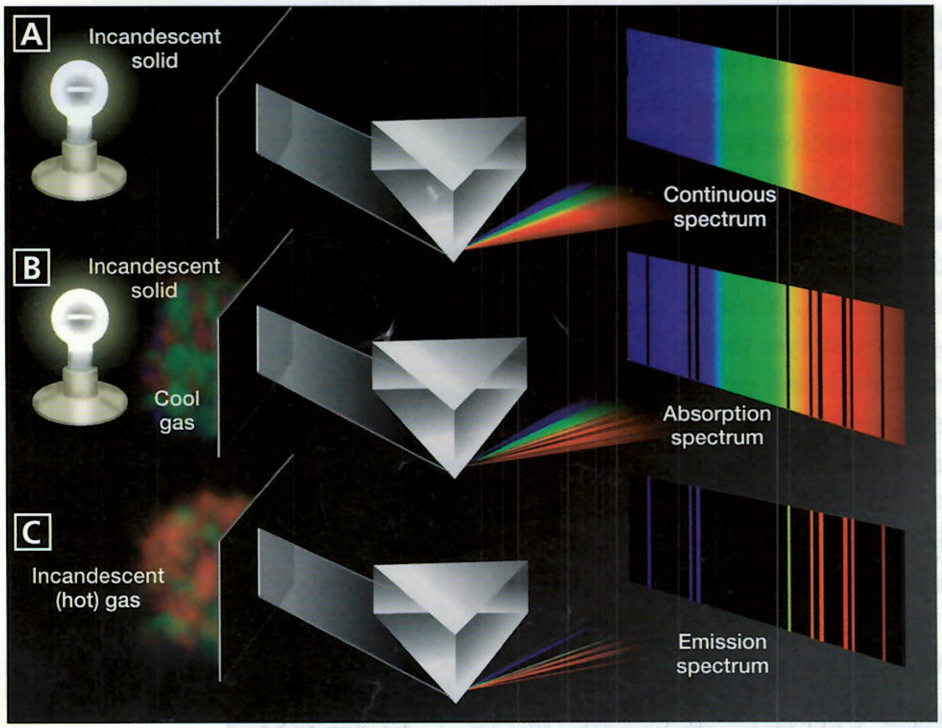


Figure 3 Formation of Spectra
A A continuous spectrum consists of a band of uninterrupted color. **B** An absorption spectrum contains dark lines. **C** An emission spectrum contains bright lines.

Spectroscopy

When Sir Isaac Newton used a prism to disperse visible light into its component colors, he unknowingly introduced the field of spectroscopy. **Spectroscopy** is the study of the properties of light that depend on wavelength. The rainbow of colors Newton produced included all wavelengths of light. It was later learned that two other types of spectra exist. Each is generated under somewhat different conditions.

Continuous Spectrum A **continuous spectrum** is produced by an incandescent solid, liquid, or gas under high pressure. (*Incandescent* means "to emit light when hot.") The spectrum consists of an uninterrupted band of color, as shown in Figure 3A. One example would be light generated by a common light bulb. This is the type of spectrum Newton produced.

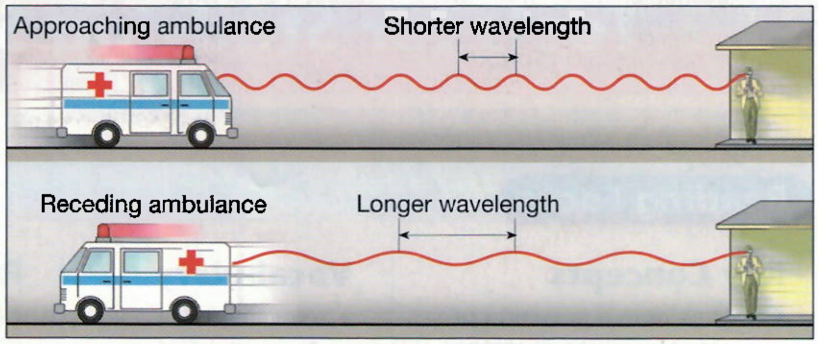
Absorption Spectrum An **absorption spectrum** is produced when visible light is passed through a relatively cool gas under low pressure. The gas absorbs selected wavelengths of light. So the spectrum appears continuous, but with a series of dark lines running through it, as shown in Figure 3B.

Emission Spectrum An **emission spectrum** is produced by a hot gas under low pressure. It is a series of bright lines of particular wavelengths, depending on the gas that produces them. As shown in Figure 3C, these bright lines appear in the exact location as the dark lines that are produced by the same gas in an absorption spectrum.

The spectra of most stars are of the dark-line, or absorption, type. The importance of these spectra is that each element or compound in its gaseous form produces a unique set of spectral lines. **When the spectrum of a star is studied, the spectral lines act as "fingerprints." These lines identify the elements present and thus the star's chemical composition.** The spectrum of the sun contains thousands of dark lines. More than 60 elements have been identified by matching these lines with those of elements known on Earth.

Reading Checkpoint *What is spectroscopy?*

The Doppler Effect



When an ambulance approaches, the siren seems to have a higher-than-normal pitch. When it is moving away, the pitch sounds lower than normal. This effect, which occurs for both sound and light waves, is called the Doppler effect. The **Doppler effect** refers to the perceived change in wavelength of a wave that is emitted from a source that is moving away or toward an object. It takes time for the wave to be emitted. If the source is moving away from you, the beginning of the wave is emitted nearer to you than the end. From the listener's perspective the wave appears to be stretched, as shown in the model for Figure 4. The opposite is true for a wave moving toward you.

Figure 4 The Doppler Effect The wavelength of the sound of an approaching ambulance is compressed as it approaches an observer. For a receding ambulance, the wavelength is stretched out and the observer notes a lower-pitched sound. When this effect is applied to light, a shorter wavelength is noted for an approaching object and is seen as blue light. A longer wavelength is noted for a receding object, which is seen as red light.

The light from a source that is moving away from an observer appears redder than it actually is because its waves are lengthened. This effect is only noticeable to the human eye at velocities approaching the speed of light. Objects moving toward an object have their light waves shifted toward the blue, or shorter wavelength. In addition, the amount of shift is related to the rate of movement. Thus, if a source of red light moved toward you, it could actually appear blue. The same effect would be produced if you moved and the light source was stationary.

In astronomy, the Doppler effect is used to determine whether a star or other body in space is moving away from or toward Earth. Larger Doppler shifts indicate higher speeds; smaller Doppler shifts indicate slower speeds. Doppler shifts are generally measured from the dark lines in the spectra of stars by comparing them with a standard spectrum produced in the laboratory.

Section 24.1 Assessment

Reviewing Concepts

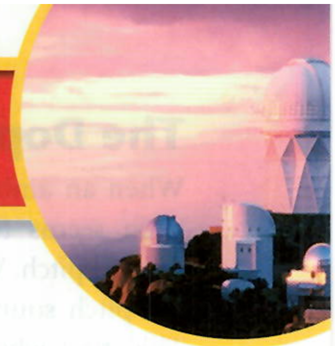
1. What types of radiation make up the electromagnetic spectrum?
2. Compare and contrast the three different types of spectra.
3. How do scientists determine the elements present in a star?
4. How can scientists determine whether a star is moving toward or away from Earth?

Critical Thinking

5. **Sequencing** Sequence the components of visible light according to wavelength, beginning with the shortest wavelength.
6. **Applying Concepts** Based on what you know about visible light, how do rainbows form in Earth's atmosphere?

Writing in Science

List of Questions Make a list of questions that you would like to ask a scientist about the nature of light. Your questions should cover both the wave theory and the particle theory of light.



24.2 Tools for Studying Space

Reading Focus

Key Concepts

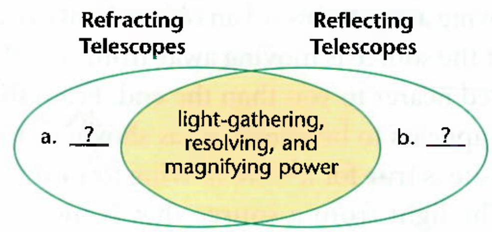
- How does a refracting telescope produce an image?
- Why are most large telescopes reflecting telescopes?
- How does a radio telescope gather data?
- What advantages do space telescopes have over Earth-based telescopes?

Vocabulary

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

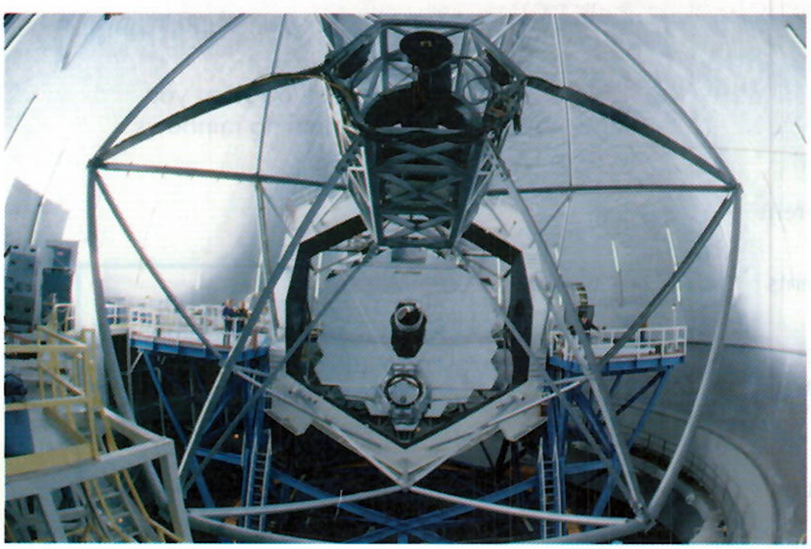
Reading Strategy

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.

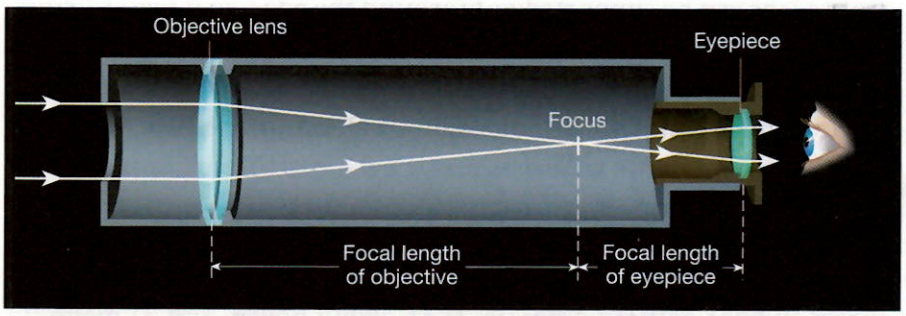


Figure 6 Simple Refracting Telescope A refracting telescope uses a lens to bend light.

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?*

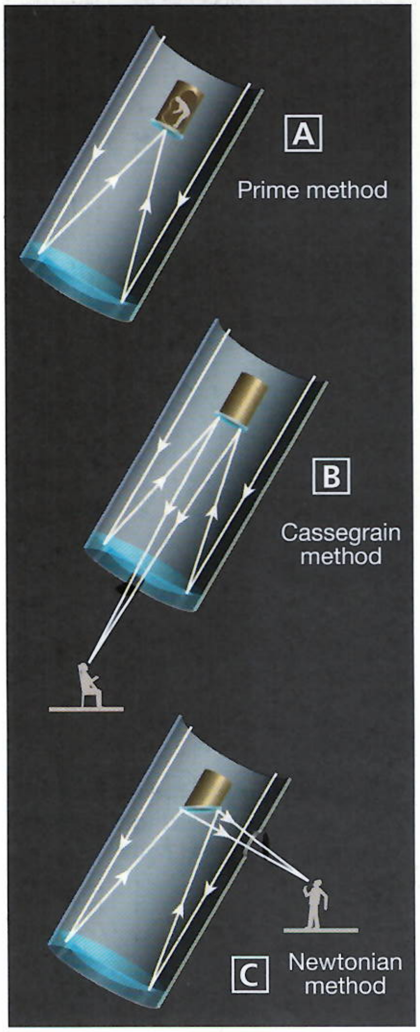


Figure 7 Viewing Methods with Reflecting Telescopes
A The prime method is only used with very large telescopes.
B The Cassegrain method is most commonly used. Note that a small hole in the center of the mirror allows light to pass through.
C This figure shows the Newtonian method.

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?*

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.

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

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.

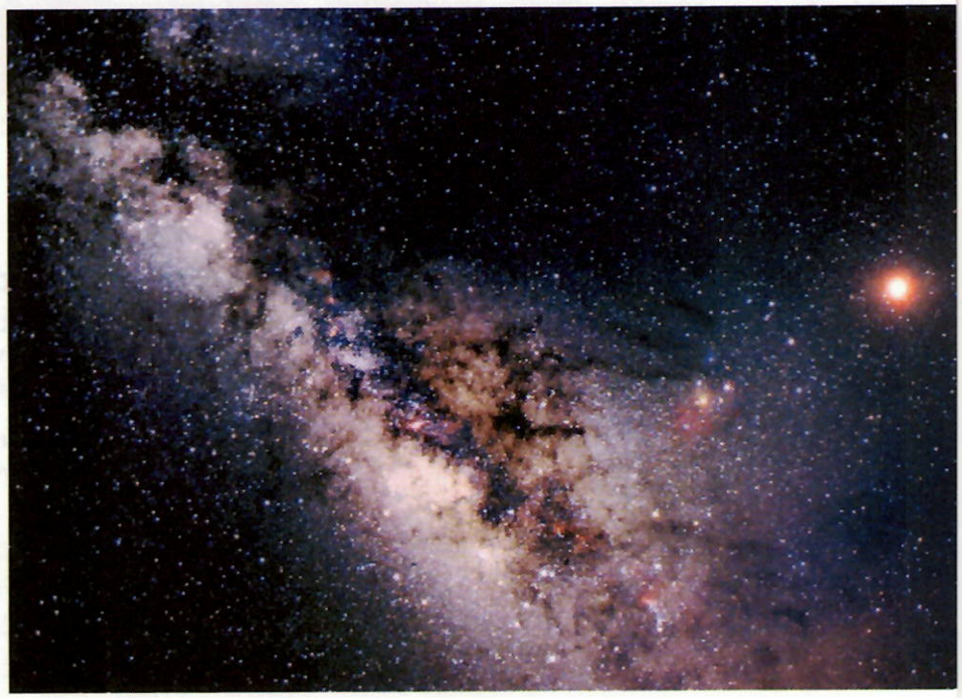


Figure 10 Images of the Milky Way Galaxy These images were taken by different types of telescopes, including visible light, X-ray, gamma ray, and infrared.

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.

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?

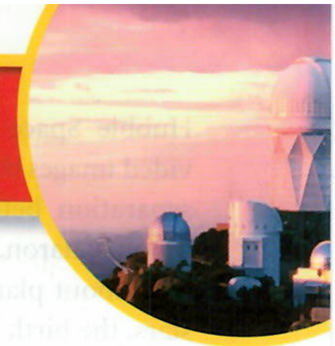
Critical Thinking

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?

24.3 The Sun



Reading Focus

Key Concepts

- What is the structure of the sun?
- What are the characteristics of features on the sun?
- How does the sun produce energy?

Vocabulary

- photosphere
- chromosphere
- corona
- solar wind
- sunspot
- prominence
- solar flare
- aurora
- nuclear fusion

Reading Strategy

Monitoring Your Understanding Preview the Key Concepts, topic headings, vocabulary, and figures in this section. Copy the table below, listing two things you expect to learn. After reading, fill in the table below, stating what you have learned about each item you listed.

What I Expect to Learn	What I Learned
a. ___?___	b. ___?___
c. ___?___	d. ___?___

The sun is one of the 100 billion stars that make up the Milky Way galaxy. Although the sun is of no significance to the universe as a whole, it is Earth's primary source of energy. Everything—from the fossil fuels we burn in our automobiles to the food that we eat—is ultimately derived from solar energy. The sun is also important to astronomers, since it is the only star whose surface we can study. Even with the largest telescopes, other stars appear only as points of light.

Because of the sun's brightness and its damaging radiation, it is not safe to observe it directly. However, a telescope can project its image on a piece of cardboard held behind the telescope's eyepiece. In this manner, the sun can be studied safely. This basic method is used in several telescopes around the world, which keep a constant watch of the sun. One of the finest is at the Kitt Peak National Observatory in southern Arizona, shown in Figure 11. It consists of an enclosure with moving mirrors that directs sunlight to an underground mirror. From the mirror, an image of the sun is projected to an observing room, where it is studied.

Figure 11 The McMath-Pierce Solar Telescope at Kitt Peak Near Tucson, Arizona Movable mirrors at the top follow the sun, reflecting its light down the sloping tunnel.

Compared to other stars, the sun is an "average star." However, on the scale of our solar system, it is truly gigantic. Its diameter is equal to 109 Earth diameters, or 1.35 million kilometers. Its volume is 1.25 million times as great as Earth's. Its mass is 332,000 times the mass of Earth and its density is only one quarter that of solid Earth.

Structure of the Sun

Because the sun is made of gas, no sharp boundaries exist between its various layers. **Keeping this in mind, we can divide the sun into four parts: the solar interior; the visible surface, or photosphere; and two atmospheric layers, the chromosphere and corona.** These parts are shown in Figure 12. The sun's interior makes up all but a tiny fraction of the solar mass. Unlike the outer three layers, the solar interior cannot be directly observed. Let's discuss the visible layers first.

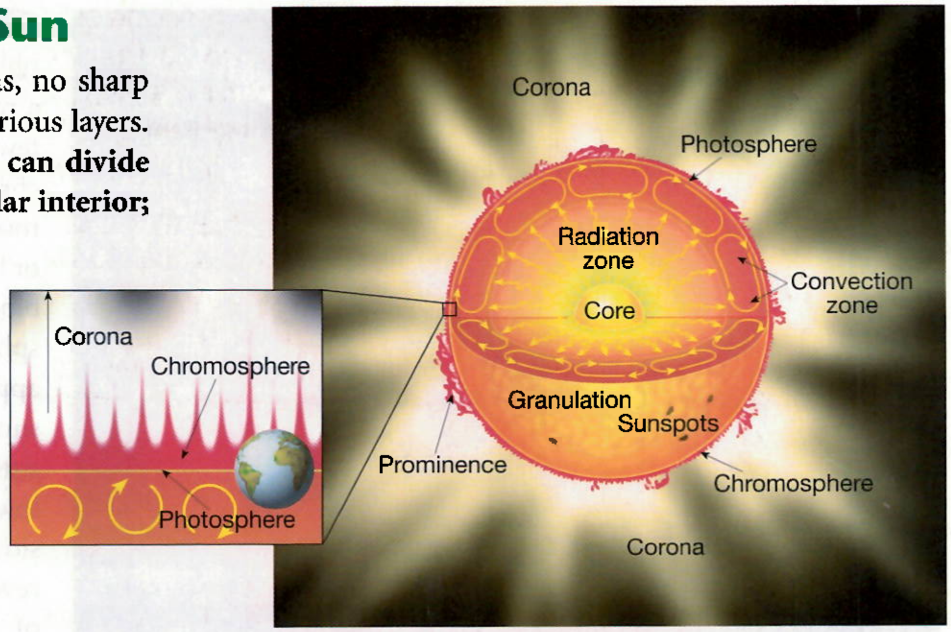


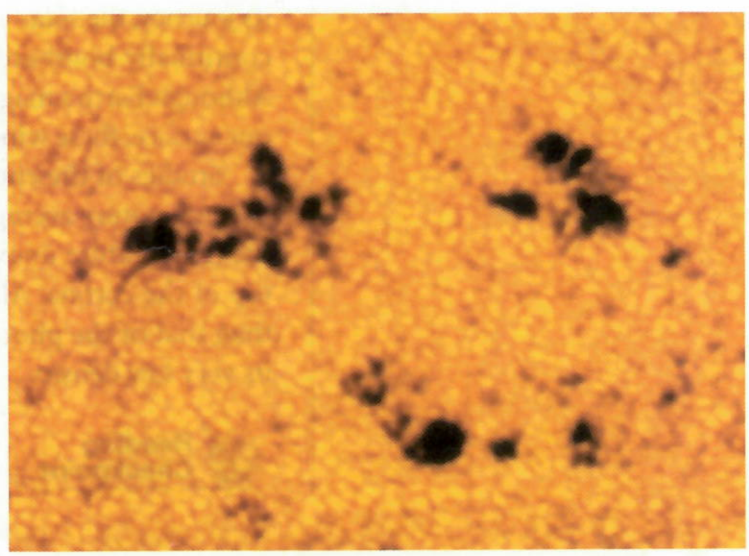
Figure 12 Structure of the Sun The sun can be divided into four parts: the solar interior, the photosphere, the chromosphere, and the corona.

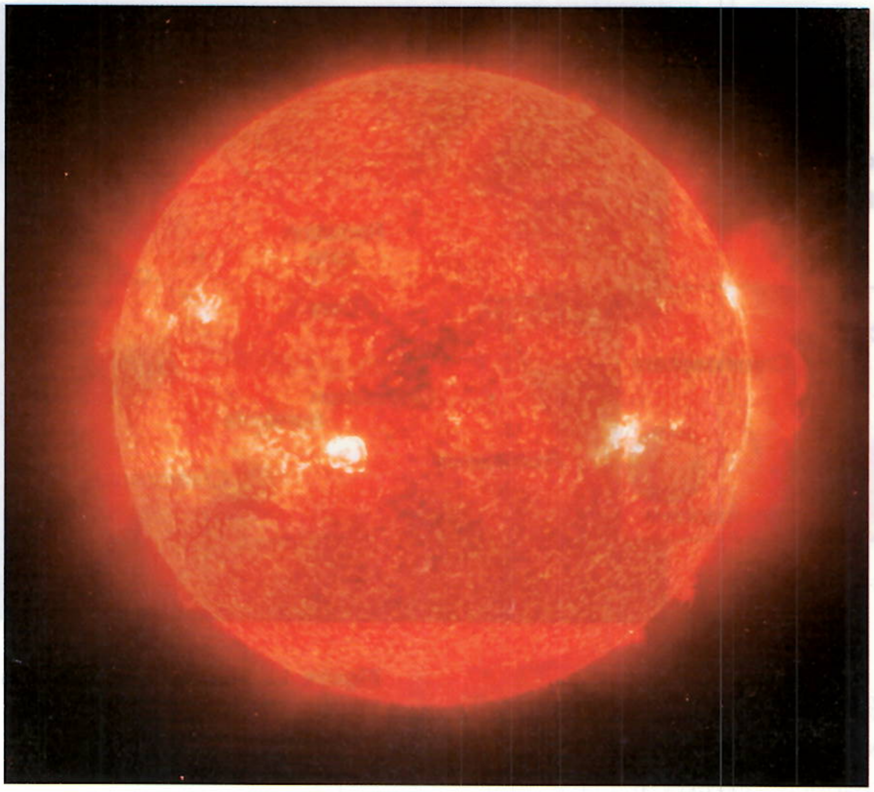
Photosphere The **photosphere** (*photos* = light, *sphere* = a ball) radiates most of the sunlight we see and can be thought of as the visible "surface" of the sun. The photosphere consists of a layer of gas less than 500 kilometers thick. It is neither smooth nor uniformly bright, as the ancients had imagined.

When viewed through a telescope, the photosphere's grainy texture is apparent. This is the result of numerous relatively small, bright markings called granules, which are surrounded by narrow, dark regions, as shown in Figure 13. Granules are typically the size of Texas, and they owe their brightness to hotter gases that are rising from below. As this gas spreads, cooling causes it to darken and sink back into the interior. Each granule survives only 10 to 20 minutes. The combined motion of new granules replacing old ones gives the photosphere the appearance of boiling. This up-and-down movement of gas is called convection. Besides producing the grainy appearance of the photosphere, convection is believed to be responsible for the transfer of energy in the uppermost part of the sun's interior.

The composition of the photosphere is revealed by the dark lines of its absorption spectrum. Studies reveal that 90 percent of the sun's surface atoms are hydrogen, almost 10 percent are helium, and only minor amounts of the other detectable elements are present. Other stars also have high proportions of these two lightest elements, a fact we shall discuss later.

Figure 13 Granules Granules are the yellowish-orange patches on the photosphere.
Describing ***Describe the movement of gases in the convection zone.***





Chromosphere Just above the photosphere lies the **chromosphere,** a relatively thin layer of hot gases a few thousand kilometers thick. The chromosphere is observable for a few moments during a total solar eclipse or by using a special instrument that blocks out the light from the photosphere. Under such conditions, it appears as a thin red rim around the sun. Because the chromosphere consists of hot, incandescent gases under low pressure, it produces an emission spectrum that is nearly the reverse of the absorption spectrum of the photosphere. One of the bright lines of hydrogen contributes a good portion of its total light and accounts for this sphere's red color.

Figure 14 Chromosphere The chromosphere is a thin layer of hot gases that appears as a red rim around the sun.

Corona The outermost portion of the solar atmosphere, the **corona** (*corona* = crown) is very weak and, as with the chromosphere, is visible only when the brilliant photosphere is covered. This envelope of ionized gases normally extends a million kilometers from the sun and produces a glow about half as bright as the full moon.

At the outer fringe of the corona, the ionized gases have speeds great enough to escape the gravitational pull of the sun. The streams of protons and electrons that boil from the corona constitute the **solar wind.** This wind travels outward through the solar system at speeds up to 800 kilometers per second and eventually is lost to space. During its journey, the solar wind interacts with the bodies of the solar system, continually bombarding lunar rocks and altering their appearance. Although Earth's magnetic field prevents the solar winds from reaching our surface, these winds do affect our atmosphere, as we'll discuss later.

Studies of the energy emitted from the photosphere indicate that its temperature averages about 6000 K. Upward from the photosphere, the temperature unexpectedly increases, exceeding 1 million K at the top of the corona. Although the corona temperature is much higher than that of the photosphere, it radiates much less energy because of its very low density.

Reading Checkpoint ***What is the solar wind?***

The Active Sun

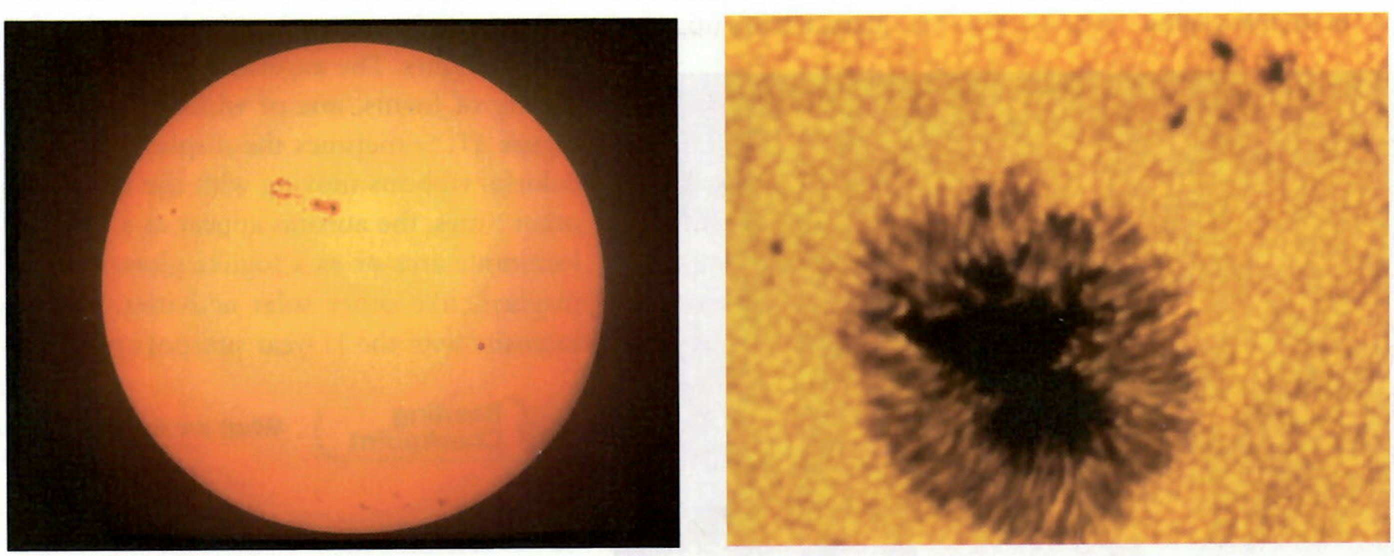
The most conspicuous features on the surface of the sun are the dark regions. They were occasionally observed before the advent of the telescope, but were generally regarded as objects located somewhere between the sun and Earth. In 1610, Galileo concluded that these regions were part of the solar surface. From their motion, he deduced that the sun rotates on its axis about once a month. Later observations indicated that not all parts of the sun rotate at the same speed. The sun's equator rotates once in 25 days, while a location 70 degrees from the solar equator, whether north or south, requires 33 days for one rotation. Imagine if Earth rotated in a similar manner! The sun's nonuniform rotation is evidence of its gaseous nature.

Sunspots What are those dark areas Galileo observed? The dark regions on the surface of the photosphere are called **sunspots.** As Figure 15 shows, an individual spot contains a black center rimmed by a lighter region. **Sunspots appear dark because of their temperature, which is about 1500 K less than that of the surrounding solar surface.** If these dark spots could be observed away from the sun, they would appear many times brighter than the full moon.

During the early nineteenth century, it was believed that a tiny planet named Vulcan orbited between Mercury and the sun. In the search for Vulcan an accurate record of sunspot occurrences was kept. Although the planet was never found, the sunspot data revealed that the number of sunspots observable varies in an 11-year cycle.

First, the number of sunspots increases to a maximum, with perhaps a hundred or more visible at a given time. Then their numbers gradually decline to a minimum, when only a few or even none are visible.

Figure 15 Sunspots A Sunspots often appear as groups of dark areas on the sun. **B** A close-up of an individual sunspot shows a black center surrounded by a lighter region.



A B

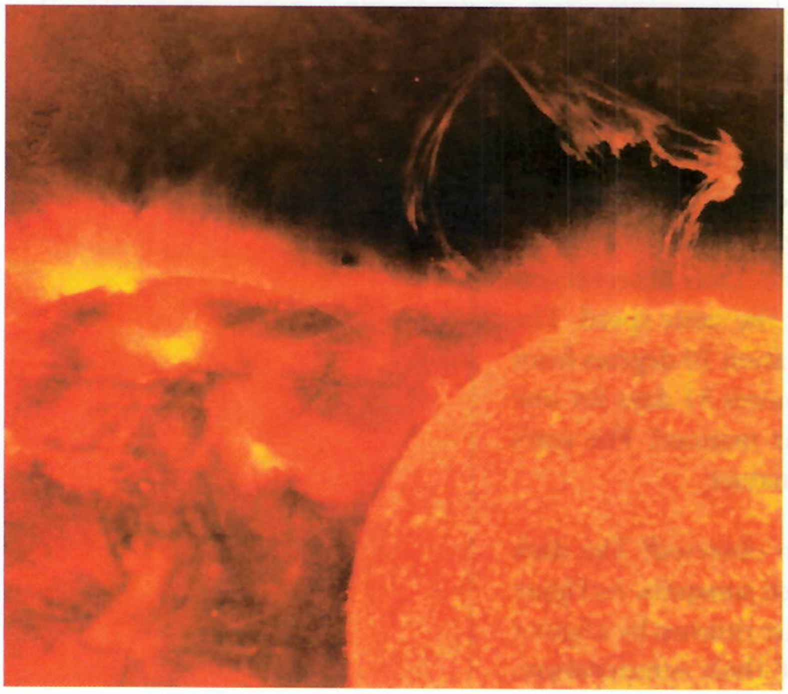


Figure 16 Solar Prominence Solar prominences are huge, arched structures, best observed when they are on the edge of the sun.

Prominences Among the more spectacular features of the active sun are prominences (*prominere* = to jut out). **Prominences** are huge cloudlike structures consisting of chromospheric gases. They often appear as great arches that extend well into the corona. Many prominences have the appearance of a fine tapestry and seem to hang motionless for days at a time. Others rise almost explosively away from the sun. These eruptive prominences reach speeds up to 1000 kilometers per second and may leave the sun entirely. **Prominences are ionized gases trapped by magnetic fields that extend from regions of intense solar activity.** Refer to Figure 16.

Solar Flares The most explosive events associated with sunspots are solar flares. **Solar flares** are brief outbursts that normally last about an hour and appear as a sudden brightening of the region above a sunspot cluster. **During their existence, solar flares release enormous amounts of energy, much of it in the form of ultraviolet, radio, and X-ray radiation.** At the same time, fast-moving atomic particles are ejected, causing the solar wind to intensify. Although a major flare could conceivably endanger the crew of a space flight, they are relatively rare. About a day after a large outburst, the ejected particles reach Earth, where they can affect long-distance radio communications.

The most spectacular effects of solar flares, however, are the **auroras,** also called the northern and southern lights. Following a strong solar flare, Earth's upper atmosphere near its magnetic poles is set aglow for several nights. The auroras appear in a wide variety of forms, one of which is shown in Figure 17. Sometimes the display looks like colorful ribbons moving with the breeze. At other times, the auroras appear as a series of luminous arcs or as a foglike glow. Auroral displays, like other solar activities, vary in intensity with the 11-year sunspot cycle.

Figure 17 Aurora Borealis or Northern Lights in Alaska The same phenomenon occurs toward the south pole, where it is called the aurora australis or southern lights.

Reading Checkpoint *What are solar flares?*

The Solar Interior

The interior of the sun cannot be observed directly. For that reason, all we know about it is based on information acquired from the energy it radiates and from theoretical studies. The source of the sun's energy was not discovered until the late 1930s.

Nuclear Fusion Deep in its interior, the sun produces energy by a process known as **nuclear fusion.** This nuclear reaction converts four hydrogen nuclei into the nucleus of a helium atom. Tremendous energy is released. **During nuclear fusion, energy is released because some matter is actually converted to energy, as shown in Figure 18.** How does this process work? Consider that four hydrogen atoms have a combined atomic mass of 4.032 atomic mass units (4 × 1.008) whereas the atomic mass of helium is 4.003 atomic mass units, or 0.029 less than the combined mass of the hydrogen. The tiny missing mass is emitted as energy according to Einstein's equation:

$$E = mc^2$$

E equals energy, m equals mass, and c equals the speed of light. Because the speed of light is very great (300,000 km/s), the amount of energy released from even a small amount of mass is enormous.

The conversion of just one pinhead's worth of hydrogen to helium generates more energy than burning thousands of tons of coal. Most of this energy is in the form of high-energy photons that work their way toward the solar surface. The photons are absorbed and reemitted many times until they reach a layer just below the photosphere. Here, convection currents help transport this energy to the solar surface, where it radiates through the transparent chromosphere and corona.

Only a small percentage of the hydrogen in the nuclear reaction is actually converted to energy. Nevertheless, the sun is consuming an estimated 600 million tons of hydrogen each second; about 4 million tons are converted to energy. As hydrogen is consumed, the product of this reaction—helium—forms the solar core, which continually grows in size.

Reading Checkpoint ***What happens during the process of nuclear fusion?***

Go Online SciLinks NSTA

For: Links on nuclear fusion in the sun

Visit: www.SciLinks.org

Web Code: cjn-7243

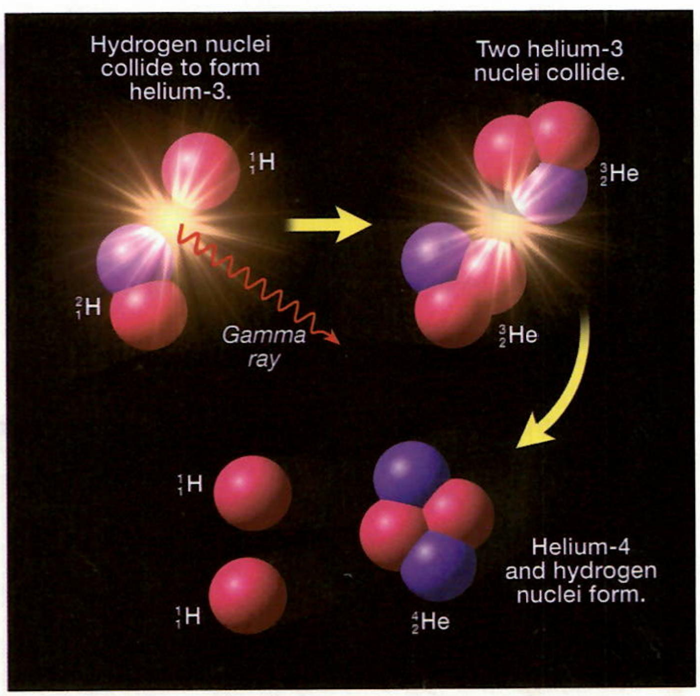


Figure 18 Nuclear Fusion During nuclear fusion, four hydrogen nuclei combine to form one helium nucleus. Some matter is converted to energy.

Figure 19 The sun is the source of more than 99 percent of all energy on Earth.

Just how long can the sun produce energy at its present rate before all of its hydrogen fuel is consumed? Even at the enormous rate of consumption, the sun, shown in Figure 19, has enough fuel to last easily another 100 billion years. However, evidence from other stars indicates that the sun will grow dramatically and engulf Earth long before all of its hydrogen is gone. It is thought that a star the size of the sun can exist in its present stable state for 10 billion years. As the sun is already 4.5 billion years old, it is "middle-aged."

To initiate nuclear fusion, the sun's internal temperature must have reached several million degrees. But what was the source of this heat? The solar system is believed to have formed from an enormous compressed cloud of dust and gases—mostly hydrogen. When gases are compressed, their temperature increases. All of the bodies in the solar system were compressed. However, the sun was the only one, because of its size, that became hot enough to trigger nuclear fusion. Astronomers currently estimate its internal temperature at 15 million K.

The planet Jupiter is basically a hydrogen-rich gas ball; if it were about 10 times more massive, it too might have become a star. The idea of one star orbiting another may seem odd, but recent evidence indicates that about 50 percent of the stars in the universe probably occur in pairs or multiples!

Section 24.3 Assessment

Reviewing Concepts

1. What is the structure of the sun?
2. Which layer of the sun can be thought of as its surface?
3. Describe some characteristics of features on the sun.
4. Are the same number of sunspots always present on the sun? Explain.
5. How does the sun produce energy?
6. How much longer will the sun likely exist in its present state?

Critical Thinking

7. **Relating Cause and Effect** Why do sunspots appear dark?
8. **Applying Concepts** What is the effect on Earth's atmosphere of a strong solar flare?

Math Practice

9. Of the 6×10^8 tons of hydrogen the sun consumes each second, about 4×10^8 tons are converted to energy. What percentage of the total energy consumed per second is converted to energy?

earth as a SYSTEM

Solar Activity and Climatic Change

Some people believe that changes in solar activity relate to climatic change. The effect of such changes would seem direct and easily understood: Increases in solar output would cause the atmosphere to warm, and reductions would result in cooling. This notion is appealing because it can be used to explain climatic changes of any length or intensity. Still, there is at least one major drawback: No major long-term variations in the total intensity of solar radiation have yet been measured. Such measurements were not even possible until satellite technology became available. Now that it is possible, we will need many years of records before we begin to sense how variable the sun really is.

Sunspot Cycles

Several theories for climatic change based on a variable sun relate to sunspot cycles. The most recognizable features on the surface of the sun are the dark regions called sunspots. See Figure 20. The number of sunspots seems to increase and decrease over a cycle of about 11 years. The graph in Figure 21 below shows the annual number of sunspots, beginning in the early 1700s. However, this pattern is not always regular.

There have been long periods when sunspots have been absent or nearly absent. These events correspond closely with cold periods in Europe and North America. In contrast, periods of high sunspot activity have been associated with warmer times in these regions.

Conflicting Evidence

Because of these data, some scientists have suggested that changes in solar activity are an important cause of climatic change. But other scientists seriously question this notion. Their hesitation stems in part from investigations using different climatic records from around the world that failed to find a significant relationship between solar activity and climate. Even more troubling is that there is no way to test the relationship.

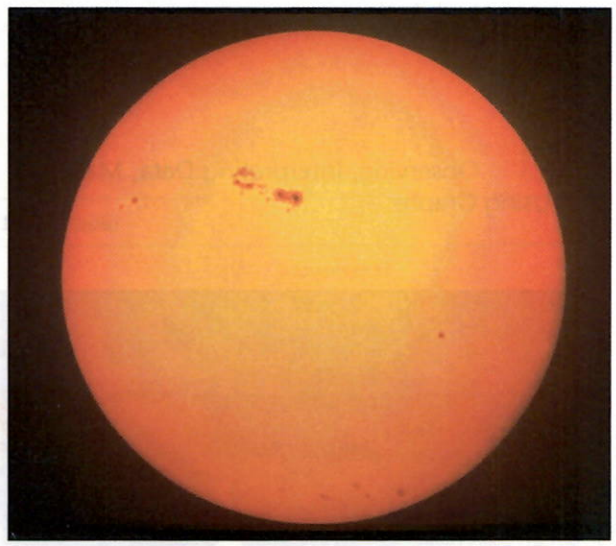


Figure 20 Dark regions on the surface of the sun are called sunspots.

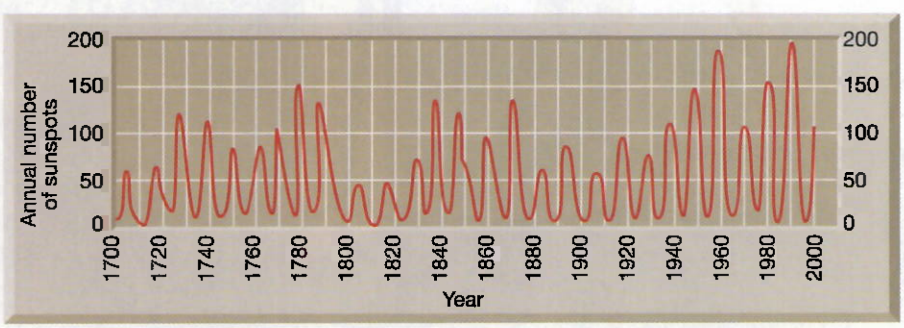


Figure 21 Mean Annual Sunspot Numbers

CHAPTER 24

Study Guide

24.1 The Study of Light

Key Concepts

- Electromagnetic radiation includes gamma rays, X-rays, ultraviolet light, visible light, infrared radiation, microwaves, and radio waves.
- When the spectrum of a star is studied, the spectral lines act as "fingerprints." These lines identify the elements present and thus the star's chemical composition.
- In astronomy, the Doppler effect is used to determine whether a star or other body in space is moving away from or toward Earth.

Vocabulary

electromagnetic spectrum, *p. 674;* photon, *p. 675;* spectroscopy, *p. 676;* continuous spectrum, *p. 676;* absorption spectrum, *p. 676;* emission spectrum, *p. 676;* Doppler effect, *p. 677*

24.2 Tools for Studying Space

Key Concepts

- In a refracting telescope, the objective lens produces an image by bending light from a distant object in such a way that the light converges at an area called the focus.
- 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. This means chromatic aberration is not a problem.
- A radio telescope focuses the incoming radio waves on an antenna, which absorbs and transmits these waves to an amplifier, just like any radio antenna.
- Space telescopes orbit above Earth's atmosphere and thus produce clearer images than Earth-based telescopes.

Vocabulary

refracting telescope, *p. 678;* chromatic aberration, *p. 679;* reflecting telescope, *p. 680;* radio telescope, *p. 681*

24.3 The Sun

Key Concepts

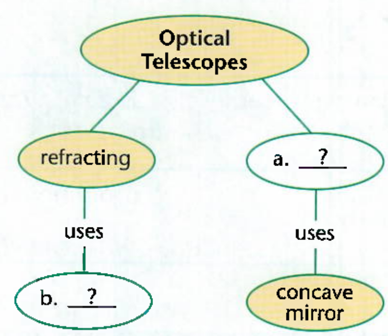
- The sun can be divided into four parts: the solar interior; the visible surface, or photosphere; and two atmospheric layers, the chromosphere and corona.
- Sunspots appear dark because of their temperature, which is about 1500 K less than that of the surrounding solar surface.
- Prominences are ionized gases trapped by magnetic fields that extend from regions of intense solar activity.
- Solar flares release enormous amounts of energy, much of it in the form of ultraviolet, radio, and X-ray radiation.
- During nuclear fusion, energy is released because some matter is converted to energy.

Vocabulary

photosphere, *p. 685;* chromosphere, *p. 686;* corona, *p. 686;* solar wind, *p. 686;* sunspot, *p. 687;* prominence, *p. 688;* solar flare, *p. 688;* aurora, *p. 688;* nuclear fusion, *p. 689*

Thinking Visually

Concept Map Use information from the chapter to complete the concept map below.



CHAPTER 24

Assessment

Interactive textbook with assessment at PHSchool.com

Interactive Textbook

Reviewing Content

Choose the letter that best answers the question or completes the statement.

1. Which type of radiation has the shortest wavelength?
   a. gamma rays b. X-rays
   c. visible light d. radio waves

2. The energy of a photon is related to its
   a. size. b. mass.
   c. density. d. wavelength.

3. As light passes through a prism, which color will bend the most?
   a. red b. violet
   c. yellow d. blue

4. Which type of telescope uses a concave mirror?
   a. refracting b. reflecting
   c. ultraviolet d. infrared

5. Which of the following is not a property of optical telescopes?
   a. resolving power
   b. magnifying power
   c. reflecting power
   d. light-gathering power

6. When several radio telescopes are wired together, the resulting network is called a radio
   a. receiver.
   b. interferometer.
   c. tuner.
   d. antenna.

7. The numerous, relatively small bright markings on the sun's photosphere are called
   a. auroras. b. sunspots.
   c. granules. d. prominences.

8. The thin, red rim seen around the sun during a total solar eclipse is the
   a. chromosphere. b. corona.
   c. solar wind. d. photosphere.

9. Which features of the sun look like huge cloudlike arches?
   a. solar flares b. sunspots
   c. auroras d. prominences

10. What is the source of the sun's energy?
    a. magnetism
    b. nuclear fission
    c. nuclear fusion
    d. radiation pressure

Understanding Concepts

11. What two factors determine how radiation is arranged on the electromagnetic spectrum?
12. Which color has the longest wavelength? The shortest?
13. Compare and contrast the wave theory and the particle theory of light.
14. Describe a continuous spectrum. Give an example of a natural phenomenon that exhibits a continuous spectrum.
15. Which type of spectrum do most stars have?
16. What optical defect is associated with refracting telescopes?
17. What three properties do optical telescopes have that aid astronomers?
18. What are some advantages of radio telescopes over optical telescopes?
19. List three space telescopes and describe the type of radiation studied by each.
20. Compare the diameter of the sun to that of Earth.
21. What is solar wind?
22. What "fuel" does the sun consume?
23. What happens to the matter that is consumed in nuclear fusion?

Assessment *continued*

Critical Thinking

24. **Summarizing** Briefly summarize the relationship between Doppler shift and the speed of a moving object.

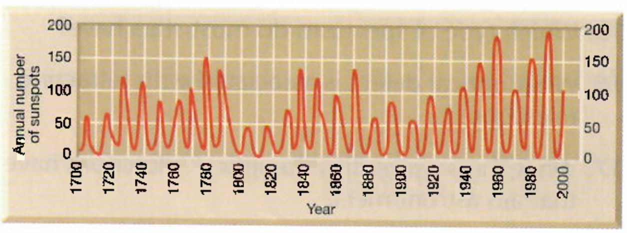
25. **Inferring** Why would the moon make a good site for an observatory?

26. **Relating Cause and Effect** The photosphere has a boiling appearance. Why?

27. **Drawing Conclusions** The solar wind can be thought of as evidence for which theory of light? Explain your answer.

Analyzing Data

Use the graph to answer Questions 28–31.



28. **Identifying** Which years had the lowest number of sunspots? The highest?

29. **Interpreting Data** Describe any patterns in the data.

30. **Predicting** When will the next period of maximum sunspot activity occur?

31. **Analyzing Data** Based on the data alone, is it possible to predict how many sunspots will occur during the next peak? Why or why not?

Concepts in Action

32. **Inferring** What can you infer about a star that exhibits a red shift in its spectra?

33. **Explaining** Why do astronomers seek to design telescopes with larger and larger objectives?

34. **Relating Cause and Effect** What could you infer about solar activity if you spotted an aurora that lasted several nights?

Performance-Based Assessment

Oral Presentation The sun is Earth's main source of energy. Work in a group to develop a presentation describing what might happen if the sun's energy increased by 10 percent. Discuss the effects on global temperatures, ocean shorelines, and polar caps. Be sure to consider changes in the amount of surface vegetation, and the impact of these changes on levels of atmospheric carbon dioxide.

Standardized Test Prep

Test-Taking Tip

Scientific Drawings

Some test questions may include a drawing of a scientific instrument, such as a telescope, or an object studied by scientists, such as the sun. It is important that you carefully study the information presented in the question, as well as the picture provided. Keep these tips in mind when answering a question with drawings of objects or scientific instruments.

- Identify the item shown so you can determine what information the drawing can provide.
- Think of similar drawings or questions you have seen. These may help you determine information available from the drawing.
- The illustrations may not be drawn to scale. You must read and interpret the scales carefully.
- Carefully read the question. You may not need all the information. You may need more information than is presented in the drawing.

Practice using these tips in Questions 5 and 6.

Choose the letter that best answers the question or completes the statement.

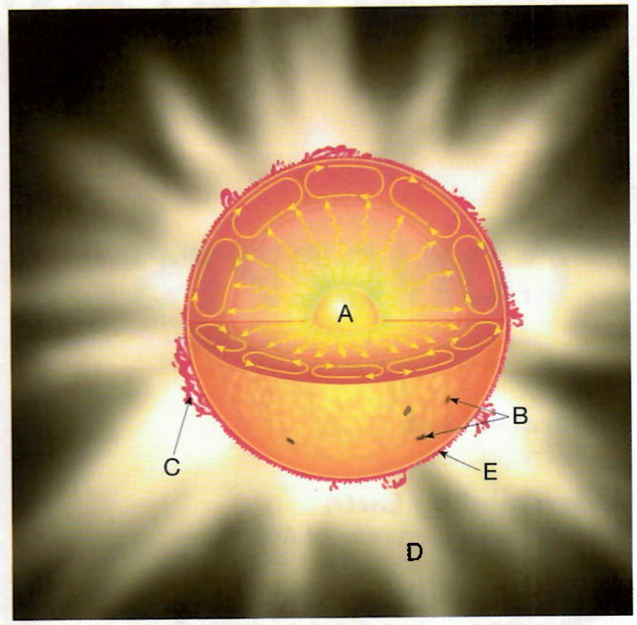
1. Which of the following is NOT considered a form of electromagnetic radiation?
   (A) radio waves
   (B) gravity
   (C) gamma rays
   (D) visible light

2. The sun produces energy by converting
   (A) oxygen nuclei to carbon dioxide.
   (B) oxygen nuclei to nitrogen nuclei.
   (C) hydrogen nuclei to helium nuclei.
   (D) helium nuclei to hydrogen nuclei.

Answer the following questions in complete sentences.

3. What happens to the temperature of a gas when it is compressed?

4. Describe the composition of the sun's surface and compare it with that of other stars.



Use the diagram above to answer Questions 5 and 6.

5. What is the innermost layer of the sun called? What is the outermost layer?

6. What letters represent features found on the sun? Identify each feature.

CHAPTER 25

Beyond Our Solar System

CONCEPTS in Action

Exploration Lab
Observing Stars

Understanding Earth
Astrology—Forerunner of Astronomy

Discovery Channel School **Video Field Trip**

Stars: Life and Death

Take a field trip through outer space with Discovery Channel and find out how stars are born, and why they die. Answer the following questions after watching the video.

1. What happens when a star runs out of hydrogen fuel?
2. Describe what will happen to the sun when it dies.

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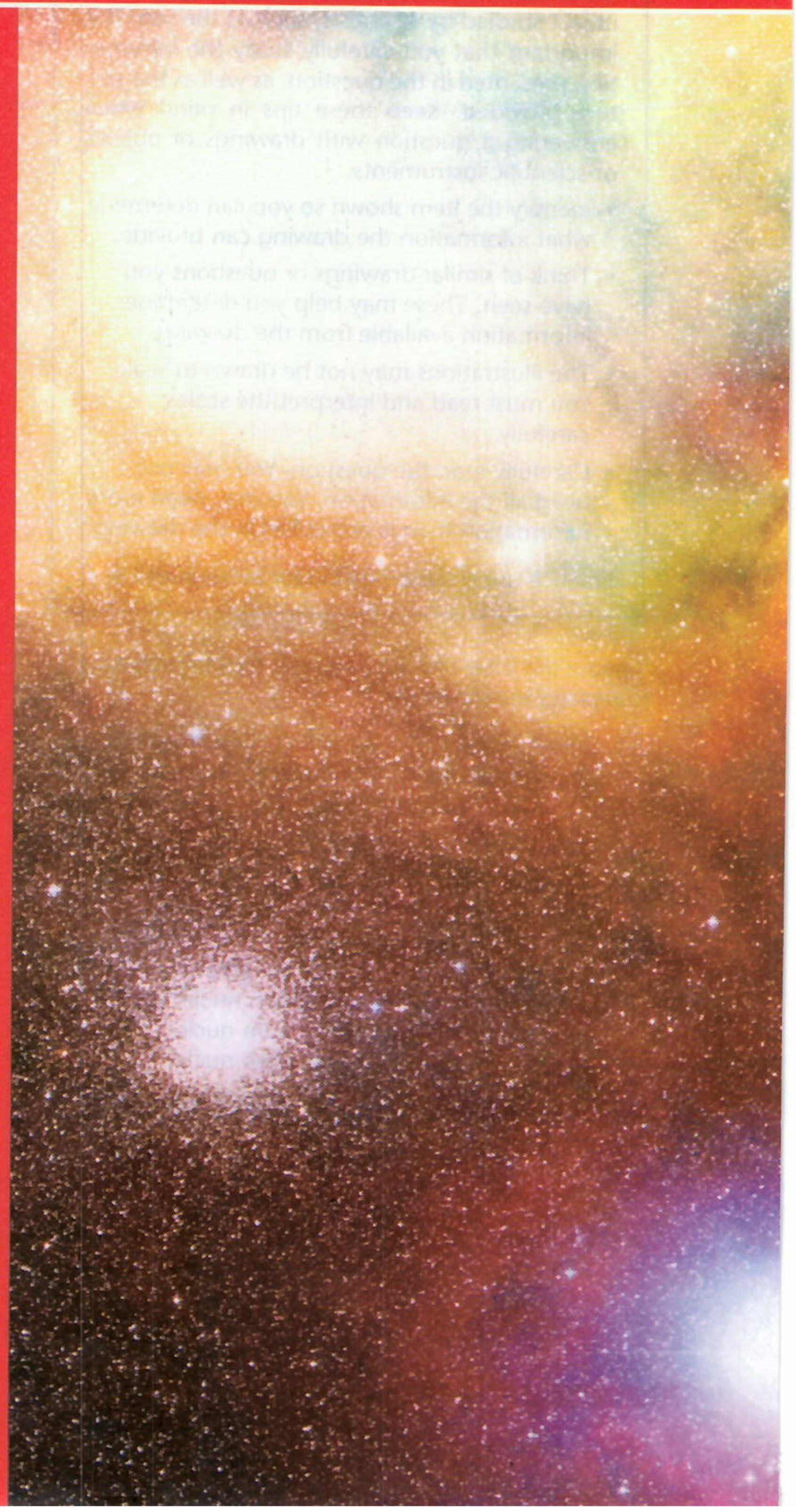


Stars embedded in clouds of dust and gases produce colorful nebulae. ▶

Chapter Preview

Inquiry Activity

How Do Astronomers Measure Distances to Nearby Stars?

Procedure

1. Close your left eye. With your index finger in a vertical position, use your right eye to line up your finger with a distant object, such as a tree.
2. Without moving your finger, view the object with your left eye opened and your right eye closed.

Think About It

1. **Observing** What happened to the position of your finger when you observed it with your left eye?
2. **Predicting** What might happen if you repeated the activity, holding your finger farther from your eyes? Test your prediction.

25.1 Properties of Stars

Reading Focus

Key Concepts

- What can we learn by studying star properties?
- How does distance affect parallax?
- What factors determine a star's apparent magnitude?
- What relationship is shown on a Hertzsprung-Russell diagram?

Vocabulary

- constellation
- binary star
- light-year
- apparent magnitude
- absolute magnitude
- main-sequence star
- red giant
- supergiant
- Cepheid variable
- nova
- nebulae

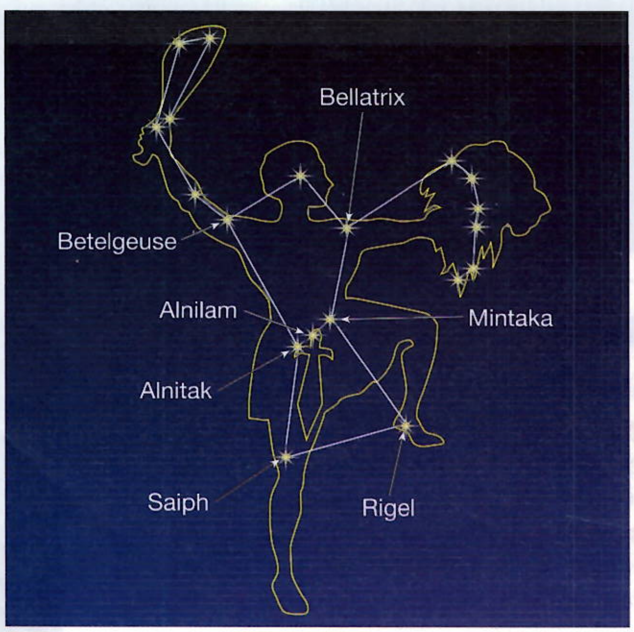
Reading Strategy

Previewing Copy the table below. Before you read, write two questions about the Hertzsprung-Russell diagram on page 704. As you read, write answers to your questions.

Questions about the Hertzsprung-Russell Diagram	
Question	Answer
a. ?	b. ?
c. ?	d. ?

The star Proxima Centauri is about 100 million times farther away from Earth than the moon. Yet, besides the sun, it is the closest star to Earth. The universe is incomprehensibly large. What is the nature of this vast universe? Do stars move, or do they remain in one place? Does the universe extend infinitely in all directions, or does it have boundaries? This chapter will answer these questions by examining the universe and the most numerous objects in the night sky—the stars.

Figure 1 Orion The constellation Orion was named for a hunter.



As early as 5000 years ago, people became fascinated with the star-studded skies and began to name the patterns they saw. These patterns of stars, called **constellations,** were named in honor of mythological characters or great heroes, such as Orion, shown in Figure 1.

Although the stars that make up a constellation all appear to be the same distance from Earth, some are many times farther away than others. So, the stars in a particular constellation are not associated with one another in any physical way.

Today 88 constellations are recognized. They are used to divide the sky into units, just as state boundaries divide the United States. Every star in the sky is in, but is not necessarily part of, one of these constellations. Therefore, constellations can be used as a "map" of the night sky.

Characteristics of Stars

A great deal is known about the universe beyond our solar system. This knowledge hinges on the fact that stars, and even gases in the "empty" space between stars, radiate energy in all directions into space. The key to understanding the universe is to collect this radiation and unravel the secrets it holds. Astronomers have devised many ways to do just that. We will begin by examining some properties of stars, such as color, temperature, and mass.

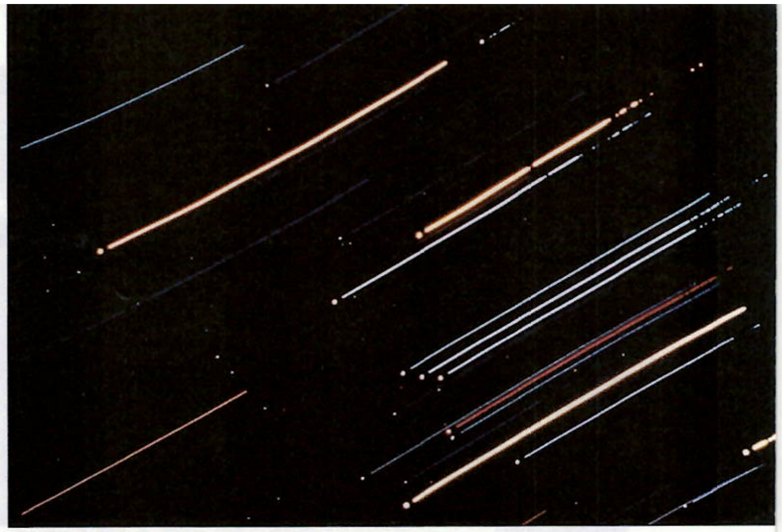


Figure 2 Stars of Orion This time-lapse photograph shows stars as streaks across the night sky as Earth rotates. The streaks clearly show different star colors.

Star Color and Temperature Study the stars in Figure 2 and note their color. **Color is a clue to a star's temperature.** Very hot stars with surface temperatures above 30,000 K emit most of their energy in the form of short-wavelength light and therefore appear blue. Red stars are much cooler, and most of their energy is emitted as longer-wavelength red light. Stars with temperatures between 5000 and 6000 K appear yellow, like the sun.

Binary Stars and Stellar Mass In the early nineteenth century, astronomers discovered that many stars orbit each other. These pairs of stars, pulled toward each other by gravity, are called **binary stars.** More than 50 percent of the stars in the universe may occur in pairs or multiples.

Binary stars are used to determine the star property most difficult to calculate—its mass. The mass of a body can be calculated if it is attached by gravity to a partner. This is the case for any binary star system. As shown in Figure 3, binary stars orbit each other around a common point called the center of mass. For stars of equal mass, the center of mass lies exactly halfway between them. If one star is more massive than its partner, their common center will be closer to the more massive one. If the sizes of their orbits are known, the stars' masses can be determined.

Reading Checkpoint *What is a binary star system?*

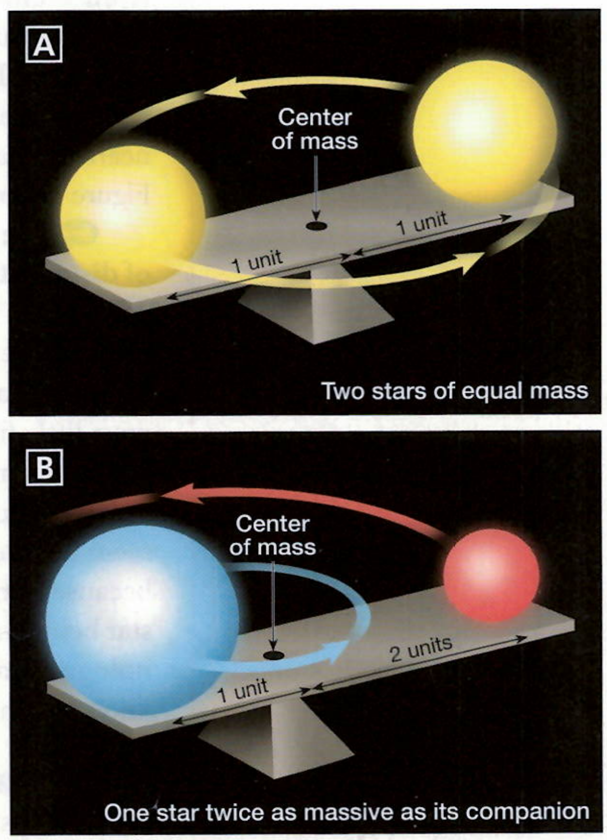


Figure 3 Common Center of Mass
A For stars of equal mass, the center of mass lies in the middle. **B** A star twice as massive as its partner is twice as close to the center of mass. It therefore has a smaller orbit than its less massive partner.

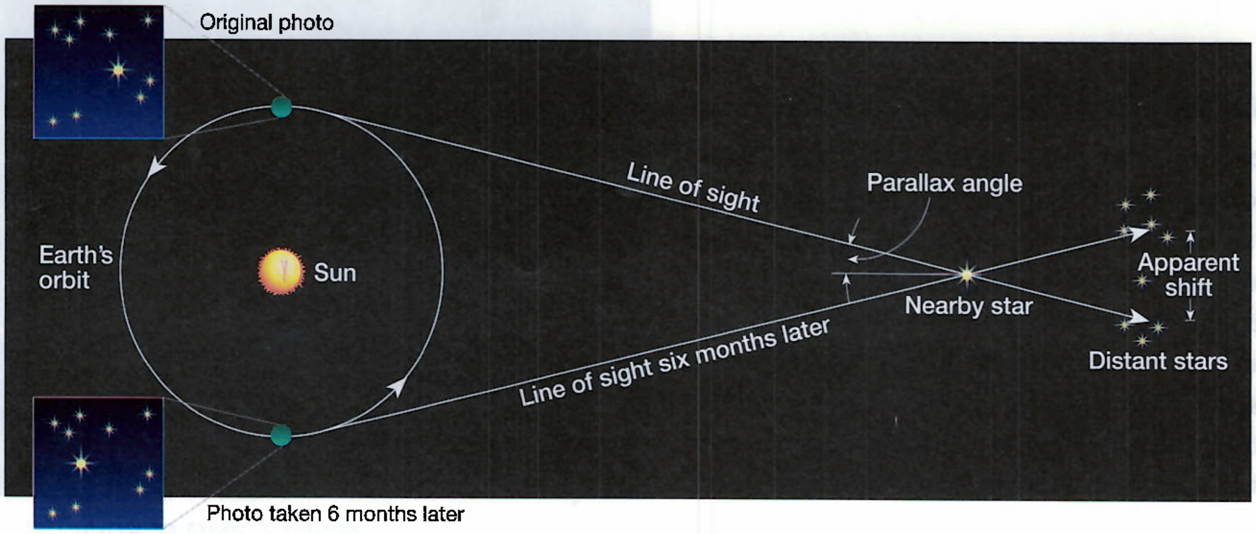


Figure 4 Parallax The parallax angle shown here is exaggerated to illustrate the principle. Because the distances to even the nearest stars are huge, astronomers work with very small angles.
Relating Cause and Effect
What caused the star to appear to shift?

Measuring Distances to Stars

Although measuring the distance to a star is very difficult, astronomers have developed some methods of determining stellar distances.

Parallax The most basic way to measure star distance is parallax. Parallax is the slight shifting in the apparent position of a nearby star due to the orbital motion of Earth. Parallax is determined by photographing a nearby star against the background of distant stars. Then, six months later, when Earth has moved halfway around its orbit, a second photograph is taken. When these photographs are compared, the position of the nearby star appears to have shifted with respect to the background stars. Figure 4 shows this shift and the resulting parallax angle.

The nearest stars have the largest parallax angles, while those of distant stars are too small to measure. In fact, all parallax angles are very small. The parallax angle to the nearest star (besides the sun), Proxima Centauri, is less than 1 second of arc, which equals 1/3600 of a degree. To put this in perspective, fully extend your arm and raise your little finger. Your finger is roughly 1 degree wide. Now imagine tracking a movement that is only 1/3600 as wide as your finger.

In principle, the method used to measure stellar distances may seem simple. But in practice, measurements are greatly complicated because of the tiny angles involved and because the sun, as well as the star being measured, also move through space. Even with today's technology, parallax angles for only a few thousand of the nearest stars are known with certainty.

Light-Year Distances to stars are so large that units such as kilometers or astronomical units are often too hard to use. A better unit to express stellar distance is the **light-year,** which is the distance light travels in one year—about 9.5×10^{12} or 9.5 trillion kilometers. Proxima Centauri is about 4.3 light-years away from the sun.

Reading Checkpoint *What is a light-year?*

Stellar Brightness

The measure of a star's brightness is its magnitude. The stars in the night sky have an assortment of sizes, temperatures, and distances, so their brightnesses vary widely.

Apparent Magnitude Some stars may appear dimmer than others only because they are farther away. A star's brightness as it appears from Earth is called its **apparent magnitude.** **Three factors control the apparent brightness of a star as seen from Earth: how big it is, how hot it is, and how far away it is.**

Astronomers use numbers to rank apparent magnitude. The larger the number is, the dimmer the star. Just as we can compare the brightness of a 50-watt bulb to that of a 100-watt bulb, we can compare the brightness of stars having different magnitudes. A first-magnitude star is about 100 times brighter than a sixth-magnitude star. Therefore, two stars that differ by 5 magnitudes have a ratio in brightness of 100 to 1. It follows, then, that the brightness ratio of two stars differing by only one magnitude is about 2.5. A star of the first magnitude is about 2.5 times brighter than a star of the second magnitude.

Reading Checkpoint ***What is apparent magnitude?***

Absolute Magnitude Astronomers are also interested in how bright a star actually is, or its **absolute magnitude.** Two stars of the same absolute magnitude usually do not have the same apparent magnitude because one may be much farther from us than the other. The one that is farther away will appear dimmer. To compare their absolute brightness, astronomers determine what magnitude the stars would have if they were at a standard distance of about 32.6 light-years. For example, the sun, which has an apparent magnitude of −26.7, would, if located at a distance of 32.6 light-years, have an absolute magnitude of about 5. Stars with absolute magnitude values lower than 5 are actually brighter than the sun. Because of their distance, however, they appear much dimmer. Table 1 lists the absolute and apparent magnitudes of some stars as well as their distances from Earth.

Table 1 Distance, Apparent Magnitude, and Absolute Magnitude of Some Stars

Name	Distance (light-years)	Apparent Magnitude*	Absolute Magnitude*
Sun	NA	−26.7	5.0
Alpha Centauri	4.27	0.0	4.4
Sirius	8.70	−1.4	1.5
Arcturus	36	−0.1	−0.3
Betelgeuse	520	0.8	−5.5
Deneb	1600	1.3	−6.9

*The more negative, the brighter; the more positive, the dimmer.

Reading Checkpoint ***What is absolute magnitude?***

Hertzsprung-Russell Diagram

Early in the twentieth century, Einar Hertzsprung and Henry Russell independently developed a graph used to study stars. It is now called a Hertzsprung-Russell diagram (H-R diagram). **A Hertzsprung-Russell diagram shows the relationship between the absolute magnitude and temperature of stars.** By studying H-R diagrams, we learn a great deal about the sizes, colors, and temperatures of stars.

In the H-R diagram shown in Figure 5, notice that the stars are not uniformly distributed. About 90 percent are **main-sequence stars** that fall along a band that runs from the upper-left corner to the lower-right corner of the diagram. As you can see, the hottest main-sequence stars are the brightest, and the coolest main-sequence stars are the dimmest.

The brightness of the main-sequence stars is also related to their mass. The hottest blue stars are about 50 times more massive than the sun, while the coolest red stars are only 1/10 as massive. Therefore, on the H-R diagram, the main-sequence stars appear in decreasing order, from hotter, more massive blue stars to cooler, less massive red stars.

Above and to the right of the main sequence in the H-R diagram lies a group of very bright stars called **red giants.** The size of these giants can be estimated by comparing them with stars of known size that have the same surface temperature. Objects with equal surface temperatures radiate the same amount of energy per unit area. Therefore, any difference in the brightness of two stars having the same surface temperature is due to their relative sizes. Some stars are so large that they are called **supergiants.** Betelgeuse, a bright red supergiant in the constellation Orion, has a radius about 800 times that of the sun.

Stars in the lower-central part of the H-R diagram are much fainter than main-sequence stars of the same temperature. Some probably are no bigger than Earth. This group is called white dwarfs, although not all are white.

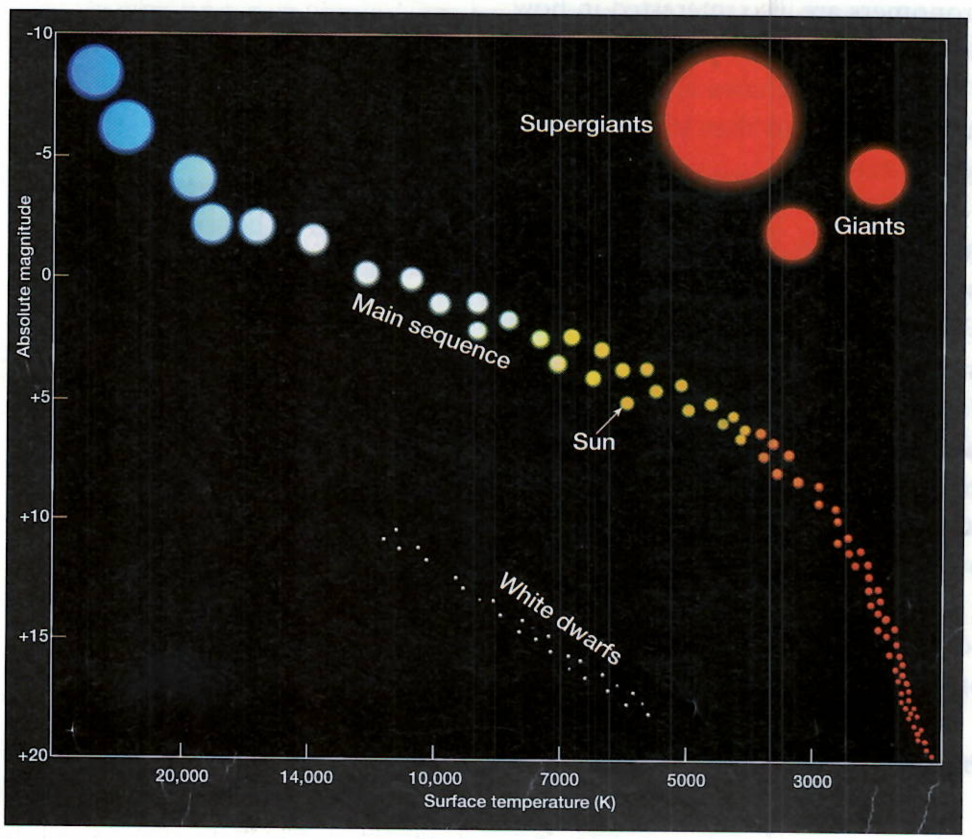


Figure 5 Hertzsprung-Russell Diagram In this idealized chart, stars are plotted according to temperature and absolute magnitude.

Soon after the first H-R diagrams were developed, astronomers realized their importance in interpreting stellar evolution. Just as with living things, a star is born, ages, and dies. After considering some variable stars and the nature of interstellar matter, we'll return to the topic of stellar evolution.

Variable Stars Stars may fluctuate in brightness. Some stars, called **Cepheid variables,** get brighter and fainter in a regular pattern. The interval between two successive occurrences of maximum brightness is called a light period. In general, the longer the light period of a Cepheid, the greater its absolute magnitude is. Once the absolute magnitude is known, it can be compared to the apparent magnitude of the Cepheid. Measuring Cepheid variable periods is an important means of determining distances within our universe.

A different type of variable is associated with a **nova,** or sudden brightening of a star. During a nova eruption, the outer layer of the star is ejected at high speed. A nova, shown in Figure 6, generally reaches maximum brightness in a few days, remains bright for only a few weeks, then slowly returns in a year or so to its original brightness. Only a small amount of its mass is lost during the flare-up. Some stars have experienced more than one such event. In fact, the process probably occurs repeatedly.

Scientists think that novas occur in binary systems consisting of an expanding red giant and a nearby hot white dwarf. Hydrogen-rich gas from the oversized giant is transferred by gravity to the white dwarf. Eventually, the added gas causes the dwarf to ignite explosively. Such a reaction rapidly heats and expands the outer layer of the hot dwarf to produce a nova. In a relatively short time, the white dwarf returns to its prenova state, where it remains inactive until the next buildup occurs.

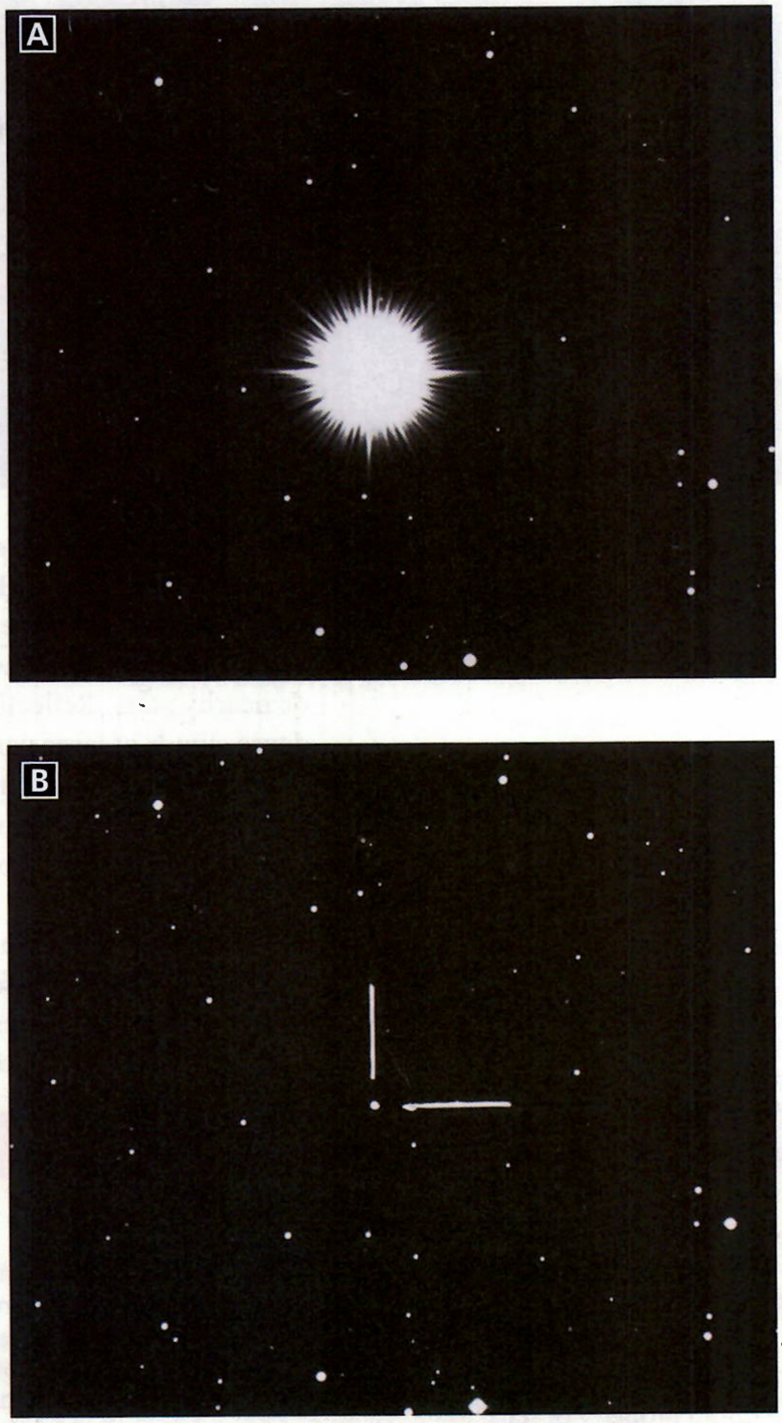


Figure 6 Nova These photographs, taken two months apart, show the decrease in brightness that follows a nova flare-up.

Figure 7 Dark Nebula The Horsehead Nebula is found in the constellation Orion.

Interstellar Matter Between existing stars is "the vacuum of space." However, it is not a pure vacuum, for there are clouds of dust and gases known as **nebulae.** If this interstellar matter is close to a very hot star, it will glow and is called a bright nebula. The two main types of bright nebulae are emission nebulae and reflection nebulae.

Emission nebulae consist largely of hydrogen. They absorb ultraviolet radiation emitted by a nearby hot star. Because these gases are under very low pressure, they emit this energy as visible light. This conversion of ultraviolet light to visible light is known as fluorescence. You can see this effect in fluorescent lights. Reflection nebulae, as the name implies, merely reflect the light of nearby stars. Reflection nebulae are thought to be composed of dense clouds of large particles called interstellar dust.

Some nebulae are not close enough to a bright star to be lit up. They are called dark nebulae. Dark nebulae, such as the one shown in Figure 7, can easily be seen as starless regions when viewing the Milky Way.

Although nebulae appear very dense, they actually consist of thinly scattered matter. Because of their enormous size, however, their total mass may be many times that of the sun. Astronomers study nebulae because stars and planets form from this interstellar matter.

Section 25.1 Assessment

Reviewing Concepts

1. What can astronomers learn by studying a star's color?
2. Binary stars can be used to establish what property of stars?
3. How does distance affect parallax?
4. What factors determine a star's apparent magnitude?
5. The H-R diagram shows the relationship between what two factors?

Critical Thinking

6. **Problem Solving** How many times brighter is a star with a magnitude of 7 than a star with a magnitude of 12?
7. **Inferring** Scientists think that only a small amount of a star's mass is lost during a nova. Based on what you have learned about novas, infer what evidence scientists use to support this theory.

Writing in Science

Web Site Make an educational Web site about the H-R diagram for younger students. Use Figure 5 as a guide. Include a color key and other elements to help clarify concepts such as star temperature, the Kelvin scale, and absolute magnitude.

25.2 Stellar Evolution

Reading Focus

Key Concepts

- What stage marks the birth of a star?
- Why do all stars eventually die?
- What stages make up the sun's life cycle?

Vocabulary

- protostar
- supernova
- white dwarf
- neutron star
- pulsar
- black hole

Reading Strategy

Sequencing Copy the flowchart below. As you read, complete it to show how the sun evolves. Expand the chart to show the evolution of low-mass and high-mass stars.

Evolution of Sun → a. ? → b. ?

Determining how stars are born, age, and then die was difficult because the life of a star can span billions of years. However, by studying stars of different ages, astronomers have been able to piece together the evolution of a star. Imagine that an alien from outer space lands on Earth. This alien wants to study the stages of human life. By examining a large number of humans, the alien observes the birth of babies, the activities of children and adults, and the death of elderly people. From this information, the alien then attempts to put the stages of human development into proper sequence. Based on the number of humans in each stage of development, the alien would conclude that humans spend more of their lives as adults than as children. In a similar way, astronomers have pieced together the story of stars.

Star Birth

The birthplaces of stars are dark, cool interstellar clouds, such as the one in Figure 8. These nebulae are made up of dust and gases. In the Milky Way, nebulae consist of 92 percent hydrogen, 7 percent helium, and less than 1 percent of the remaining heavier elements. For some reason not yet fully understood, some nebulae become dense enough to begin to contract. A shock wave from an explosion of a nearby star may trigger the contraction. Once the process begins, gravity squeezes particles in the nebula, pulling every particle toward the center. As the nebula shrinks, gravitational energy is converted into heat energy.

Figure 8 Nebula Dark, cool clouds full of interstellar matter are the birthplace of stars.

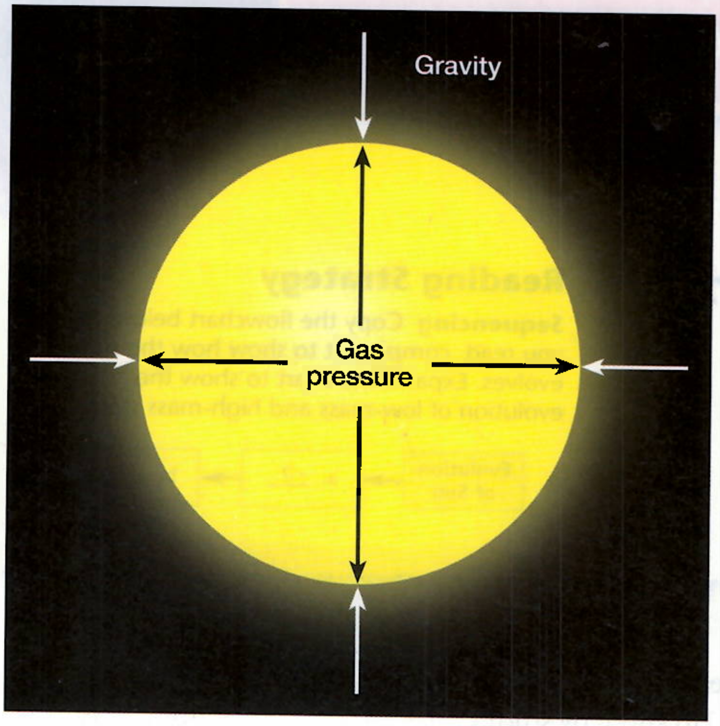


Figure 9 Balanced Forces A main-sequence star is balanced between gravity, which is trying to squeeze it, and gas pressure, which is trying to expand it.

Protostar Stage The initial contraction spans a million years or so. As time passes, the temperature of this gaseous body slowly rises until it is hot enough to radiate energy from its surface in the form of long-wavelength red light. This large red object is called a protostar. A **protostar** is a developing star not yet hot enough to engage in nuclear fusion.

During the protostar stage, gravitational contraction continues—slowly at first, then much more rapidly. This collapse causes the core of the protostar to heat much more intensely than the outer layer. **When the core of a protostar has reached about 10 million K, pressure within is so great that nuclear fusion of hydrogen begins, and a star is born.**

Heat from hydrogen fusion causes the gases to increase their motion. This in turn causes an increase in the outward gas pressure. At some point, this outward pressure exactly balances the inward force of gravity, as shown in Figure 9. When this balance is reached, the star becomes a stable main-sequence star. Stated another way, a stable main-sequence star is balanced between two forces: gravity, which is trying to squeeze it into a smaller sphere, and gas pressure, which is trying to expand it.

Main-Sequence Stage From this point in the evolution of a main-sequence star until its death, the internal gas pressure struggles to offset the unyielding force of gravity. Typically, hydrogen fusion continues for a few billion years and provides the outward pressure required to support the star from gravitational collapse.

Different stars age at different rates. Hot, massive blue stars radiate energy at such an enormous rate that they deplete their hydrogen fuel in only a few million years. By contrast, the least massive main-sequence stars may remain stable for hundreds of billions of years. A yellow star, such as the sun, remains a main-sequence star for about 10 billion years.

An average star spends 90 percent of its life as a hydrogen-burning, main-sequence star. Once the hydrogen fuel in the star's core is depleted, it evolves rapidly and dies. However, with the exception of the least-massive red stars, a star can delay its death by fusing heavier elements and becoming a giant.

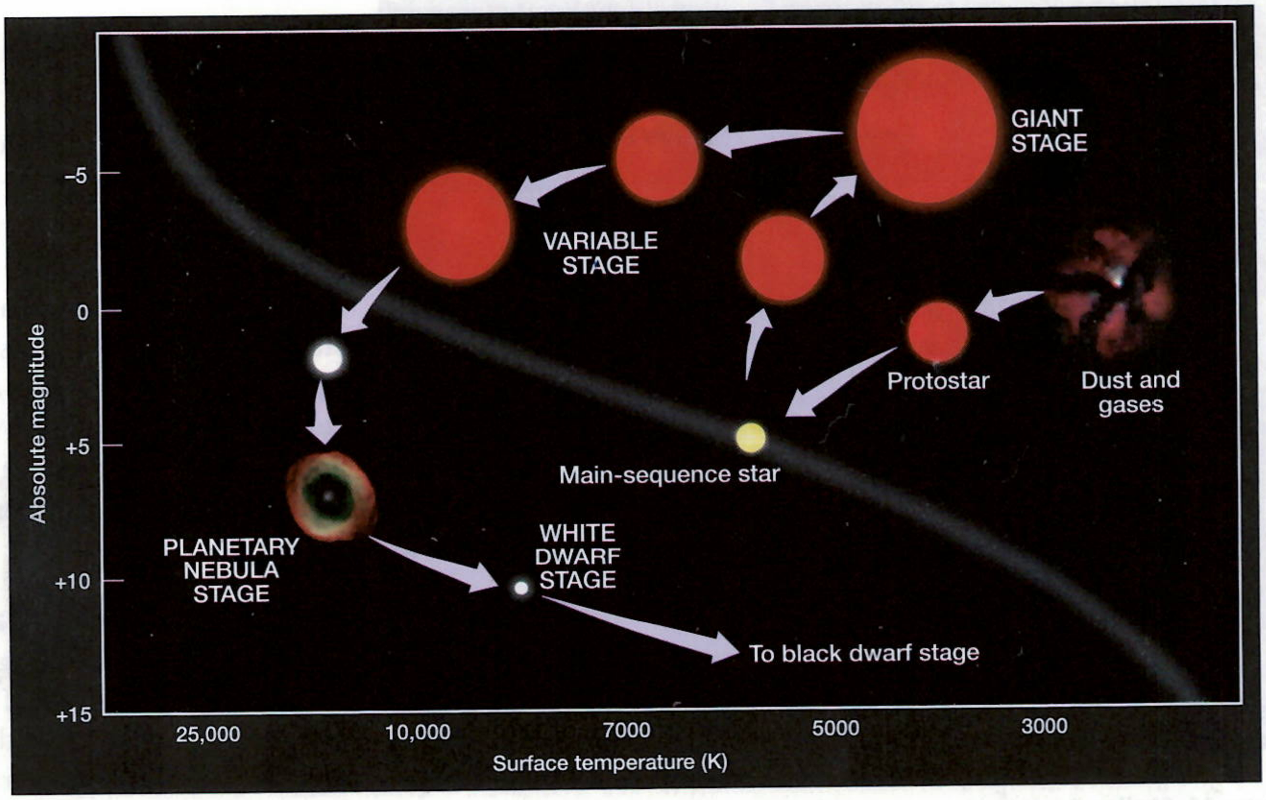


Figure 10 Life Cycle of a Sunlike Star A medium-mass star, similar to the sun, will evolve along the path shown here. **Interpreting Diagrams** ***What is the first stage in the formation of the star? What is the last stage?***

Red-Giant Stage The red-giant stage occurs because the zone of hydrogen fusion continually moves outward, leaving behind a helium core. Eventually, all the hydrogen in the star's core is consumed. While hydrogen fusion is still progressing in the star's outer shell, no fusion is taking place in the core. Without a source of energy, the core no longer has enough pressure to support itself against the inward force of gravity. As a result, the core begins to contract.

As the core contracts, it grows hotter by converting gravitational energy into heat energy. Some of this energy is radiated outward, increasing hydrogen fusion in the star's outer shell. This energy in turn heats and expands the star's outer layer. The result is a giant body hundreds to thousands of times its main-sequence size, as shown in Figure 10.

As the star expands, its surface cools, which explains the star's reddish appearance. During expansion, the core continues to collapse and heat until it reaches 100 million K. At this temperature, it is hot enough to convert helium to carbon. So, a red giant consumes both hydrogen and helium to produce energy.

Eventually, all the usable nuclear fuel in these giants will be consumed. The sun, for example, will spend less than a billion years as a giant. More massive stars will pass through this stage even more rapidly. The force of gravity will again control the star's destiny as it squeezes the star into the smallest, most dense piece of matter possible.

Reading Checkpoint ***Why do red giants have a reddish appearance?***

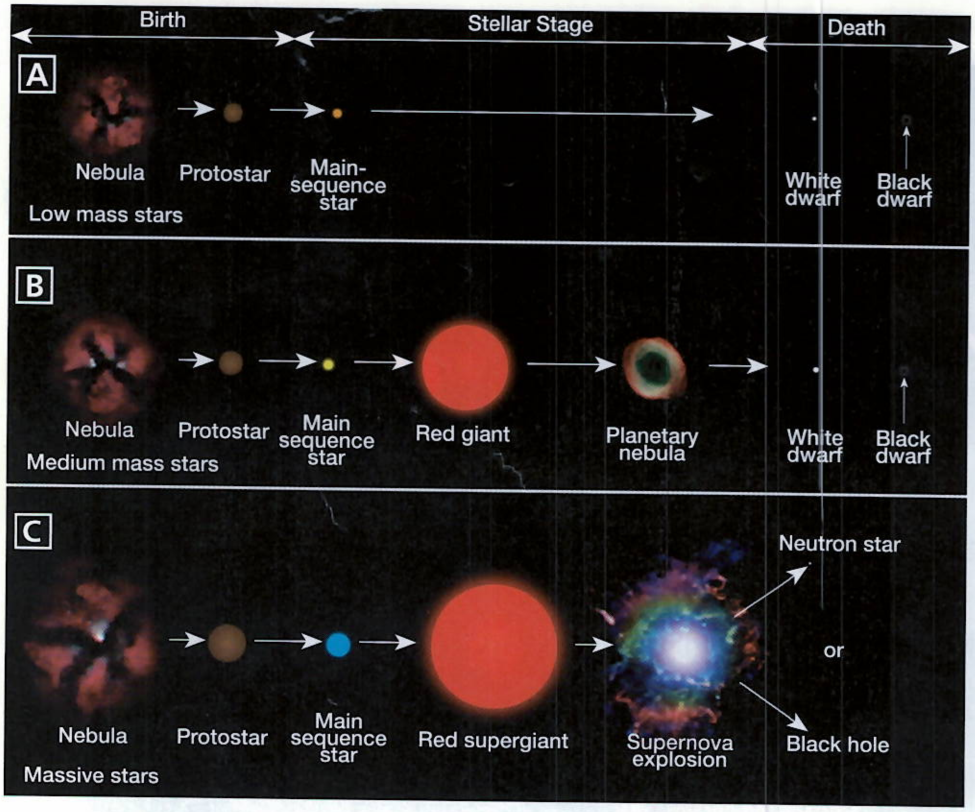


Figure 11 Stellar Evolution
A A low-mass star uses fuel at a low rate and has a long life span. **B** Like a low-mass star, a medium-mass star ends as a black dwarf. **C** Massive stars end in huge explosions, then become either neutron stars or black holes.

Burnout and Death

Most of the events of stellar evolution discussed so far are well documented. What happens next is based more on theory. **We do know that all stars, regardless of their size, eventually run out of fuel and collapse due to gravity.** With this in mind, let's consider the final stages of stars of different masses.

Death of Low-Mass Stars As shown in Figure 11A, stars less than one half the mass of the sun consume their fuel at a fairly slow rate. Consequently, these small, cool red stars may remain on the main sequence for up to 100 billion years. Because the interior of a low-mass star never reaches high enough temperatures and pressures to fuse helium, its only energy source is hydrogen. So, low-mass stars never evolve into red giants. Instead, they remain as stable main-sequence stars until they consume their hydrogen fuel and collapse into a white dwarf, which you will learn more about later.

Figure 12 Planetary Nebula
During its collapse from a red giant to a white dwarf, a medium-mass star ejects its outer layer, forming a round cloud of gas.

Death of Medium-Mass Stars As shown in Figure 11B, stars with masses similar to the sun evolve in essentially the same way. During their giant phase, sunlike stars fuse hydrogen and helium fuel at a fast rate. Once this fuel is exhausted, these stars also collapse into white dwarfs.

During their collapse from red giants to white dwarfs, medium-mass stars are thought to cast off their bloated outer layer, creating an expanding round cloud of gas. The remaining hot, central white dwarf heats the gas cloud, causing it to glow. These often beautiful, gleaming spherical clouds are called planetary nebulae. An example of a planetary nebula is shown in Figure 12.

Death of Massive Stars

In contrast to sunlike stars, which die gracefully, stars with masses three times that of the sun have relatively short life spans, as shown in Figure 11C. These stars end their lives in a brilliant explosion called a **supernova.** During a supernova, a star becomes millions of times brighter than its prenova stage. If one of the nearest stars to Earth produced such an outburst, it would be brighter than the sun. Supernovae are rare. None have been observed in our galaxy since the invention of the telescope, although Tycho Brahe and Galileo each recorded one about 30 years apart. An even larger supernova was recorded in 1054 by the Chinese. Today, the remnant of this great outburst is the Crab Nebula, shown in Figure 13.

A supernova event is thought to be triggered when a massive star consumes most of its nuclear fuel. Without a heat engine to generate the gas pressure required to balance its immense gravitational field, the star collapses. This implosion, or bursting inward, is huge, resulting in a shock wave that moves out from the star's interior. This energetic shock wave destroys the star and blasts the outer shell into space, generating the supernova event.

Figure 13 Crab Nebula This nebula, found in the constellation Taurus, is the remains of a supernova that took place in 1054.

H-R Diagrams and Stellar Evolution Hertzsprung-Russell diagrams have been helpful in formulating and testing models of stellar evolution. They are also useful for illustrating the changes that take place in an individual star during its life span. Refer back to Figure 10, which shows the evolution of a star about the size of the sun. Keep in mind that the star does not physically move along this path. Its position on the H-R diagram represents the color and absolute magnitude of the star at various stages in its evolution.

Reading Checkpoint *What is a supernova?*

Stellar Remnants

Eventually, all stars consume their nuclear fuel and collapse into one of three documented states—white dwarf, neutron star, or black hole. Although different in some ways, these small, compact objects are all composed of incomprehensibly dense material and all have extreme surface gravity.

White Dwarfs **White dwarfs** are the remains of low-mass and medium-mass stars. They are extremely small stars with densities greater than any known material on Earth. Although some white dwarfs are no larger than Earth, the mass of such a dwarf can equal 1.4 times that of the sun. So, their densities may be a million times greater than water. A spoonful of such matter would weigh several tons. Densities this great are possible only when electrons are displaced inward from their regular orbits, around an atom's nucleus, allowing the atoms to take up less than the "normal" amount of space. Material in this state is called degenerate matter.

In degenerate matter, the atoms have been squeezed together so tightly that the electrons are displaced much nearer to the nucleus. Degenerate matter uses electrical repulsion instead of molecular motion to support itself from total collapse. Although atomic particles in degenerate matter are much closer together than in normal Earth matter, they still are not packed as tightly as possible. Stars made of matter that has an even greater density are thought to exist.

As a star contracts into a white dwarf, its surface becomes very hot, sometimes exceeding 25,000 K. Even so, without a source of energy, it can only become cooler and dimmer. Although none have been observed, the last stage of a white dwarf must be a small, cold body called a black dwarf. Table 2 summarizes the evolution of stars of various masses. **As you can see, the sun begins as a nebula, spends much of its life as a main-sequence star, becomes a red giant, planetary nebula, white dwarf, and finally, black dwarf.**

Table 2 Summary of Evolution for Stars of Various Masses

Initial Mass of Interstellar Cloud (Sun = 1)	Main-Sequence Stage	Giant Phase	Evolution After Giant Phase	Final Stage
1–3	Yellow	Yes	Planetary nebula	White dwarf
6	White	Yes	Supernova	Neutron star
20	Blue	Yes (Supergiant)	Supernova	Black hole

Neutron Stars After studying white dwarfs, scientists made what might at first appear to be a surprising conclusion. The smallest white dwarfs are the most massive, and the largest are the least massive. The explanation for this is that a more massive star, because of its greater gravitational force, is able to squeeze itself into a smaller, more densely packed object than can a less massive star. So, the smaller white dwarfs were produced from the collapse of larger, more massive stars than were the larger white dwarfs.

This conclusion led to the prediction that stars smaller and more massive than white dwarfs must exist. These objects, called **neutron stars,** are thought to be the remnants of supernova events. In a white dwarf, the electrons are pushed close to the nucleus, while in a neutron star, the electrons are forced to combine with protons to produce neutrons. If Earth were to collapse to the density of a neutron star, it would have a diameter equal to the length of a football field. A pea-size sample of this matter would weigh 100 million tons. This is approximately the density of an atomic nucleus. Neutron stars can be thought of as large atomic nuclei.

Figure 14 Veil Nebula Located in the constellation Cygnus, this nebula is the remnant of an ancient supernova.

Supernovae During a supernova, the outer layer of the star is ejected, while the core collapses into a very hot neutron star about 20 kilometers in diameter. Although neutron stars have high surface temperatures, their small size would greatly limit their brightness. Finding one with a telescope would be extremely difficult.

However, astronomers think that a neutron star would have a very strong magnetic field. Further, as a star collapses, it will rotate faster, for the same reason ice skaters rotate faster as they pull in their arms. Radio waves generated by these rotating stars would be concentrated into two narrow zones that would align with the star's magnetic poles. Consequently, these stars would resemble a rapidly rotating beacon emitting strong radio waves. If Earth happened to be in the path of these beacons, the star would appear to blink on and off, or pulsate, as the waves swept past.

In the early 1970s, a source that radiates short bursts or pulses of radio energy, called a **pulsar**, was discovered in the Crab Nebula. Studies of this radio source revealed it to be a small spinning star centered in the nebula. The pulsar found in the Crab Nebula is undoubtedly the remains of the supernova of 1054.

Black Holes Are neutron stars made of the most dense materials possible? No. During a supernova event, remnants of stars three times more massive than the sun apparently collapse into objects even smaller and denser than neutron stars. Even though these objects, called **black holes,** are very hot, their gravity is so strong that not even light can escape their surface. So they disappear from sight. Anything that moves too near a black hole would be swept in by its gravity and lost forever.

How can astronomers find an object whose gravitational field prevents the escape of all matter and energy? One strategy is to find evidence of matter being rapidly swept into a region of apparent nothingness. Scientists think that as matter is pulled into a black hole, it should become very hot and emit a flood of X-rays before being pulled in. Because isolated black holes would not have a source of matter to swallow up, astronomers first looked at binary-star systems.

A likely candidate for a black hole is Cygnus X-1, a strong X-ray source in the constellation Cygnus. In this case, the X-ray source can be observed orbiting a supergiant companion with a period of 5.6 days. It appears that gases are pulled from this companion and spiral into the disk-shaped structure around the black hole, as shown in Figure 15.

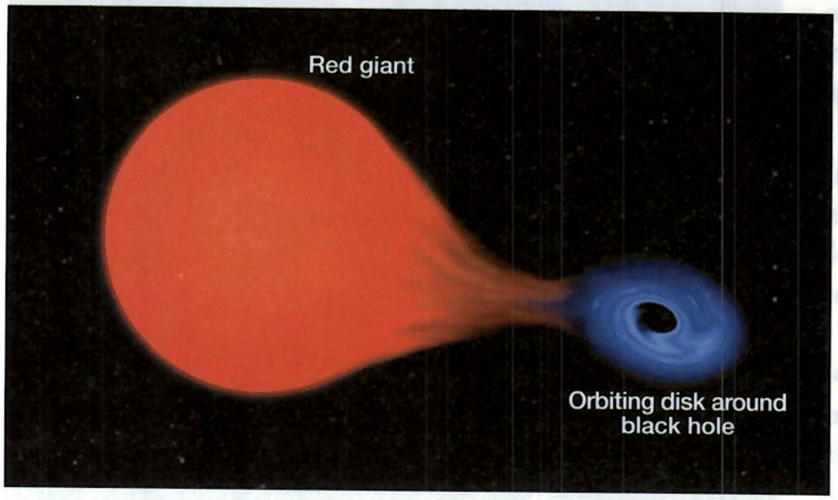


Figure 15 Black Hole Gases from the red giant spiral into the black hole.

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For: Links on black holes
Visit: www.SciLinks.org
Web Code: cjn-7252

Section 25.2 Assessment

Reviewing Concepts

1. What is a protostar?
2. At what point is a star born?
3. What causes a star to die?
4. Describe the life cycle of the sun.

Critical Thinking

5. **Inferring** Why are less massive stars thought to age more slowly than more massive stars, even though less massive stars have much less "fuel"?
6. **Relating Cause and Effect** Why is interstellar matter important to stellar evolution?

Connecting Concepts

Supernova If a supernova explosion were to occur near our solar system, what might be some possible consequences of the intense X-ray radiation that would reach Earth?

25.3 The Universe

Reading Focus

Key Concepts

- What is the size and structure of the Milky Way Galaxy?
- In what ways do galaxies differ from one another?
- What evidence indicates that the universe is expanding?
- According to the big bang theory, how did the universe begin?

Vocabulary

- galaxy
- galaxy cluster
- Hubble's law
- big bang theory

Reading Strategy

Outlining As you read, make an outline of the most important ideas in this section.

I. The Universe
  A. Milky Way Galaxy
    1. ______ ? ______
    2. ______ ? ______
  B. ______ ? ______
    1. Spiral Galaxy
    2. Elliptical Galaxy
    3. ______ ? ______

On a clear and moonless night away from city lights, you can see a truly marvelous sight—our own Milky Way Galaxy, as shown in Figure 16. **Galaxies** are groups of stars, dust, and gases held together by gravity. There may be more than 100 billion stars in the Milky Way Galaxy alone. Our galaxy looks milky because the solar system is located within a flat disk—the galactic disk. We view it from the inside and see stars in every direction.

The Milky Way Galaxy

When astronomers began to survey the stars located along the plane of the Milky Way, it appeared that equal numbers lay in every direction. Could Earth actually be at the center of the galaxy? Scientists came up with a better explanation. Imagine that the trees in an enormous forest represent the stars in the galaxy. After hiking into this forest, you look around. You see an equal number of trees in every direction. Are you in the center of the forest? Not necessarily. Anywhere in the forest will seem to be the center, except at the very edge.

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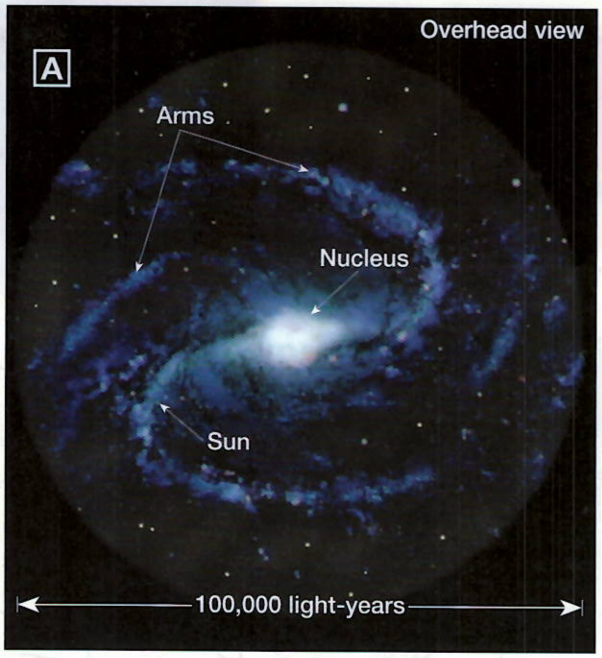
Figure 16 Milky Way Galaxy Notice the dark band caused by interstellar dark nebulae.



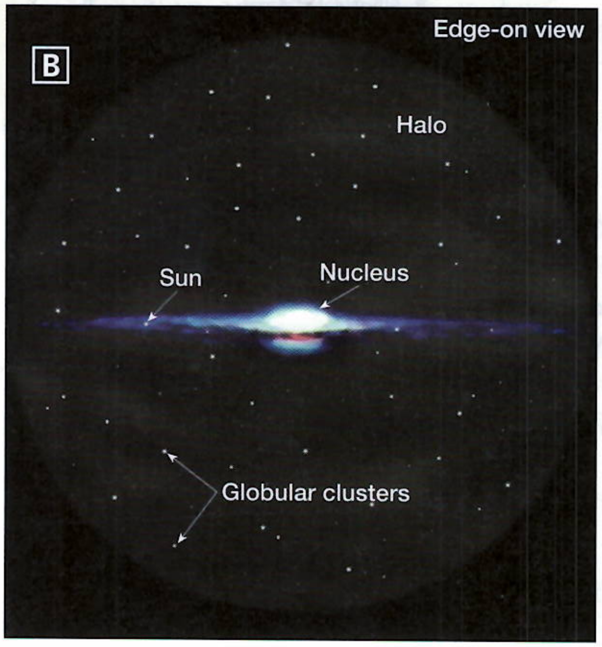


Figure 17 Structure of the Milky Way A The spiral arms are clearly visible in the overhead view of our galaxy. **B** Our solar system is located about 30,000 light-years from the galactic nucleus.

Size of the Milky Way It's hard to study the Milky Way Galaxy with optical telescopes because large quantities of interstellar matter block our vision. With the aid of radio telescopes, scientists have determined the structure of our galaxy. **The Milky Way is a large spiral galaxy whose disk is about 100,000 light-years wide and about 10,000 light-years thick at the nucleus, as shown in Figure 17A.** As viewed from Earth, the center of the galaxy lies beyond the constellation Sagittarius. Figure 17B shows an edge-on view of the Milky Way.

Reading Checkpoint *How big is the Milky Way Galaxy?*

Structure of the Milky Way Radio telescopes reveal that the Milky Way has at least three distinct spiral arms, with some signs of splintering. The sun is positioned in one of these arms about two thirds of the way from the center, or galactic nucleus, at a distance of about 30,000 light-years. The stars in the arms of the Milky Way rotate around the galactic nucleus. The most outward arms move the slowest, and the ends of the arms appear to trail. Our solar system orbits the galactic nucleus about every 200 million years.

Surrounding the galactic disk is a nearly round halo made of thin gas and numerous clusters of stars. These star clusters do not participate in the rotating motion of the arms but have their own orbits that carry them through the disk. Although some clusters are very dense, they pass among the stars of the arms with plenty of room to spare.

Reading Checkpoint *Where is our solar system located within the Milky Way Galaxy?*

Types of Galaxies

In the mid-1700s, German philosopher Immanuel Kant proposed that the fuzzy patches of light scattered among the stars were actually distant galaxies like the Milky Way. Today we know that the universe includes hundreds of billions of galaxies, each containing hundreds of billions of stars. From these hundreds of billions of galaxies, scientists have identified several basic types.

Spiral Galaxies As shown in Figure 18A, spiral galaxies are usually disk-shaped, with a somewhat greater concentration of stars near their centers. There are numerous variations, though. Viewed broadside, the arms are often seen extending from the central nucleus and sweeping gracefully away. The outermost stars of these arms rotate most slowly, giving the galaxy the appearance of a pinwheel.

One type of spiral galaxy, however, has its stars arranged in the shape of a bar, which rotates as a rigid system. Attached to each end of these bars are curved spiral arms. These have become known as barred spiral galaxies, as shown in Figure 18B. Recent evidence indicates that the Milky Way may be a barred spiral galaxy. Spiral galaxies are generally quite large. About 10 percent of all galaxies are thought to be barred spirals, and another 20 percent are regular spiral galaxies.

Figure 18 Spiral Galaxies
A A spiral galaxy looks somewhat like a pinwheel. **B** A barred spiral galaxy has a bar through its center, with arms extending outward from the bar.

Elliptical Galaxies About 60 percent of galaxies are classified as elliptical galaxies. Elliptical galaxies range in shape from round to oval. Although most are small, the very largest known galaxies—200,000 light-years in diameter—are elliptical. This type of galaxy, shown in Figure 19, does not have spiral arms.

Irregular Galaxies Only 10 percent of the known galaxies have irregular shapes and are classified as irregular galaxies. The best-known irregular galaxies, the Large and Small Magellanic Clouds, are easily visible with the unaided eye. These galaxies were named after the explorer Ferdinand Magellan, who observed them when he sailed around Earth in 1520. They are our nearest galactic neighbors—only 150,000 light-years away. An irregular galaxy is shown in Figure 20.

In addition to shape and size, one of the major differences among different types of galaxies is the age of their stars. Irregular galaxies are composed mostly of young stars, while elliptical galaxies contain old stars. The Milky Way and other spiral galaxies have both young and old stars, with the youngest located in the arms.

Figure 19 Elliptical Galaxy Most galaxies are classified as elliptical with shapes ranging from round to oval.

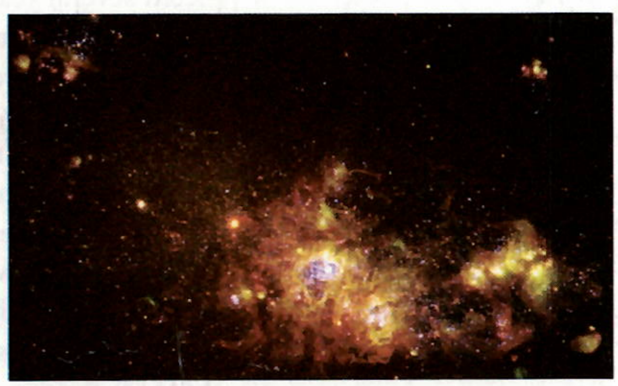


Figure 20 Irregular Galaxy Irregular galaxies have irregular shapes.
Describing ***What type of stars would you find in an irregular galaxy?***

Figure 21 Galaxy Cluster This cluster of galaxies is located about 1 million light-years from Earth.

Galaxy Clusters Once astronomers discovered that stars were found in groups, they wondered whether galaxies also were grouped or just randomly distributed throughout the universe. They found that, like stars, galaxies are grouped in **clusters.** One such cluster is shown in Figure 21. Some clusters may contain thousands of galaxies. Our own cluster, called the Local Group, contains at least 28 galaxies. Of these, three are spirals, 11 are irregulars, and 14 are ellipticals. Galaxy clusters also make up huge groups called superclusters. Studies indicate that superclusters may be the largest entities in the universe.

Reading Checkpoint *Describe the shape of elliptical galaxies.*

The Expanding Universe

Recall the Doppler effect that you read about in Chapter 24. Remember that when a source is moving away, its light appears redder than it actually is, because its waves appear lengthened. Objects approaching have their light waves shifted toward the blue or shorter wavelengths. Therefore, the Doppler effect reveals whether a star or other body in space is moving away from Earth or toward Earth. The amount of shift allows us to calculate the rate at which the relative movement is occurring. Large Doppler shifts indicate higher speeds; smaller Doppler shifts indicate lower speeds.

Red Shifts One of the most important discoveries of modern astronomy was made in 1929 by Edwin Hubble. Observations completed several years earlier revealed that most galaxies have Doppler shifts toward the red end of the spectrum. The red shift occurs because the light waves are "stretched," which shows that Earth and the source are moving away from each other. Hubble set out to explain this red shift phenomenon.

Hubble realized that dimmer galaxies were probably farther away than were brighter galaxies. He tried to determine whether a relationship existed between the distances to galaxies and their red shifts. Hubble used estimated distances based on relative brightness and Doppler red shifts to discover that galaxies that exhibit the greatest red shifts are the most distant.

Reading Checkpoint *What relationship did Hubble discover between red shifts and the distances of galaxies from Earth?*

Hubble's Law A consequence of the universal red shift is that it predicts that most galaxies—except for a few nearby—are moving away from us. Recall that the amount of Doppler red shift depends on the speed at which the object is moving away. Greater red shifts indicate faster speeds. Because more distant galaxies have greater red shifts, Hubble concluded that they must be retreating from us at greater speeds. This idea is currently termed **Hubble's law.** It states that galaxies are retreating from us at a speed that is proportional to their distance.

Hubble was surprised at this discovery because it implied that the most distant galaxies are moving away from us many times faster than those nearby. What does this mean? **The red shifts of distant galaxies indicate that the universe is expanding.**

To help visualize the nature of this expanding universe, imagine a loaf of raisin bread dough that has been set out to rise for a few hours. As shown in Figure 22 , as the dough doubles in size, so does the distance between all of the raisins. However, the raisins that were originally farther apart traveled a greater distance in the same time span than those located closer together. We therefore conclude that in an expanding universe, as in the raisin bread dough analogy, those objects located farther apart move away from each other more rapidly.

Another feature of the expanding universe can be demonstrated. No matter which raisin you select, it will move away from all the other raisins. Likewise, no matter where one is located in the universe, every other galaxy—again, except those in the same cluster—will be moving away. Hubble had indeed advanced our understanding of the universe. The Hubble Space Telescope is named in his honor.

Reading Checkpoint ***What is Hubble's law?***

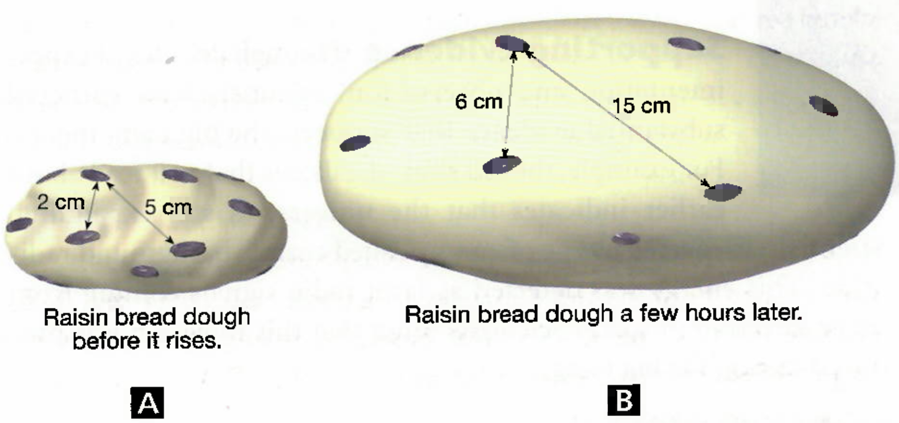


Figure 22 Raisin Dough Analogy As the dough rises, raisins that were farther apart travel a greater distance in the same time as those that were closer together. Like galaxies in an expanding universe, the distant raisins move away from one another more rapidly than those that are near one another.

The Big Bang

Did the universe have a beginning? Will it have an end? Scientists are trying to answer these questions.

Any theory about the origin of the universe must account for the fact that all distant galaxies are moving away from us. Because all galaxies appear to be moving away from Earth, is our planet in the center of the universe? Probably not, because if we are not even in the center of our own solar system, and our solar system is not even in the center of the galaxy, it seems unlikely that we could be in the center of the universe.

A more probable explanation exists. Imagine a balloon with paper-punch dots glued to its surface. When the balloon is inflated, each dot spreads apart from every other dot. Similarly, if the universe is expanding, every galaxy would be moving away from every other galaxy.

This concept of an expanding universe led to the widely accepted big bang theory. According to the **big bang theory,** the universe began as a violent explosion from which the universe continues to expand, evolve, and cool. **The big bang theory states that at one time, the entire universe was confined to a dense, hot, supermassive ball. Then, about 13.7 billion years ago, a violent explosion occurred, hurling this material in all directions.** The big bang, as shown in Figure 23, marks the beginning of the universe. All matter and space were created at that instant. After several hundred thousand years, the universe became cool enough for atoms to form. Gases in the universe continued to cool and condense. They eventually formed the stars that make up the galaxies we now observe moving away from us.

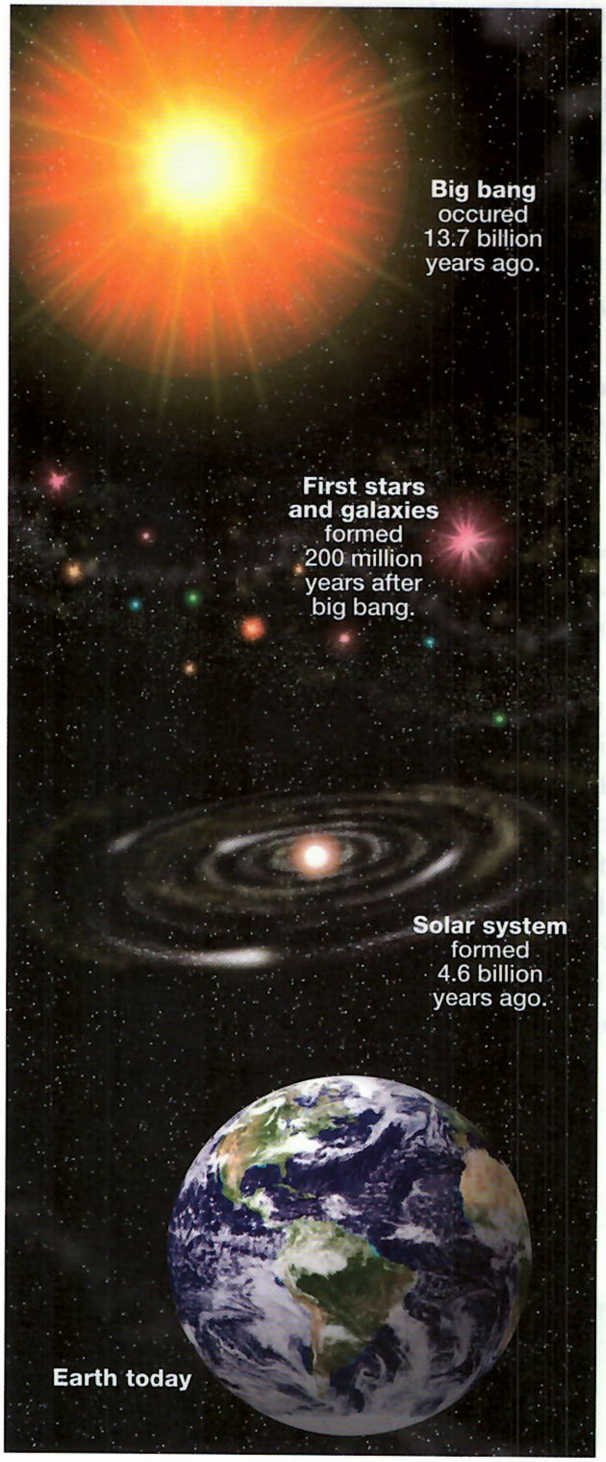


Figure 23 The Big Bang According to the big bang theory, the universe began 13.7 billion years ago. Two hundred million years later, the first stars and galaxies began to form.

Supporting Evidence Through decades of experimentation and observation, scientists have gathered substantial evidence that supports the big bang theory. For example, the red shift of galaxies that you read about earlier indicates that the universe is still expanding. Scientists discovered a type of energy called cosmic background radiation. This energy was detected as faint radio signals coming from every direction in space. Scientists think that this radiation was produced during the big bang.

Reading Checkpoint *What evidence supports the big bang?*

The Big Crunch? If the universe began with a big bang, how will it end? One view is that the universe will last forever. In this scenario, the stars will slowly burn out, being replaced by invisible degenerate matter and black holes that will travel outward through an endless, dark, cold universe. The other possibility is that the outward flight of the galaxies will slow and eventually stop. Gravitational contraction would follow, causing the galaxies to collide and combine into the high-energy, high-density mass from which the universe began. This fiery death of the universe, the big bang operating in reverse, has been called the "big crunch."

Whether or not the universe will expand forever or eventually collapse upon itself depends on its average density. If the average density of the universe is more than its critical density—about one atom for every cubic meter—the gravitational field is enough to stop the outward expansion and cause the universe to contract. On the other hand, if the density of the universe is less than the critical value, it will expand forever. Current estimates of the density of the universe place it below the critical density, which predicts an ever-expanding, or open, universe. Additional support for an open universe comes from studies that indicate the universe is expanding faster now than in the past. The view currently favored by most scientists is an expanding universe with no ending point.

It should be noted, however, that the methods used to determine the ultimate fate of the universe have substantial uncertainties. It is possible that previously undetected matter exists in great quantities in the universe. If this is so, the galaxies could, in fact, collapse in the "big crunch."

Section 25.3 Assessment

Reviewing Concepts

1. What is a galaxy?
2. Describe the size and structure of the Milky Way Galaxy.
3. How do galaxies differ?
4. What evidence indicates that the universe is expanding?
5. What is the big bang theory?

Critical Thinking

6. **Comparing and Contrasting** Compare and contrast the three types of galaxies.
7. **Inferring** If the universe is an open universe, what can you infer about its average density?

Writing in Science

Descriptive Paragraph Scientists are continuously searching the Milky Way Galaxy for other stars that may have planets. What types of stars would most likely have a planet or planets suitable for life as we know it? Write a paragraph describing these stars.

understanding EARTH

Astrology—Forerunner of Astronomy

Many people confuse astrology and astronomy to the point of believing these terms to be synonymous. Nothing can be further from the truth. Astronomy is a scientific investigation of the universe to discover the properties of celestial objects and the laws under which the universe operates. Astrology, on the other hand, is based on ancient superstitions that a person's actions and personality are based on the positions of the planets and stars now, and at the person's birth. Scientists do not accept astrology, regarding it as a pseudoscience ("false science"). Most people who read horoscopes do so only as a pastime and do not let them influence their daily living.

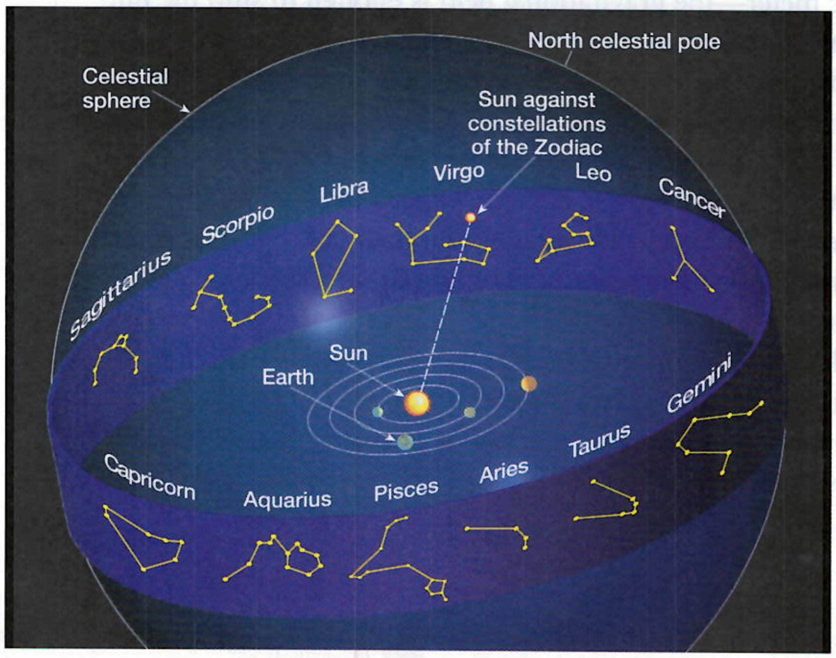


Figure 24 The Constellations of the Zodiac Earth is shown in its autumn (September) position in orbit, from which the sun is seen against the background of the constellation Virgo.

Astrology began more than 3000 years ago when the positions of the planets were plotted as they regularly migrated against the background of the "fixed" stars. Because the solar system is "flat," like a whirling Frisbee, the planets orbit the sun along nearly the same plane. Therefore, the planets, sun, and moon all appear to move along a band around the sky known as the zodiac. Because Earth's moon cycles through its phases about 12 times each year, the Babylonians divided the zodiac into 12 constellations, as shown in Figure 24. Thus, each successive full moon can be seen against the backdrop of the next constellation.

When the zodiac was first established, the vernal equinox (first day of spring) occurred when the sun was viewed against the constellation Aries. However, during each succeeding vernal equinox, the position of the sun shifts very slightly against the background of stars. Now, over 2000 years later, the vernal equinox occurs when the sun is in Pisces. In several years, the vernal equinox will occur when the sun appears against Aquarius.

Although astrology is not a science and has no basis in fact, it did contribute to the science of astronomy. The positions of the moon, sun, and planets at the time of a person's birth (sign of the zodiac) were considered to have great influence on that person's life. Even the great astronomer Kepler was required to make horoscopes part of his duties. To make horoscopes for the future, astrologers tried to predict the future positions of the celestial bodies. Thus, some of the improvements in astronomical instruments were made because of the desire for more accurate predictions of events such as eclipses, which were considered highly significant in a person's life.

Exploration Lab

Observing Stars

Throughout history, people have been recording the nightly movement of stars that results from Earth's rotation, as well as the seasonal changes in the constellations as Earth revolves around the sun. Early astronomers offered many explanations for the changes before the true nature of the motions was understood in the seventeenth century. In this lab, you'll observe and identify stars.

Problem How can you use star charts to identify constellations and track star movements?

Materials

- star charts (in the Appendix)
- penlight
- notebook

Skills Observing, Summarizing, Interpreting Data

Procedure

1. On a clear, moonless night far from street lights, go outside and observe the stars.
2. In a data table like the one below, make a list of the different colors of stars that you see.
3. Select one star that is overhead or nearly so. Observe and record its movement over a period of one hour. Also note the direction of its movement (eastward, westward).
4. Select a star chart suitable for your location and season. Locate several constellations. Sketch and label the constellations in your notebook.
5. Locate the North Star (Polaris) in the night sky. Observe the motion of stars that surround the North Star.
6. Repeat your observations several weeks later at the exact location.

Analyze and Conclude

1. **Observing** How many different colors of stars did you observe? How do these colors relate to star temperature?
2. **Interpreting Data** In which direction did the star that you observed appear to move? How is this movement related to the direction of Earth's rotation?
3. **Summarizing** Write a brief summary of the motion of the stars that surround the North Star. Be sure to include any changes you observed during your second viewing.

Go Further Find the Big Dipper, which is part of the constellation Ursa Minor. A binary star system makes up the stars of the Big Dipper. Locate the star pair and sketch them in their proper location in the Big Dipper.

Data Table

Date	Star Colors	Star Movement	Constellations	Motions of Stars Around North Star

CHAPTER 25

Study Guide

25.1 Properties of Stars

Key Concepts

- Color is a clue to a star's temperature.
- Binary stars can be used to determine stellar mass.
- The nearest stars have the largest parallax angles, while those of distant stars are too small to measure.
- Three factors control the apparent brightness of a star as seen from Earth: how big it is, how hot it is, and how far away it is.
- A Hertzsprung-Russell diagram shows the relationship between the absolute magnitude and temperature of stars.

Vocabulary

constellation, *p. 700;* binary star, *p. 701;* light-year, *p. 702;* apparent magnitude, *p. 703;* absolute magnitude, *p. 703;* main-sequence star, *p. 704;* red giant, *p. 704;* supergiant, *p. 704;* Cepheid variable, *p. 705;* nova, *p. 705;* nebulae, *p. 706*

25.2 Stellar Evolution

Key Concepts

- When the core of a protostar has reached at least 10 million K, pressure within is so great that nuclear fusion of hydrogen begins, and a star is born.
- All stars, regardless of their size, eventually run out of fuel and collapse due to gravity.
- Stars like the sun begin as a nebula, spend much of their lives as main-sequence stars, become red giants, planetary nebulae, white dwarfs, and finally, black dwarfs.

Vocabulary

protostar, *p. 708;* supernova, *p. 711;* white dwarf, *p. 712;* neutron star, *p. 713;* pulsar, *p. 713;* black hole, *p. 714*

25.3 The Universe

Key Concepts

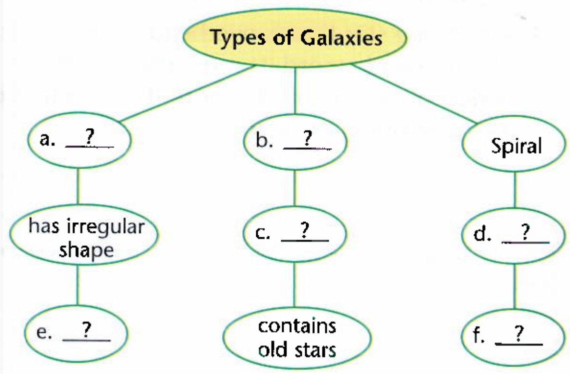
- The Milky Way is a large spiral galaxy whose disk is about 100,000 light-years wide and about 10,000 light-years thick at the nucleus.
- In addition to shape and size, one of the major differences among different types of galaxies is the age of their stars.
- The red shifts of distant galaxies indicate that the universe is expanding.
- The big bang theory states that at one time, the entire universe was confined to a dense, hot, supermassive ball. Then, about 13.7 billion years ago, a violent explosion occurred, hurling this material in all directions.

Vocabulary

galaxy, *p. 715;* galaxy cluster, *p. 718;* Hubble's law, *p. 719;* big bang theory, *p. 720*

Thinking Visually

Concept Map Use information from the chapter to complete the concept map below.



Assessment

Interactive textbook with assessment at PHSchool.com

Reviewing Content

Choose the letter that best answers the question or completes the statement.

1. Distances to stars are usually expressed in units called
   a. miles. b. kilometers.
   c. light-years. d. astronomical units.
2. The measure of a star's brightness is called its
   a. parallax.
   b. color index.
   c. visual binary.
   d. magnitude.
3. Distances to nearby stars can be determined from
   a. fluorescence.
   b. stellar parallax.
   c. stellar mass.
   d. emission nebulae.
4. Which color stars have the highest surface temperature?
   a. red b. orange
   c. yellow d. blue
5. Which type of star is the sun?
   a. black hole
   b. black dwarf
   c. main sequence
   d. red giant
6. What happens to a sun-like star after it has used up all the fuel in its core?
   a. supernova b. neutron star
   c. red giant d. nebula
7. Which object has such a strong surface gravity that light cannot escape it?
   a. black hole
   b. black dwarf
   c. red giant
   d. white dwarf
8. Stars that are composed of matter in which electrons have combined with protons are called
   a. black holes.
   b. neutron stars.
   c. red giants.
   d. white dwarfs.
9. Hubble's law states that galaxies are retreating from Earth at a speed that is proportional to their
   a. distance.
   b. volume.
   c. mass.
   d. temperature.
10. What theory states that the universe began in a violent explosion?
    a. the big crunch
    b. the Doppler effect
    c. Hubble's law
    d. the big bang

Understanding Concepts

11. Which property of a star can be determined by its color?
12. About how many stars are estimated to occur in pairs or multiples?
13. What is parallax?
14. Compare and contrast apparent magnitude and absolute magnitude.
15. What color is the most massive type of main-sequence star? The least massive?
16. At what temperature does nuclear fusion begin?
17. A stable main-sequence star is balanced between which two forces?
18. What element is the main fuel for main-sequence stars? For red giants?
19. What type of stars end their lives as supernovae?
20. What is a pulsar?
21. How long does it take our solar system to orbit the Milky Way Galaxy?
22. More distant galaxies have greater red shifts. What does this indicate about the universe?
23. What is cosmic background radiation?

Assessment *continued*

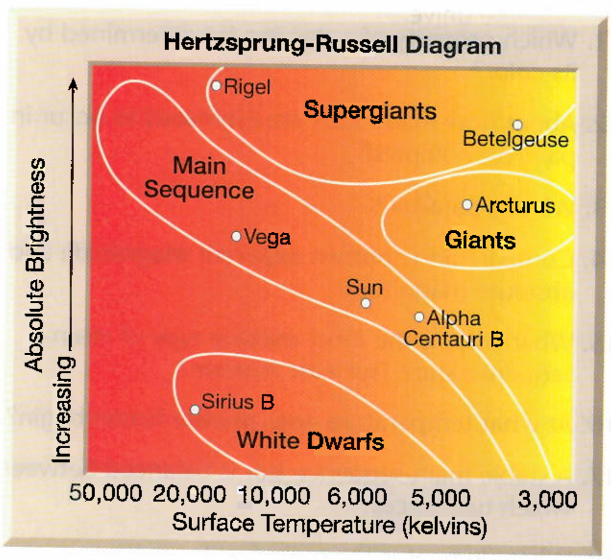
Critical Thinking

24. **Explaining** Why are radio telescopes instead of optical telescopes used to determine the structure of the Milky Way Galaxy?

25. **Drawing Conclusions** Imagine that you are a scientist studying the birth of stars in a spiral galaxy. Which part of the galaxy would you study? Explain your answer.

Analyzing Data

Use the diagram below to answer Questions 28–30.



26. **Interpreting Graphs** What is the brightest star in the diagram? The hottest?

27. **Analyzing Data** How does the absolute brightness of white dwarfs compare with that of supergiants?

28. **Summarizing** What is the relationship between absolute brightness and temperature for a main-sequence star?

Concepts in Action

29. **Explaining** How can a binary star system be used to determine a star's mass?

30. **Inferring** Would you use parallax to determine the distance to a faraway star? Why or why not?

31. **Calculating** The closest star to the sun, Proxima Centauri, is 4.3 light-years away. How many kilometers from the sun is Proxima Centauri?

Performance-Based Assessment

Using Models Use materials provided by your teacher to construct a scale model of the Milky Way Galaxy. Before you begin, be sure to develop a workable scale for your model.

Standardized Test Prep

Test-Taking Tip

Sequencing a Series of Events

When a test question requires you to sequence a series of events, first try to predict the correct sequence before looking at the answer choices. Then compare your sequence to those listed. Be sure to pay attention to qualifiers in the question, such as *first, earliest, increasing,* or *decreasing,* as these may help you eliminate choices.

Which sequence of events describes the big bang theory? Begin with the earliest event.

(A) Explosion; atoms form; stars form; all matter concentrated at a single point.
(B) All matter concentrated at a single point; explosion; atoms form; stars form.
(C) Explosion; stars form; all matter concentrated at a single point; atoms form.
(D) Stars form; atoms form; all matter concentrated at a single point; explosion.

(Answer: B)

Choose the letter that best answers the question or completes the statement.

1. What can you estimate about a Cepheid variable if you know its absolute magnitude and apparent magnitude?
   (A) mass
   (B) distance
   (C) temperature
   (D) volume

2. Based on the red shifts of distant galaxies, astronomers conclude that
   (A) Earth is in the center of the universe.
   (B) the universe is contracting.
   (C) the universe is expanding.
   (D) new galaxies are continually being added to the universe.

Answer the following questions in complete sentences.

3. What types of stars are thought to be the remnants of supernova explosions?

4. How do the lives of the most massive stars end? What are the two possible products of this event?

Use the illustration below to answer Questions 5 and 6.

5. Sequence the steps in the evolution of a medium-mass star, such as the sun.

6. At which stage in its evolution is the star the hottest? The brightest?