Section 26.2

1 FOCUS

Objectives

26.2.1 **Demonstrate** how distance to a star is measured.

26.2.2 **Classify** stars according to chemical and physical properties.

26.2.3 **Interpret** the H-R diagram.

Reading Focus

Build Vocabulary L2

Compare/Contrast Tables Have students make tables comparing and contrasting groups of vocabulary terms for this section. Students should look for relationships among the words before they develop their tables. For example, *main sequence, supergiants, giants,* and *white dwarfs* are all types of stars.

Reading Strategy L2

a. and b. Various properties may be listed, such as color or temperature, absolute brightness, and size.

2 INSTRUCT

Distances to the Stars

Build Science Skills L2

Inferring Tell students that a light-year is more than a unit of distance. It is also a glimpse into the past. For example, it takes light 4.3 years to travel the 4.3 light-years from Proxima Centauri to Earth. When you look at Proxima Centauri in the night sky, you are seeing the star as it was 4.3 years ago. Ask, **If Proxima Centauri no longer generated light, how long would it take before we knew the star had died?** *(4.3 years)* **Verbal, Logical**

Address Misconceptions L2

Given its name, students often think of a light-year as a unit of time, rather than a unit of measure. To help overcome this misconception, have them read the text on p. 834 under the heading The Light-Year. Then, have them confirm that the distance to Proxima Centauri (4.3 light-years) equals 41 trillion km. *([41 trillion km]/[9.5 trillion km/light-year] = 4.3 light-years)* **Logical**

26.2 Stars

Reading Focus

Key Concepts

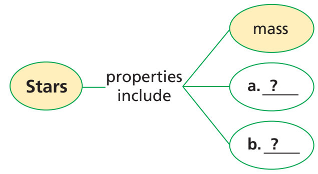
- How can the distance to a star be measured?
- How do astronomers categorize stars?
- What elements are found in stars?
- How do astronomers use H-R diagrams?

Vocabulary

- star
- light-year
- parallax
- apparent brightness
- absolute brightness
- absorption lines
- H-R diagram
- main sequence
- supergiants
- giants
- white dwarf

Reading Strategy

Using Prior Knowledge Copy the concept map below. Add what you already know about stars. After you read, complete your concept map, adding more ovals as needed.



If you look up at the sky at night, you'll see that stars look like points of light. You will probably also notice that some stars are brighter than others. If you look closely, you'll see that some stars have different colors, as shown in Figure 8. However, you can't tell how large or how far away a star is simply by looking at it. You can't poke a star, crawl around inside it, or take its temperature with a thermometer. To explore the stars, modern astronomers use spectrographs and other instruments mounted on telescopes.

A **star** is a large, glowing ball of gas in space, which generates energy through nuclear fusion in its core. The closest star to Earth is the sun, which is considered to be a fairly average star.

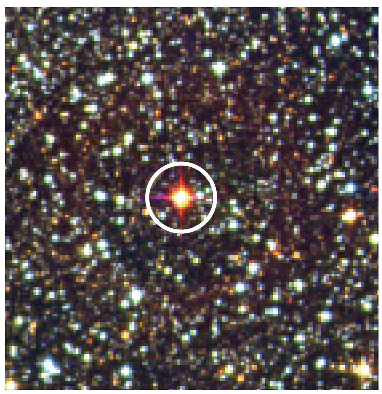


Figure 8 Proxima Centauri, the red star at the center, is the closest star to the sun.

Distances to the Stars

Although the sky seems full of stars, most of the universe is nearly empty space. This seeming contradiction exists because most stars are separated by vast distances.

The Light-Year You wouldn't measure the distance between two distant cities in centimeters. Similarly, because stars are so far apart, it's not practical to measure their distances in units that might be used on Earth, such as kilometers. Instead, astronomers use much larger units, including the light-year. A **light-year** is the distance that light travels in a vacuum in a year, which is about 9.5 trillion kilometers. Proxima Centauri, the closest star to the sun, is about 4.3 light-years away.

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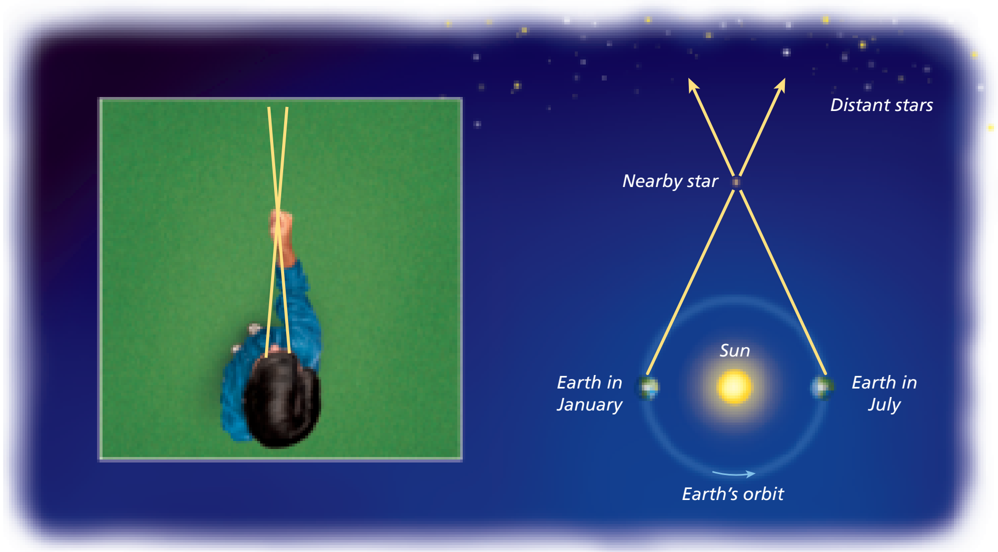
Section Resources

Print
- ***Reading and Study Workbook With Math Support,*** Section 26.2 and **Math Skill:** Calculating Distances to Stars
- ***Transparencies,*** Section 26.2

Technology
- ***Interactive Textbook,*** Section 26.2
- ***Presentation Pro CD-ROM,*** Section 26.2
- ***Go Online,*** *Planet Diary*, Astronomy



Parallax Stars are so far away that astronomers cannot measure their distances directly. Astronomers have developed various methods of determining the distances to stars. Different methods are used for stars at different distances.

To understand how astronomers can measure distances to nearby stars, hold your thumb up at arm's length in front of you, as the student is doing in Figure 9. Close your left eye and look at your thumb with just your right eye open. Then cover your right eye and look with just your left eye open. Even though you didn't move your thumb, it appeared to move relative to the background because you looked at it from slightly different angles. The apparent change in position of an object with respect to a distant background is called **parallax.**

As Earth moves in its orbit, astronomers are able to observe stars from two different positions. Imagine looking at the stars in winter and then six months later in summer. During this time, Earth has moved from one side of its orbit to the other—a distance of about 300 million kilometers. Because people on Earth are looking from a different angle, the nearby star appears to move against the more-distant background stars.

Before the invention of the telescope, astronomers couldn't measure a star's position very accurately. They couldn't detect the apparent movement of even a single nearby star as Earth moved around the sun.

With the invention of the telescope, astronomers could measure the positions of stars with much greater accuracy. **Astronomers measure the parallax of nearby stars to determine their distance from Earth.** The closer a star is to Earth, the greater is its parallax.

Figure 9 You can observe parallax by holding your thumb in front of you. Compare its positions when you look at it first with one eye and then with the other. Astronomers can measure the parallax of nearby stars by measuring their position relative to distant stars as the Earth revolves around the sun. **Observing** ***Is the parallax of your thumb greater when it is closer to your eyes or when it is farther from your eyes?***

Customize for Inclusion Students

Learning Disabled
Inspire confidence in learning-disabled students by beginning each new topic with a question or activity that they can successfully master. For example, you could start this section by asking students to describe the night sky. Or, you could ask them to calculate their age when light from Proxima Centauri left the star. Simply say, **Light left the star more than four years ago. How old were you then?**

Build Math Skills (L1)

Exponents: Multiplication and Division Have students practice working with exponents by comparing the light-year to the AU. Ask them to write 9.46 trillion km (one light-year) in exponential form. *(9.46×10^{12} km)* Remind students that the average distance from Earth to the sun is 149,598,000 km (one AU). Have them write this number in exponential form. *(1.496×10^{8} km)* Then, have students divide the numbers to determine how many AU equal one light-year. *($[9.46 \times 10^{12}$ km/light-year$]/[1.496 \times 10^{8}$ km/AU$] = 63{,}200$ AU/light-year)*
Logical

Direct students to the **Math Skills** in the **Skills and Reference Handbook** at the end of the student text for additional help.

Use Visuals (L1)

Figure 9 Tell students that even the largest measured parallax of a star is less than the apparent width of a dime at a distance of a mile. It is much too small to be seen with the unaided eye. Ask, **Why does the star appear to move?** *(Earth has moved from one side of its orbit to the other. An observer on Earth is viewing the star from a different angle.)* **What do the arrows show?** *(The angle of sight of an observer on Earth)*
Visual

Build Science Skills (L2)

Calculating Explain that parallax is typically measured in arc-seconds, a unit equal to 1/3600 of a degree. A star could have a parallax, for example, of 1 arc-sec, abbreviated as 1". A parsec is a unit of measure equal to the distance at which a star's parallax is 1 arc-second. One parsec is equal to 3.26 light-years. The following formula is used to calculate the distance of a star in parsecs: $d = 1/p$ where d represents distance in parsecs and p represents parallax in arc-seconds. Write the formula on the board and have students calculate the distance to a star that has a parallax of 0.20". *(1/0.20" = 5.0 parsecs)* Then, ask students to convert this distance to light-years. *(5.0 parsecs $\times$ 3.26 light-years/parsec = 16 light-years)*
Logical

Answer to . . .

Figure 9 *When it is closer to your eyes*

Properties of Stars

Build Reading Literacy

L1

Predict Refer to page **66D** in **Chapter 3**, which provides the guidelines for predicting.

Before students read about the properties of stars, tell them that stars range in color from blue to white to yellow to red, similar to flames from a fire. Have them picture a flame—different parts are hotter than others. Based on what they know about these temperature differences, ask them to predict which color indicates the hottest star. *(Blue)* Have students read the text to see if their predictions were correct.
Logical

Build Math Skills

L1

Conversion Factors Remind students that temperatures are measured from absolute zero on the Kelvin scale. On the Celsius scale, absolute zero is −273°. The formula for converting kelvins to degrees Celsius is C = K − 273. Point out that at the high surface temperatures of stars, there is not much difference between the Kelvin and Celsius scale temperatures. Have students convert the surface temperatures of the following stars from kelvins to degrees Celsius: Spica, 22,973 K; the sun, 5773 K; Castor C, 3573 K. *(Spica: 22,973 K − 273 K = 22,700°C; the sun: 5773 K − 273 K = 5500°C; Castor C: 3573 K − 273 K = 3300°C)*
Logical

Direct students to the **Math Skills** in the **Skills and Reference Handbook** at the end of the student text for additional help.

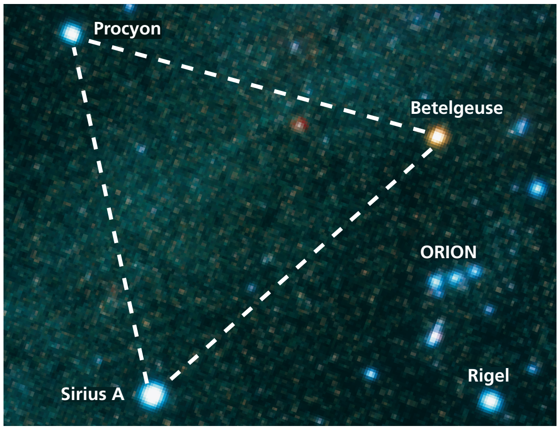
Astronomers have measured the parallax of many nearby stars and determined their distances from Earth. However, if a star is too far away, its parallax is too small to be measured. With present technology, the parallax method gives reasonably accurate distance measurements for stars within a few hundred light-years. Astronomers have developed other ways to estimate distances to more-distant stars.

Properties of Stars

There are many different types of stars. **Astronomers classify stars by their color, size, and brightness. Other important properties of stars include their chemical composition and mass.**

Color and Temperature Have you ever looked closely at a candle flame? The hottest part of the flame near the wick is blue or white, while the cooler flame tip is orange. A propane torch flame is blue. Dying campfire embers are red. You can estimate the temperature of a flame from its color. In the same way, a star's color indicates the temperature of its surface. The hottest stars, with surface temperatures above 30,000 K, appear blue. The surfaces (photospheres) of relatively cool red stars are still a toasty 3000 K or so. Stars with surface temperatures between 5000 and 6000 K appear yellow, like the sun. As shown in Figure 10, the color differences between hot blue stars and cool red stars can be seen with the unaided eye. More precise measurements of stars' temperatures can be made by studying stars' spectra.

Figure 10 The "Winter Triangle" can be seen in the late fall and winter in the eastern sky. It is made up of three of the brightest stars in the sky: Betelgeuse, Procyon, and Sirius A. Betelgeuse and the star Rigel belong to the constellation Orion.
Applying Concepts ***Which star has a higher surface temperature, Betelgeuse or Sirius A?***



Brightness When you walk along a street at night, such as the one shown in Figure 11, look up at a row of street lights. The closer lights look bright and the more distant lights look dim. However, the more distant lights are not really dimmer. They appear dim to you because, at a greater distance, their light is spread out over a greater area, so a smaller portion enters your eyes. The same is true for the light emitted by stars.

You might think that closer stars will always appear brighter than more-distant stars. Astronomers have discovered, however, that the brightness of stars can vary by a factor of more than a billion. So, stars that look bright may actually be farther away than stars that appear dim.

Although the sun appears to be the brightest star in our sky, it is really a star of only average brightness. The sun appears very bright to us because it is much closer than other stars. The brightness of a star as it appears from Earth is called its **apparent brightness.** The apparent brightness of a star decreases as its distance from you increases.

If you move away from a street light or a star, it shines just as brightly as before—but to you it appears fainter. **Absolute brightness** is how bright a star really is. A star's absolute brightness is a characteristic of the star and does not depend on how far it is from Earth. You can calculate a star's absolute brightness if you know its distance from Earth and its apparent brightness.

Size and Mass Once astronomers know a star's temperature and absolute brightness, they can estimate its diameter and then calculate its volume. However, there is no direct way of finding the mass of an isolated star. Instead, astronomers are able to calculate the masses of many stars by observing the gravitational interaction of stars that occur in pairs. From such observations, astronomers have determined that, for most stars, there is a relationship between mass and absolute brightness. Astronomers have found that many stars are similar to the sun in size and mass.

Figure 11 These streetlights all have about the same absolute brightness. **Inferring** ***Why do the nearby streetlights appear brighter than the distant ones?***

Reading Checkpoint *How can astronomers determine a star's mass?*

Composition A spectrograph is an instrument that spreads light from a hot glowing object, such as a light bulb or a star, into a spectrum. Astronomers can use spectrographs to identify the various elements in a star's atmosphere.

Each star has its own spectrum. The elements within a star's atmosphere absorb light from the star's photosphere. Each element absorbs light of different wavelengths, removing these wavelengths from the star's continuous spectrum. The result is a bright spectrum, such as the one shown in Figure 12. It contains a set of dark lines called **absorption lines** that show where light has been absorbed. Just as fingerprints can be used to identify a person, a star's absorption lines can be used to identify different elements in the star.

Absorption lines of most elements have been identified in the spectra of stars. Observations of such lines in many stars have shown that the composition of most stars is fairly similar. **Most stars have a chemical makeup that is similar to the sun, with hydrogen and helium together making up 96 to 99.9 percent of the star's mass.**

Figure 12 This is the spectrum of a star. The dark absorption lines indicate the presence of various elements in the star.

Build Science Skills L2

Communicating Results The Stefan-Boltzmann Law relates a star's absolute brightness to its size and temperature. Written in equation form, the law states that $L = 4\pi R^2 \sigma T^4$ where L is luminosity (or absolute brightness), R is the radius of a star, σ is a constant, and T is temperature. The equation can be used to determine a star's size if its temperature and absolute brightness are known. Have students research and write brief reports about how scientists use the Stefan-Boltzmann Law.
Verbal

Integrate Chemistry L2

Tell students that at the surface of stars with relatively low temperatures, atoms retain all of their electrons and radiate neutral, or normal, spectra. At very high temperatures, atoms collide and lose electrons and become thermally ionized. Ions have different spectra than atoms. Ask, **How is it possible that two stars can have a similar composition, but radiate different spectra?** *(One of the stars is much hotter than the other.)*
Logical

Facts and Figures

Discovery of Helium In 1868, a spectrometer was used for the first time to study the sun during a solar eclipse. The French astronomer Pierre Janssen analyzed the resulting spectrum and noticed that a bright yellow spectral line did not match any known elements. He proposed that the line was associated with a new element. It was named helium, which stems from the Greek word *helios,* meaning "sun." Helium, a light noble gas, is extremely difficult to detect on Earth. In 1895, Sir William Ramsay was finally able to demonstrate the presence of helium in ores by treating them with acids.

Answer to . . .

Figure 10 *Sirius A because it is blue*

Figure 11 *The nearby streetlights have a greater apparent brightness.*

Reading Checkpoint *By observing the gravitational interaction of stars that appear in pairs, which led to the determination that mass and absolute brightness are related*

The Hertzsprung-Russell Diagram

Use Visuals

L1

Figure 13 Tell students that absolute brightness is often called luminosity by astronomers. Then say, **Describe the properties of the sun shown on the H-R diagram.** *(Color: yellow; surface temperature: about 5700 K; type: main sequence; absolute brightness: average)* **What is the hottest supergiant shown on the diagram?** *(Rigel)* **What is the coolest main-sequence star labeled on the diagram?** *(Alpha Centauri B)* **Which supergiant has a temperature and color similar to the sun's?** *(Polaris)* **What color, temperature, and star type is Sirius B?** *(Color: blue-white; temperature: about 30,000 K; type: white dwarf)* **Which labeled star on the diagram has the greatest absolute brightness? The least?** *(Greatest: Deneb; least: Sirius B)*
Visual

Address Misconceptions

L2

Often students think that all of the stars in an H-R diagram are located close to one another in space. This is not the case. Emphasize that an H-R diagram is a graph, not a star chart. An H-R diagram can be used to plot any sample of stars. You may find later in this chapter that students have a similar misconception about constellations—that is, all the stars in a constellation are close to one another. Again, explain that the stars in a constellation are separated by vast distances. Ask, **Can the distance to a star be determined simply by gazing at it?** *(No)*
Verbal

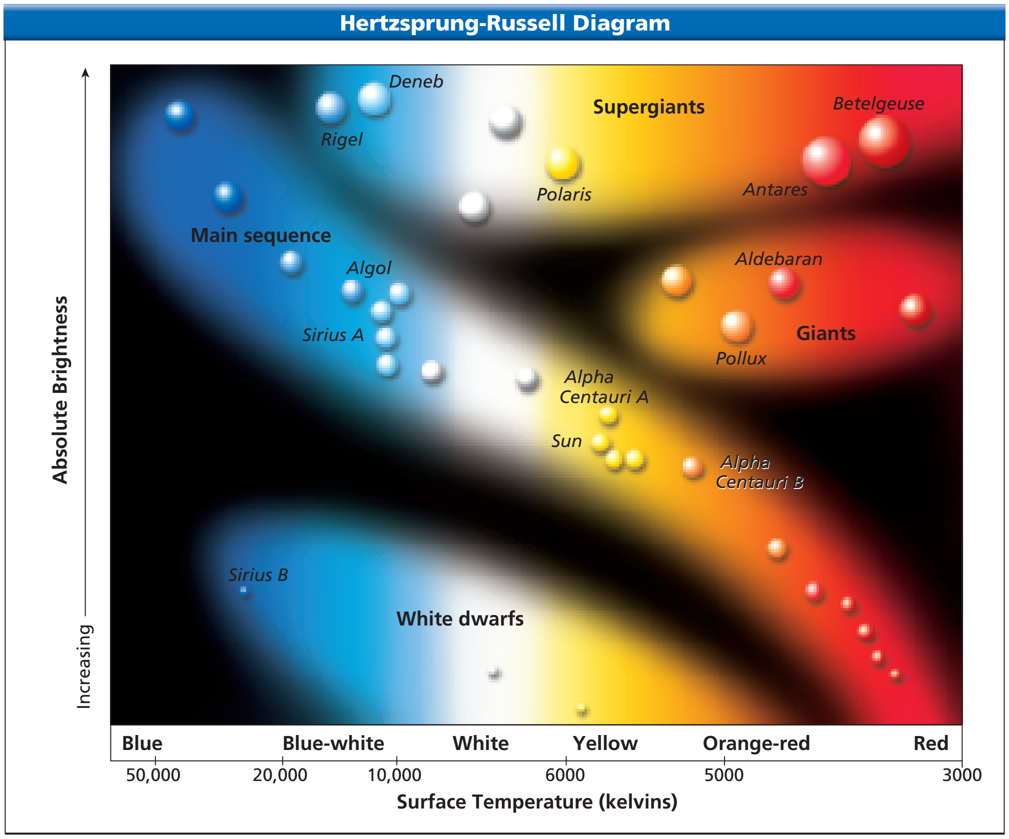


Figure 13 A star's placement on an H-R diagram indicates its absolute brightness and surface temperature (or color).
Interpreting Diagrams
Compare the sun and Aldebaran. Which is hotter and which has a greater absolute brightness?

The Hertzsprung-Russell Diagram

In the early 1900s, two astronomers working independently, Ejnar Hertzsprung and Henry Norris Russell, made a similar observation. Both discovered that stars can be classified by locating them on a graph showing two easily determined characteristics. Such a graph is called a Hertzsprung-Russell diagram, or H-R diagram. An **H-R diagram** is a graph of the surface temperature, or color, and absolute brightness of a sample of stars. These diagrams are one of modern astronomy's most important tools. **H-R diagrams are used to estimate the sizes of stars and their distances, and to infer how stars change over time.**

Look closely at the H-R diagram in Figure 13. The horizontal axis shows the surface temperatures of stars. Recall that a star's color is directly related to its surface temperature. The hottest blue stars are on the left and the coolest red stars are on the right. Surface temperatures of stars range from less than 3000 K to more than 30,000 K.

The vertical axis of the H-R diagram shows absolute brightness, with the brightest stars at the top and the faintest at the bottom. The absolute brightnesses of stars vary even more than temperature, ranging from about one ten-thousandth to a million times that of the sun!

Main-Sequence Stars Notice that stars occur only in certain places on the H-R diagram. Most stars are found along a diagonal band running from the bright hot stars on the upper left to the dim cool stars on the lower right. Astronomers call this diagonal band on the H-R diagram the **main sequence.** About 90% of all stars are found on the main sequence. The sun lies near the middle of this band.

Giants and Dwarfs In general, two factors determine a star's absolute brightness: its size and its surface temperature. Since an H-R diagram shows a star's absolute brightness and surface temperature, you can use the diagram to estimate the star's size. If you compare two stars at the same temperature, the brighter one must be larger. Similarly, hotter stars are brighter than cooler stars of the same size.

The very bright stars at the upper right of the H-R diagram are called **supergiants.** Supergiants are much brighter than main-sequence stars of the same temperature. To be so bright, these supergiants must be very large compared with main-sequence stars. In fact, supergiants range in size from 100 to 1000 times the diameter of the sun. Just below the supergiants on the H-R diagram are the **giants**—large, bright stars that are smaller and fainter than supergiants.

Below the main sequence in the lower part of the H-R diagram are white dwarfs. A **white dwarf** is the small, dense remains of a low- or medium-mass star. You can see from the diagram that white dwarfs are hot but dimmer than main-sequence stars of the same temperature.

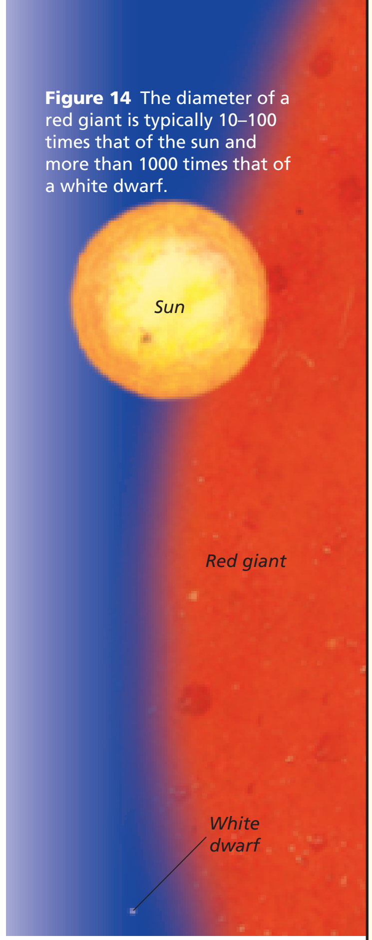


Figure 14 The diameter of a red giant is typically 10–100 times that of the sun and more than 1000 times that of a white dwarf.

Section 26.2 Assessment

Reviewing Concepts

1. What method do astronomers use to measure the distances of nearby stars?
2. What are some common properties used to classify stars?
3. Describe the chemical composition of a star like the sun.
4. What is an H-R diagram? How is one useful to an astronomer?

Critical Thinking

5. **Applying Concepts** What causes the dark lines in a star's spectrum?
6. **Comparing and Contrasting** Describe the locations of giants, supergiants, and white dwarfs on an H-R diagram.

Math Practice

7. The bright star Spica is located about 2.49×10^{15} kilometers from Earth. How many light-years is this?
8. Betelgeuse is about 427 light-years from Earth. How many kilometers is this?

Use Community Resources L2

Invite a local astronomer to discuss spectral types with the class. Ask him or her to bring along charts and stellar images, if possible. Before the visit, describe spectral classes (O, B, A, F, G, K, and M) and explain that they are based largely on temperature differences among stars, with O being the hottest and M being the coolest. Have students conduct some preliminary research on spectral types and develop questions to ask the astronomer.
Verbal, Visual

3 ASSESS

Evaluate Understanding L2

Provide students with the temperature, color, absolute brightness, and star type (white dwarf, main sequence, and so on) for a set of stars. Have them construct their own H-R diagrams.

Reteach L1

Use graphics to emphasize how the absolute brightness of a star depends on its surface temperature and its size. Draw a small circle to represent a small star. Draw a large circle to represent a large star. Pointing to the circles, explain that if two stars have equal temperatures, then they emit the same amount of light from each square kilometer of their surfaces. The star that is larger therefore has a greater absolute brightness.

Math Practice

Solutions
7. $(2.49 \times 10^{15}$ km$)/(9.5 \times 10^{12}$ km/light-year$) = 260$ light-years
8. $(427$ light-years$) \times (9.5 \times 10^{12}$ km/light-year$) = 4.1 \times 10^{15}$ km

Interactive Textbook — If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 26.2.

Section 26.2 Assessment

1. The parallax method
2. Color or surface temperature, absolute brightness, size, mass, chemical composition
3. Stars like the sun are composed mainly of hydrogen and helium.
4. An H-R diagram is a graph of surface temperature versus absolute brightness for a sample of stars. It can be used to estimate the sizes and distances of stars and to understand how stars evolve.
5. Dark absorption lines show where light has been absorbed by elements in a star's atmosphere.
6. Giants can be found above the main sequence and below the supergiants in the upper-right portion of an H-R diagram. The region where supergiants are found extends from the upper right to the upper central portion of the diagram. White dwarfs are generally found in the lower central portion of the diagram, below the main sequence.

Answer to . . .

Figure 13 *The sun has a higher surface temperature. Aldebaran has a greater absolute brightness.*