Stars

BIG Idea The life cycle of every star is determined by its mass, luminosity, magnitude, temperature, and composition.

29.1 The Sun
MAIN Idea The Sun contains most of the mass of the solar system and has many features typical of other stars.
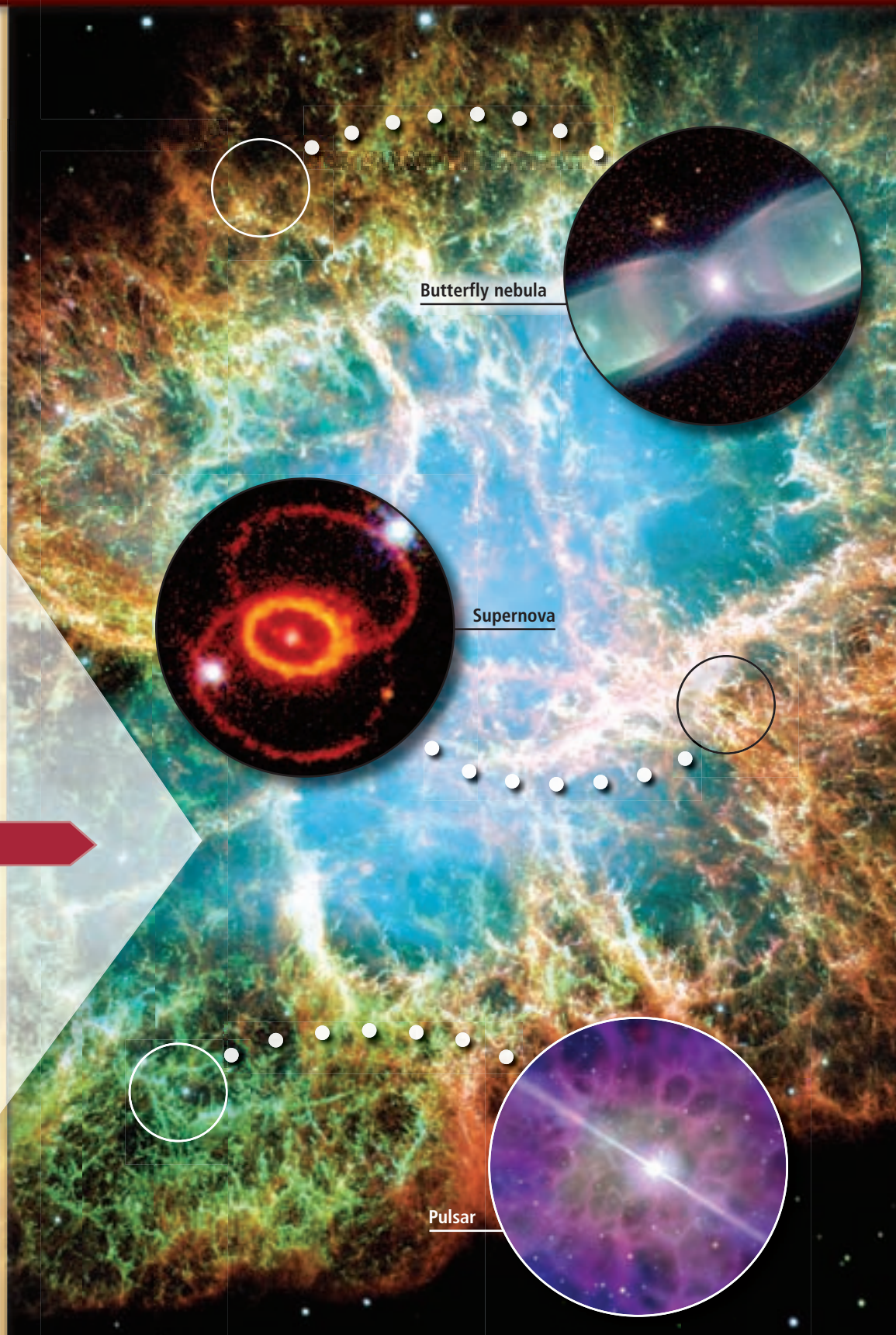
29.2 Measuring the Stars
MAIN Idea Stellar classification is based on measurement of light spectra, temperature, and composition.

29.3 Stellar Evolution
MAIN Idea The Sun and other stars follow similar life cycles, leaving the galaxy enriched with heavy elements.

GeoFacts

- The last gasp of a dying star, the Butterfly nebula erupts as a pair of jet exhausts.
- A runaway thermonuclear reaction results in a star exploding into a supernova, throwing matter away from the collapsed core.
- When a massive star collapses, it becomes a pulsar, a rapidly rotating object that has a magnetic field a trillion times that of Earth.

Butterfly nebula

Supernova

Pulsar

(t)STScI/NASA/Science Source, (c)STScI/NASA/Science Source, (b)Mark Garlick/Photo Researchers, (bkgd)NASA/ESA/J. Hester/A. Loll

LAUNCH Lab

How can you observe sunspots?

Although the Sun is an average star, it undergoes many complex processes. Sunspots are dark spots that are visible on the surface of the Sun. They can be observed moving across the face of the Sun as it rotates.

Procedure

WARNING: *Do not look directly at the Sun. Do not look through the telescope at the Sun. You could damage your eyes.*

1. Read and complete the lab safety form.
2. Observe the Sun through the **telescope** that your teacher has set up. Note that the telescope is pointed directly at the Sun, but the eyepiece is casting the shadow of the Sun on a **clipboard**.
3. Move the clipboard back and forth until you have the largest image of the Sun on the **paper.** Trace the outline of the Sun on your paper.
4. Trace sunspots that appear as dark areas on the Sun's image. Repeat this step at the same time each day for a week.
5. Measure the movement of sunspots.

Analysis
1. **Calculate** Use your data to determine the Sun's period of rotation.
2. **Determine** What is the estimated rate of motion of the largest sunspot?
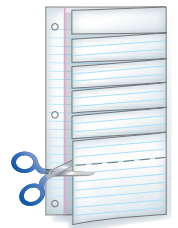
FOLDABLES™
Study Organizer

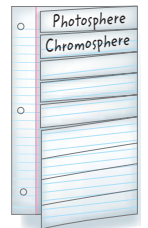**Stars** Make the following Foldable that features the key vocabulary terms associated with stars.

▶ **STEP 1** Fold a sheet of paper in half lengthwise.

▶ **STEP 2** Cut along every third or fourth line of the top flap to form nine tabs.

▶ **STEP 3** Label the tabs as you read.

Photosphere
Chromosphere

FOLDABLES **Use this Foldable with Section 29.2.** As you read this section, record key vocabulary terms and their definitions.

Earth Science Online

Visit **glencoe.com** to
▶ study entire chapters online;
▶ explore **Concepts In Motion** animations:
  ● Interactive Time Lines
  ● Interactive Figures
  ● Interactive Tables
▶ access Web Links for more information, projects, and activities;
▶ review content with the Interactive Tutor and take Self-Check Quizzes.

Objectives

▶ **Describe** the layers and features of the Sun.
▶ **Explain** the process of energy production in the Sun.
▶ **Define** the three types of spectra.

Review Vocabulary

magnetic field: the portion of space near a magnetic or current-carrying body where magnetic forces can be detected

New Vocabulary

photosphere
chromosphere
corona
solar wind
sunspot
solar flare
prominence
fusion
fission

The Sun

MAIN ‹Idea› **The Sun contains most of the mass of the solar system and has many features typical of other stars.**

Real-World Reading Link Have you ever had a sunburn from being outside too long on a sunny day? The Sun is more than 150 million km from Earth, but the Sun's rays are so powerful that humans still wear sunscreen for protection.

Properties of the Sun

The Sun is the largest object in the solar system, in both diameter and mass. It would take 109 Earths, or almost 10 Jupiters, lined up edge to edge, to fit across the Sun. The Sun is about 330,000 times as massive as Earth and 1048 times the mass of Jupiter. In fact, the Sun contains more than 99 percent of all the mass in the solar system. It should not be surprising, then, that the Sun's mass controls the motions of the planets and other objects.

The Sun's average density is similar to the densities of the gas giant planets, represented by Jupiter in **Table 29.1.** Astronomers deduce densities at specific points inside the Sun, as well as other information, by using computer models that explain the observations they make. These models show that the density in the center of the Sun is about 1.50×10^5 kg/m^3, which is about 13 times the density of lead. A pair of dice as dense as the Sun's center would have a mass of about 1 kg.

Unlike lead, which is a solid, the Sun's interior is gaseous throughout because of its high temperature—about 1×10^7 K in the center. At this temperature, all of the gases are completely ionized, meaning the interior is composed only of atomic nuclei and electrons. This state of matter is known as plasma. Though partially ionized, the outer layers of the Sun are not hot enough to be plasma. The Sun produces the equivalent of 4 trillion trillion 100-W lightbulbs of light each second. The small amount that reaches Earth is equal to 1.35 kilowatt/m^2.
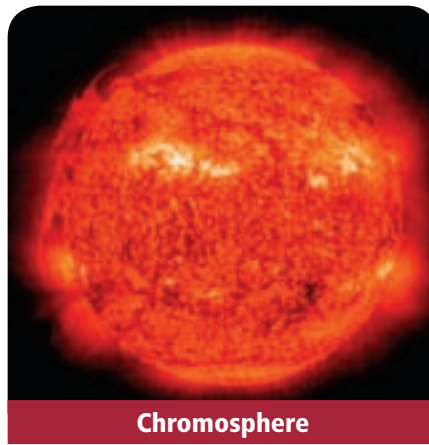
Table 29.1	Relative Properties of the Sun		
	Sun	**Earth**	**Jupiter**
Diameter (km)	1.4×10^6	1.3×10^4	1.4×10^5
Mass (kg)	2.0×10^{30}	6.0×10^{24}	1.9×10^{27}
Density (kg/m³)	1.4×10^3	5.5×10^3	1.3×10^3

Concepts In Motion

Interactive Table To explore more about the Sun, visit **glencoe.com**.
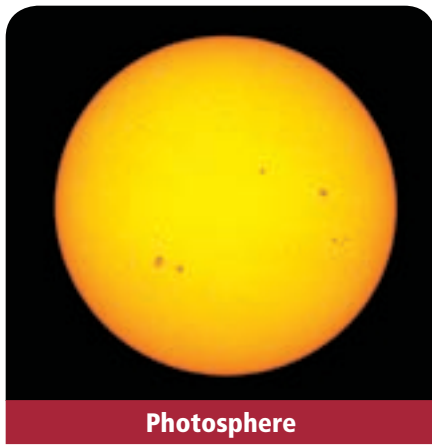
Photosphere

Chromosphere

■ **Figure 29.1** Sunspots appear dark on the photosphere, the visible surface of the Sun. The chromosphere of the Sun appears red with prominences and flares suspended in the thin layer. The white-hot areas are almost 6000 K while the darker, red areas are closer to 3000 K.

Deduce *why the images look so different.*

The Sun's Atmosphere

You might ask how the Sun could have an atmosphere when it is already gaseous. The outer regions are organized into layers, like a planetary atmosphere separated into different levels, and each layer emits energy at wavelengths resulting from its temperature.

Photosphere The **photosphere,** shown in **Figure 29.1,** is the visible surface of the Sun. It is approximately 400 km thick and has an average temperature of 5800 K. It is also the innermost layer of the Sun's atmosphere. You might wonder how it is the visible surface of the Sun if it is the innermost layer. This is because most of the visible light emitted by the Sun comes from this layer. The two outermost layers are transparent at most wavelengths of visible light. Additionally, the outermost two layers are dim in the wavelengths they emit.

✔ **Reading Check Explain** why the innermost layer of the Sun's atmosphere is visible.

Chromosphere Outside the photosphere is the **chromosphere,** which is approximately 2500 km thick and has a temperature of nearly 30,000 K. Usually, the chromosphere is visible only during a solar eclipse when the photosphere is blocked. However, astronomers can use special filters to observe the chromosphere when the Sun is not eclipsed. The chromosphere appears red, as shown in **Figure 29.1,** because its strongest emissions are in a single band in the red wavelength.

Corona The outermost layer of the Sun's atmosphere, called the **corona,** extends several million kilometers from the outside edge of the chromosphere and has a temperature range of 1 million to 2 million K. The density of the gas in the corona is very low, which explains why the corona is so dim that it can be seen only when the photosphere is blocked by either special instruments, as in a coronagraph, or by the Moon during an eclipse, as shown in **Figure 29.2.** The temperature is so high in these outer layers of the solar atmosphere that most of the emitted radiation occurs at ultraviolet wavelengths for the chromosphere, and X rays for the corona.

■ **Figure 29.2** The Sun's hottest and outermost layer, the corona, is not normally seen unless the disk of the Sun is blocked as by this solar eclipse.

Aurora from Earth
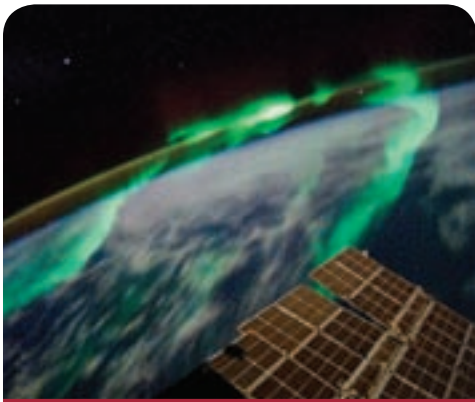
Aurora from space

■ **Figure 29.3** The aurora is the result of particles from the Sun colliding with gases in Earth's atmosphere. It is best viewed from regions around the poles of Earth.

Infer *When can you see the aurora?*

Solar wind The corona of the Sun does not have an abrupt edge. Instead, gas flows outward from the corona at high speeds and forms the **solar wind.** As this wind of charged particles, called ions, flows outward through the entire solar system, it bathes each planet in a flood of particles. At 1 AU—Earth's distance from the Sun—the solar wind flows at a speed of about 400 km/s. The charged particles are deflected by Earth's magnetic field and are trapped in two huge rings, called the Van Allen belts. The high-energy particles in these belts collide with gases in Earth's atmosphere and cause the gases to give off light. This light, called the aurora, can be seen from Earth or from space, as shown in **Figure 29.3.** The aurora are generally seen from Earth in the polar regions.

Solar Activity

While the solar wind and layers of the Sun's atmosphere are permanent features, other features on the Sun change over time in a process called solar activity. Some of the Sun's activity includes fountains and loops of glowing gas. Some of this gas has structure—a certain order in both time and place. This structure is driven by magnetic fields.

The Sun's magnetic field and sunspots The Sun's magnetic field disturbs the solar atmosphere periodically and causes new features to appear. The most obvious features are **sunspots,** shown in **Figure 29.4,** which are dark spots on the surface of the photosphere. Sunspots are bright, but they appear darker than the surrounding areas on the Sun because they are cooler. They are located in regions where the Sun's intense magnetic fields penetrate the photosphere. Magnetic fields create pressure that counteracts the pressure from the hot, surrounding gas. This stabilizes the sunspots despite their lower temperature. Sunspots occur in pairs with opposite magnetic polarities—with a north and a south pole similar to a magnet.
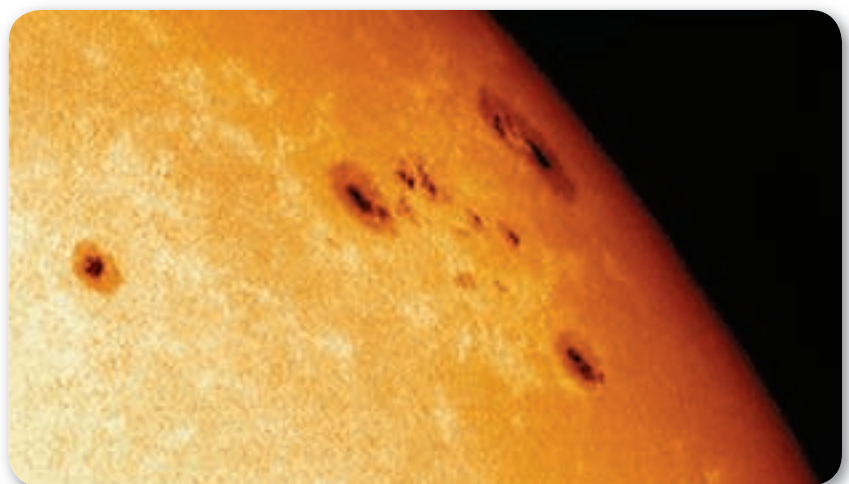
■ **Figure 29.4** Sunspots are dark spots on the surface of the photosphere. Each sunspot is accompanied by a bright, granular structure. The light and dark areas are associated with the Sun's magnetic field. Sunspots typically last about two months.

Solar activity cycle Astronomers have observed that the number of sunspots changes regularly, reaching a maximum number every 11.2 years. At this point, the Sun's magnetic field reverses, so that the north magnetic pole becomes the south magnetic pole and vice versa. Because sunspots are caused by magnetic fields, the polarities of sunspot pairs reverse when the Sun's magnetic poles reverse. Therefore, when the polarity of the Sun's magnetic field is taken into account, the length of the cycle doubles to 22.4 years. Thus, the solar activity cycle starts with minimum spots and progresses to maximum spots. The magnetic field then reverses in polarity, and the spots start again at a minimum number and progress to a maximum number. The magnetic field then switches back to the original polarity and completes the solar activity cycle.

✅ **Reading Check** **Determine** how often the Sun's magnetic poles reverse themselves.

Other solar features Coronal holes, only detectable in X-ray photography and shown in **Figure 29.5,** are often located over sunspot groups. Coronal holes are areas of low density in the gas of the corona and are the main regions from which the particles that comprise the solar wind escape.

Highly active solar flares are also associated with sunspots, as shown in **Figure 29.5.** **Solar flares** are violent eruptions of particles and radiation from the surface of the Sun. Often, the released particles escape the surface of the Sun in the solar wind and Earth gets bombarded with the particles a few days later. The largest recorded solar flare, which occurred in April 2001, hurled particles from the Sun's surface at 7.2 million km/h.

Another active feature, sometimes associated with flares, is a **prominence,** which is an arc of gas that is ejected from the chromosphere, or is gas that condenses in the inner corona and rains back to the surface. **Figure 29.5** shows an image of a prominence. Prominences can reach temperatures greater than 50,000 K and can last from a few hours to a few months. Like flares, prominences are also associated with sunspots and the magnetic field, and occurrences of both vary with the solar-activity cycle.
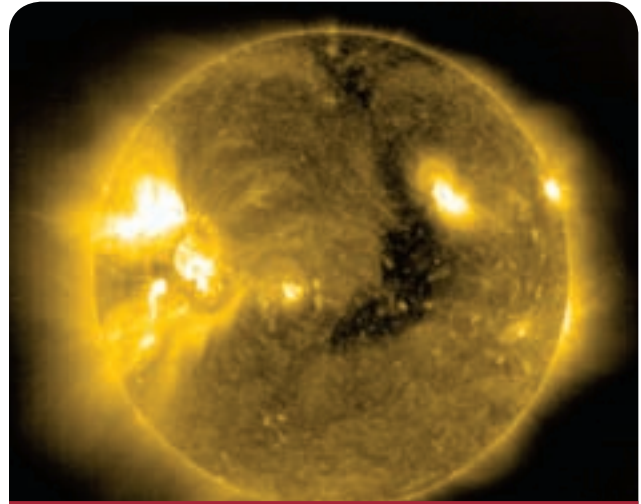
Coronal holes

Solar flares
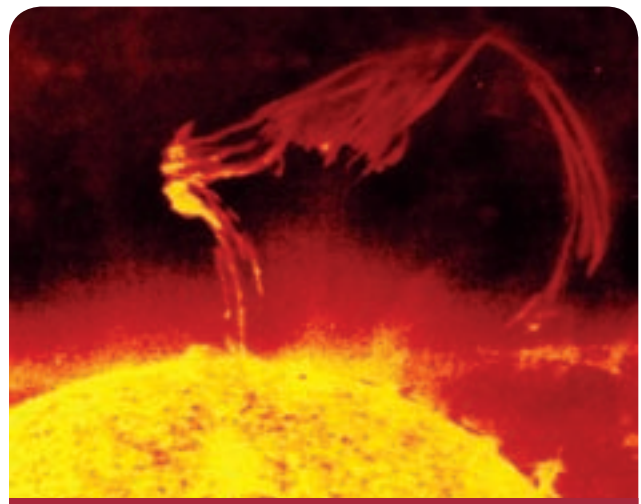
Solar prominence

■ **Figure 29.5** Features of the Sun's surface include coronal holes into the surface and solar flares and prominences that erupt from the surface.

■ **Figure 29.6** Energy in the Sun is transferred mostly by radiation from the core outward to about 86 percent of its radius. The outer layers transfer energy in convection currents.
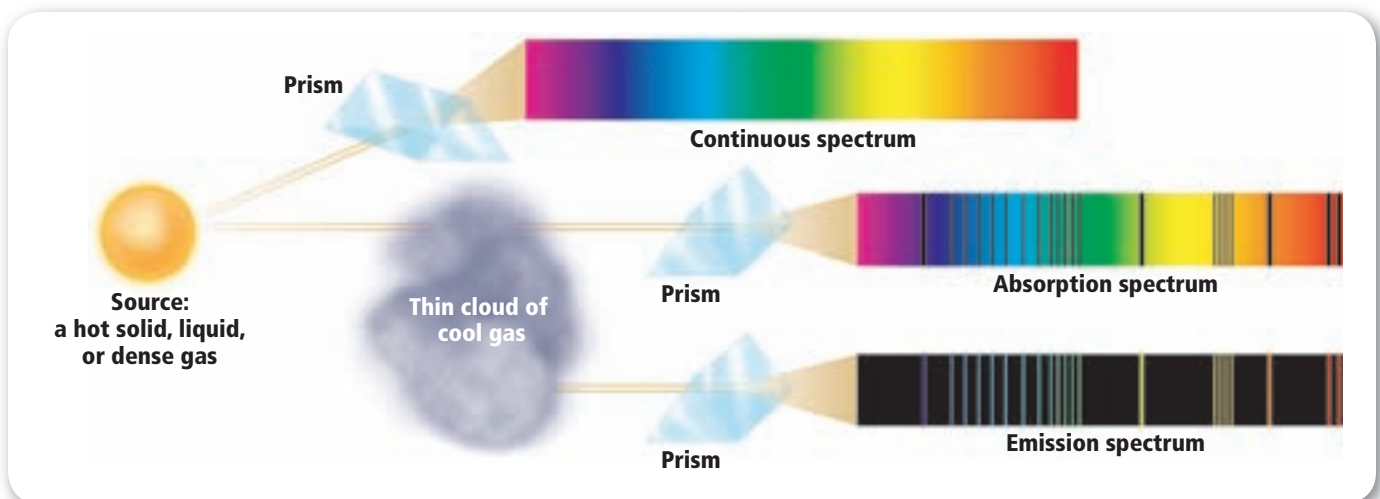
The Solar Interior

You might be wondering where all the energy that causes solar activity and light comes from. Fusion occurs in the core of the Sun, where the pressure and temperature are extremely high. **Fusion** is the combination of lightweight, atomic nuclei into heavier nuclei, such as hydrogen fusing into helium. This is the opposite of the process of **fission,** which is the splitting of heavy atomic nuclei into smaller, lighter nuclei, like uranium into lead.

Energy production in the Sun In the core of the Sun, helium is a product of the process in which hydrogen nuclei fuse. The mass of the helium nucleus is less than the combined mass of the four hydrogen nuclei, which means that mass is lost during the process. Albert Einstein's special theory of relativity shows that mass and energy are equivalent, and that matter can be converted into energy and vice versa. This relationship can be expressed as $E = mc^2$, where E is energy measured in joules, m is the quantity of mass that is converted to energy measured in kilograms, and c is the speed of light measured in m/s. This theory explains that the mass lost in the fusion of hydrogen to helium is converted to energy, which powers the Sun. At the Sun's rate of hydrogen fusing, it is about halfway through its lifetime, with approximately 5 billion years left. Even so, the Sun has used only about 3 percent of its hydrogen.

Energy transport If the energy of the Sun is produced in the core, how does it get to the surface before it travels to Earth? The answer lies in the two zones in the solar interior illustrated in **Figure 29.6.** In the inner portion of the Sun, extending to about 86 percent of its radius, energy is transferred by radiation. This is the radiation zone. Above that, in the convection zone, energy is transferred by gaseous convection currents. As energy moves outward, the temperature is reduced from a central value of about 1×10^7 K to its photospheric value of about 5800 K. Leaving the Sun's outermost layer, energy moves in a variety of wavelengths in all directions. A tiny fraction of that immense amount of solar energy eventually reaches Earth.

■ **Figure 29.7** Energy excites the elements of a substance so that it emits different wavelengths of light.

Infer *what the colors of a spectrum represent.*

Prism

Continuous spectrum

Source:
a hot solid, liquid, or dense gas

Thin cloud of cool gas

Prism

Absorption spectrum

Prism

Emission spectrum

Solar energy on Earth The quantity of energy that arrives on Earth every day from the Sun is enormous. Above Earth's atmosphere, 1354 J of energy is received in 1 m²/s (1354 W/m²). In other words, 13 100-W lightbulbs could be operated with the solar energy that strikes a 1-m² area. However, not all of this energy reaches the ground because some is absorbed and scattered by the atmosphere, as you learned in Chapter 11.

Spectra

You are probably familiar with the rainbow that appears when white light is shined through a prism. This rainbow is a spectrum (plural, spectra), which is visible light arranged according to wavelengths. There are three types of spectra: continuous, emission, and absorption, as shown in **Figure 29.7.**

A spectrum that has no breaks in it, such as the one produced when light from an ordinary bulb is shined though a prism, is called a continuous spectrum. A continuous spectrum can also be produced by a glowing solid or liquid, or by a highly compressed, glowing gas. The spectrum from a noncompressed gas contains bright lines at certain wavelengths. This is called an emission spectrum, and the lines are called emission lines. The wavelengths of the visible lines depend on the element being observed because each element has its own characteristic emission spectrum.

✔ **Reading Check Describe** continuous and emission spectra.

A spectrum produced from the Sun's light shows a series of dark bands. These dark spectral lines are caused by different chemical elements that absorb light at specific wavelengths. This is called an absorption spectrum, and the lines are called absorption lines. Absorption is caused by a cooler gas in front of a source that emits a continuous spectrum. The pattern of the dark absorption lines of an element is exactly the same as the bright emission lines for that same element. Thus, by comparing laboratory spectra of different gases with the dark lines in the solar spectrum, it is possible to identify the elements that make up the Sun's outer layers. You will experiment with identifying spectral lines in the GeoLab at the end of this chapter.

DATA ANALYSIS LAB

Based on Real Data*
Interpret Data

Can you identify elements in a star? Astronomers study the composition of stars by observing their absorption spectra. Each element in a star's outer layer produces a set of lines in the star's absorption spectrum. From the pattern of lines, astronomers can determine what elements are in a star.

Hydrogen
Helium
Sodium
Calcium
Sun
Mystery star
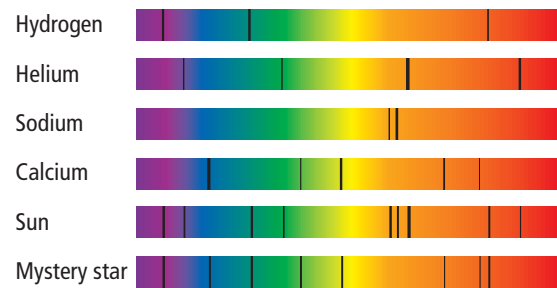
Analysis

1. Study the spectra of the four elements.
2. Examine the spectra for the Sun and the mystery star.
3. To identify the elements of the Sun and the mystery star, use a ruler to help you line up the spectral lines with the known elements.
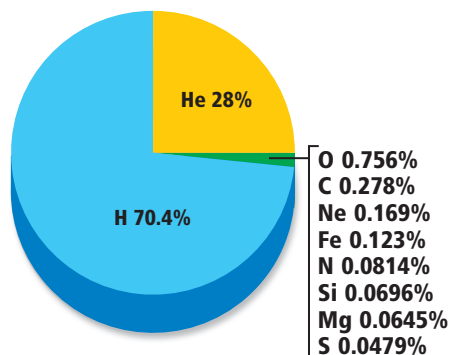
Think Critically

4. **Identify** the elements that are present in the part of the absorption spectrum shown for the Sun.
5. **Identify** the elements that are present in the absorption spectrum for the mystery star.
6. **Determine** which elements are common to both stars.

Element Composition of the Sun by Mass

He 28%

O 0.756%
C 0.278%
Ne 0.169%
Fe 0.123%
N 0.0814%
Si 0.0696%
Mg 0.0645%
S 0.0479%

H 70.4%

■ **Figure 29.8** The Sun is composed primarily of hydrogen and helium with small amounts of other gases.

Solar Composition

Although scientists cannot take samples from the Sun directly, they have learned a great deal about the Sun from its spectra. Using the lines of the absorption spectra like fingerprints, astronomers have identified the elements that compose the Sun. Sixty or more elements have been identified as solar components. The Sun consists of hydrogen (H), at about 70.4 percent by mass, helium, (He) 28 percent, and a small amount of other elements, as illustrated in **Figure 29.8.** This composition is similar to that of the gas giant planets. It suggests that the Sun and the gas giants represent the composition of the interstellar cloud from which the solar system formed. While the terrestrial planets have lost most of the lightweight gases, as you learned in Chapter 28, their heavier element composition probably came from a contribution to the interstellar cloud of by-products from long extinct stars.

The Sun's composition represents that of the galaxy as a whole. Most stars have proportions of the elements similar to the Sun. Hydrogen and helium are the predominant gases in stars, and in the rest of the universe. Even dying stars still have hydrogen and helium in their outer layers since their internal temperatures might only fuse about 10 percent of their total hydrogen into helium. All other elements are in small proportions compared to hydrogen and helium. The larger the star's mass at its inception, the more heavy elements it will produce in its lifetime. But, as you will read in this chapter, there are different results when a star dies. As stars die, they return as much as 50 percent of their mass back into interstellar space, to be recycled into new generations of stars and planets.

Section 29.1 Assessment

Section Summary

▶ Most of the mass in the solar system is found in the Sun.

▶ The Sun's average density is approximately equal to that of the gas giant planets.

▶ The Sun has a layered atmosphere.

▶ The Sun's magnetic field causes sunspots and other solar activity.

▶ The fusion of hydrogen into helium provides the Sun's energy and composition.

▶ The different temperatures of the Sun's outer layers produce different spectra.

Understand Main Ideas

1. **MAIN Idea** **Identify** which features of the Sun are typical of stars.

2. **Describe** the outer layers of gas above the Sun's visible surface.

3. **Classify** the different types of spectra by how they are created.

4. **Describe** the process of fusion in the Sun.

5. **Compare** the composition of the Sun in **Figure 29.8** to the gas giant planets composition in Chapter 28.

Think Critically

6. **Infer** how the Sun would affect Earth if Earth did not have a magnetic field.

7. **Relate** the solar activity cycle with solar flares and prominences.

WRITING in **Earth Science**

8. Create a trifold brochure relating the layers and characteristics of the Sun.

Earth Science Online **Self-Check Quiz** glencoe.com

Objectives

▶ **Determine** how distances between stars are measured.
▶ **Distinguish** between brightness and luminosity.
▶ **Identify** the properties used to classify stars.

Review Vocabulary

wavelength: the distance from one point on a wave to the next corresponding point

New Vocabulary

constellation
binary star
parallax
parsec
apparent magnitude
absolute magnitude
luminosity
Hertzsprung-Russell diagram
main sequence

FOLDABLES
Incorporate information from this section into your Foldable.

■ **Figure 29.9** Different constellations are visible in the sky due to Earth's movement around the Sun.

Measuring the Stars

MAIN Idea Stellar classification is based on measurement of light spectra, temperature, and composition.

Real-World Reading Link As you ride in a car on the highway at night and as a car approaches you, its lights seem to get larger and brighter. Distant stars might be just as large and just as bright as nearer ones, but the distance causes them to appear small and dim.

Groups of Stars

Long ago, many civilizations looked at the brightest stars and named groups of them after animals, mythological characters, or everyday objects. These groups of stars are called **constellations.** Today, astronomers group stars by the 88 constellations named by ancient peoples. Some constellations are visible throughout the year, depending on the observer's location. In the northern hemisphere, you can see constellations that appear to rotate around the north pole. These constellations are called circumpolar constellations. Ursa Major, also known as the Big Dipper, is a circumpolar constellation for the northern hemisphere.

Unlike circumpolar constellations, the other constellations can be seen only at certain times of the year because of Earth's changing position in its orbit around the Sun, as illustrated in **Figure 29.9.** For example, the constellation Orion can be seen only in the northern hemisphere's winter, and the constellation Hercules can be seen only in the northern hemisphere's summer. For this reason, constellations are classified as summer, fall, winter, and spring constellations. The most familiar constellations are the ones that are part of the zodiac. These twelve constellations lie in the ecliptic plane along the same path where the planets are seen. Different constellations can be seen in the northern and southern hemispheres, but the zodiac can be seen in both. Ancient people used the constellations to know when to prepare for planting, harvest, and ritual celebrations.

Hercules

Orion

Sun

Northern hemisphere summer
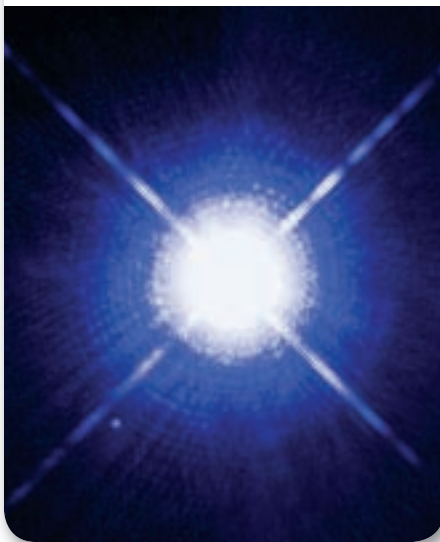
Northern hemisphere winter
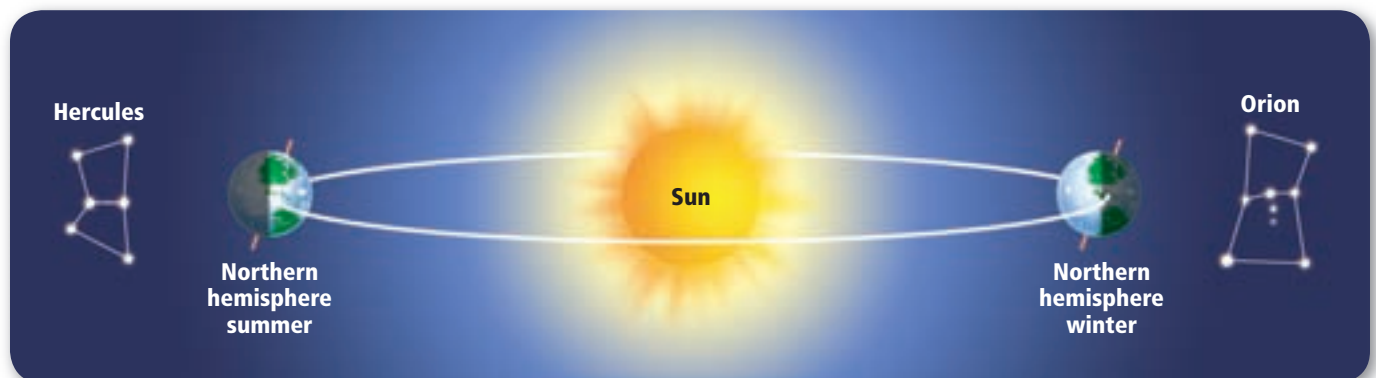
Pleiades

M13

■ **Figure 29.10** Star clusters are groups of stars that are gravitationally bound to one another. The Pleiades is an open cluster group and M13 is a globular cluster.

Star clusters Although the stars in constellations appear to be close to each other, few are gravitationally bound to one other. The reason that they appear to be close together is that human eyes cannot distinguish how far or near stars are. Two stars could appear to be located next to each other in the sky, but one might be 1 trillion km from Earth, and the other might be 2 trillion km from Earth. However, by measuring distances to stars and observing how their gravities interact with each other, scientists can determine which stars are gravitationally bound to each other. A group of stars that are gravitationally bound to each other is called a cluster. The Pleiades (PLEE uh deez) in the constellation Taurus, shown in **Figure 29.10,** is an open cluster because the stars are not densely packed. In contrast, a globular cluster is a group of stars that are densely packed into a spherical shape, such as M13 in the constellation Hercules, also shown in **Figure 29.10.** Different kinds of clusters are explained in **Figure 29.12.**

✓ **Reading Check** **Distinguish** between open and globular clusters.

Binaries When only two stars are gravitationally bound together and orbit a common center of mass, they are called **binary stars.** More than half of the stars in the sky are either binary stars or members of multiple-star systems. The bright star Sirius is half of a binary system, shown in **Figure 29.11.** Most binary stars appear to be single stars to the human eye, even with a telescope. The two stars are usually too close together to appear separately, and one of the two is often much brighter than the other.

Astronomers are able to identify binary stars through the use of several methods. For example, even if only one star is visible, accurate measurements can show that its position shifts back and forth as it orbits the center of mass between it and the unseen companion star. Also, the orbital plane of a binary system can sometimes be seen edgeways from Earth. In such cases, the two stars alternately block each other and cause the total brightness of the two-star system to dip each time one star eclipses the other. This type of binary star is called an eclipsing binary.

■ **Figure 29.11** Sirius and its companion star are the simplest form of stellar grouping, known as a binary.

Visualizing Star Groupings

Figure 29.12 When you look into the night sky, the stars seem to be randomly spaced from horizon to horizon. Upon closer inspection, you begin to see groups of stars that seem to cluster in one area. Star clusters are gravitationally bound groups of stars, which means that their gravities interact to hold the stars in a group.

Galaxy Not a true cluster, a galaxy is a very large star grouping that contains a variety of different clusters of stars.

Globular clusters are made from densely packed groups of stars that are the same age. Their gravities hold them into a rounded cluster. Many globular clusters are found in the haloes of galaxies.
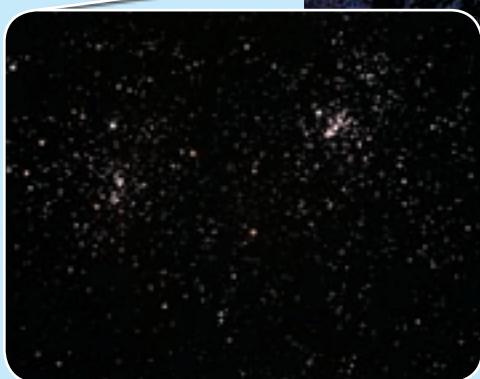
Open clusters are loosely organized groups of stars that are not densely packed. These two open clusters in Perseus are young, and contain a mixture of stellar types from stars dimmer than the Sun to giants and supergiants.
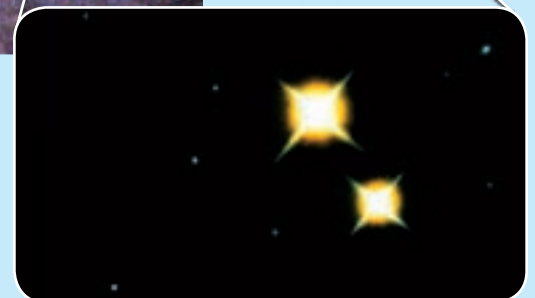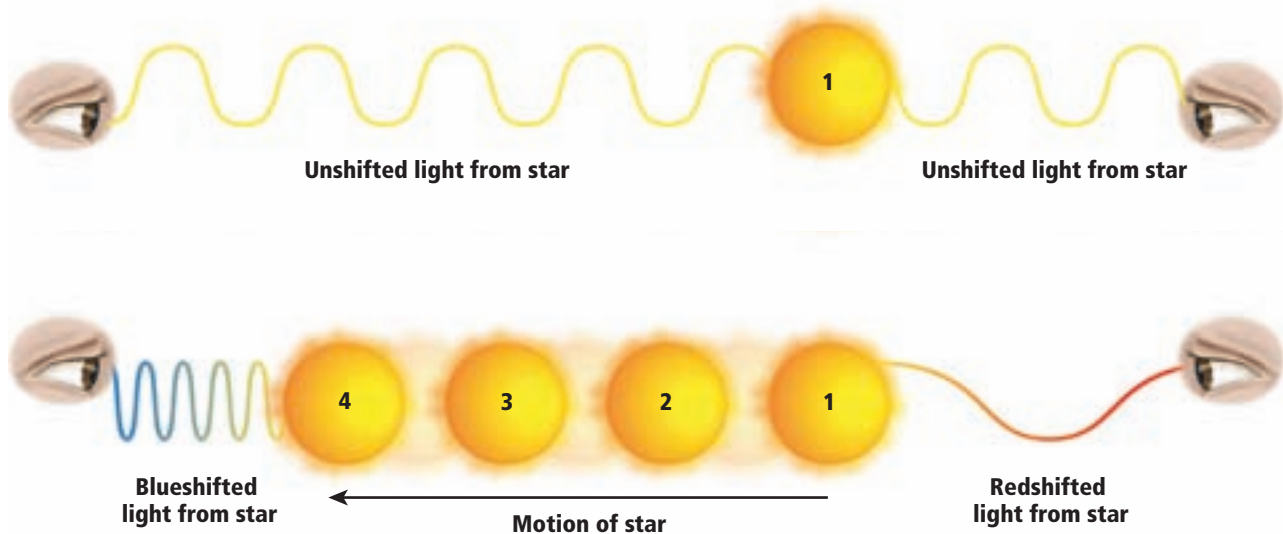
Binaries are the smallest of all star groupings, consisting of only two stars orbiting around a single center of gravity.

Concepts In Motion To explore more about star groupings, visit **glencoe.com**.

Earth Science Online

■ **Figure 29.13** When a star moves toward the observer, the light emitted by the star shifts toward the blue end of the elecromagnetic spectrum. When a star moves away from the observer, its light shifts toward the red. Scientists use Doppler shift to determine the speed and direction of a star's motion.

**Explain** *how the Doppler effect causes color changes.*

concepts In MOtion

Interactive Figure To see an animation of the Doppler effect and redshifts and blue-shifts, visit glencoe.com.

Doppler shifts The most common way to tell that a star is one of a binary pair is to find subtle wavelength shifts, called Doppler shifts. As the star moves back and forth along the line of sight, as shown in **Figure 29.13,** its spectral lines shift. If a star is moving toward the observer, the spectral lines are shifted toward shorter wavelengths, which is called a blueshift. However, if the star is moving away, the wavelengths become longer, which is called a redshift. The higher the speed, the larger the shift, thus careful measurements of spectral line wavelengths can be used to determine the speed of a star's motion. Because there is no Doppler shift for motion that is at a right angle to the line of sight, astronomers can learn only about the portion of a star's motion that is directed toward or away from Earth. The Doppler shift in spectral lines can be used to detect binary stars as they move about their center of mass toward and away from Earth with each revolution. It is also important to note that there is no way to distinguish whether the star, the observer, or both are moving. A star undergoing periodic Doppler shifts can only be interpreted as one of a binary. Stars identified in this way are called spectroscopic binaries. Binaries can reveal much about the individual properties of stars.

Stellar Positions and Distances

Astronomers use two units of measure for long distances. One, which you are probably familiar with, is a light-year (ly). A light-year is the distance that light travels in one year, equal to 9.461×10^{12} km. Astronomers often use a unit larger than a light-year—a parsec. A **parsec** (pc) is equal to 3.26 ly, or 3.086×10^{13} km.
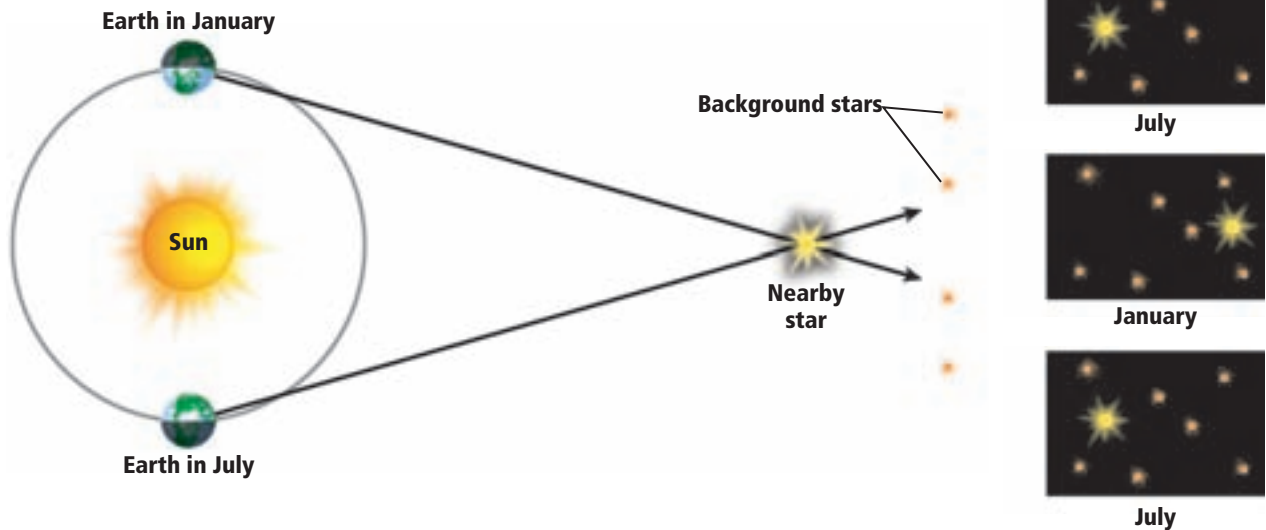
■ **Figure 29.14** As Earth orbits the Sun, nearby stars appear to change position in the sky compared to faraway stars. Earth reaches its maximum change in position at six months, so the angle measured to the star from these two positions is also at the maximum. This shift in observation position is called parallax and can be used to estimate the distance to the star being observed. **Predict** *the position of the star in September.*

Concepts In Motion

Interactive Figure To see an animation of parallax, visit **glencoe.com**.

Parallax Precise position measurements are important for determining distances to stars. When estimating the distance of stars from Earth, astronomers must account for the fact that nearby stars shift in position as observed from Earth. This apparent shift in position caused by the motion of the observer is called **parallax.** In this case, the motion of the observer is the change in position of Earth as it orbits the Sun. As Earth moves from one side of its orbit to the opposite side, a nearby star appears to be shifting back and forth, as illustrated in **Figure 29.14.** The closer the star, the larger the shift. The distance to a star can be estimated from its parallax shift by measuring the angle of the change. A pc is defined as the distance at which an object has a parallax of 1 arcsecond. Using the parallax technique, astronomers could find accurate distances to stars up to only 100 pc, or approximately 300 ly, until recently. With advancements in technology, such as the *Hipparcos* satellite, astronomers can find accurate distances up to 500 pc by using parallax.

✔ **Reading Check** **Identify** the motion of the observer in the diagram.
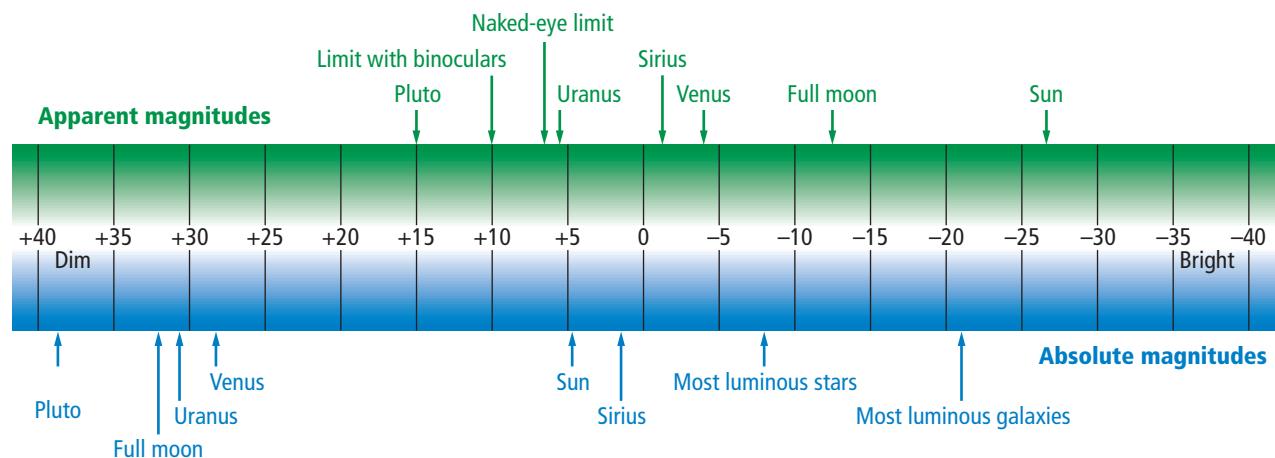
Basic Properties of Stars

The basic properties of a star are mass, diameter, and luminosity, which are all related to each other. Temperature is another property and is estimated by finding the spectral type of a star. Temperature controls the nuclear reaction rate and governs the luminosity, or apparent magnitude. The absolute magnitude compared to the apparent magnitude is used to find the distance to a star.

Apparent magnitudes

| Naked-eye limit |
| Limit with binoculars |
| Pluto | Uranus | Sirius | Venus | Full moon | Sun |

+40 +35 +30 +25 +20 +15 +10 +5 0 −5 −10 −15 −20 −25 −30 −35 −40
Dim   Bright

Absolute magnitudes

Pluto | Full moon | Venus | Uranus | Sun | Sirius | Most luminous stars | Most luminous galaxies

■ **Figure 29.15** Apparent magnitude is how bright the stars and planets appear in the sky from Earth. Absolute magnitude takes into account the distance to that star or planet and makes adjustments for distance.

Magnitude One of the most basic observable properties of a star is how bright it appears, or the **apparent magnitude.** The ancient Greeks established a classification system based on the brightness of stars. The brightest stars were given a ranking of +1, the next brightest +2, and so on. Today's astronomers still use this system, but they have refined it. In this system, a difference of 5 magnitudes corresponds to a factor of 100 in brightness. Thus, a magnitude +1 star is 100 times brighter than a magnitude +6 star.

Absolute magnitude Apparent magnitude does not indicate the actual brightness of a star because it does not account for distance. A faint star can appear to be very bright because it is relatively close to Earth, while a bright star can appear to be faint because it is far away. To account for these phenomena, astronomers have developed another classification system for brightness. **Absolute magnitude** is how bright a star would appear if it were placed at a distance of 10 pc. The classification of stars by absolute magnitude allows comparisons that are based on how bright the stars would appear at equal distances from an observer. The disadvantage of absolute magnitude is that it can be calculated only when the actual distance to a star is known. The apparent and absolute magnitudes for several objects are shown in **Figure 29.15.**

Luminosity Apparent magnitudes do not give an actual measure of energy output. To measure the energy output from the surface of a star per second, called its power or **luminosity,** an astronomer must know both the star's apparent magnitude and how far away it is. The brightness observed depends on both a star's luminosity and distance from Earth, and because brightness diminishes with the square of the distance, a correction must be made for distance. Luminosity is measured in units of energy emitted per second, or watts. The Sun's luminosity is about 3.85×10^{26} W. This is equivalent to 3.85×10^{24} 100-W lightbulbs. The values for other stars vary widely, from about 0.0001 to more than 1 million times the Sun's luminosity. No other stellar property varies as much.

Classification of Stars

You have learned that the Sun has dark absorption lines at specific wavelengths in its spectrum. Other stars also have dark absorption lines in their spectra and are classified according to their patterns of absorption lines. Spectral lines provide information about a star's composition and temperature.

   Temperature Stars are assigned spectral types in the following order: O, B, A, F, G, K, and M. Each class is subdivided into more specific divisions with numbers from 0 to 9. For example, a star can be classified as being a type A4 or A5.

   The classes were originally based only on the pattern of spectral lines, but astronomers later discovered that the classes also correspond to stellar temperatures, with the O stars being the hottest and the M stars being the coolest. Thus, by examination of a star's spectra, it is possible to estimate its temperature.

   The Sun is a type G2 star, which corresponds to a surface temperature of about 5800 K. Surface temperatures range from about 50,000 K for the hottest O stars to as low as 2000 K for the coolest M stars. **Figure 29.16** shows how spectra from some different star classes appear.

   Temperature is also related to luminosity and absolute magnitude. Hotter stars put out more light than stars with lower temperatures. In most normal stars, the temperature corresponds to the luminosity. Since the temperature is not affected by its distance, by measuring the temperature and luminosity, distance is known.


B5

F5

K5

M5
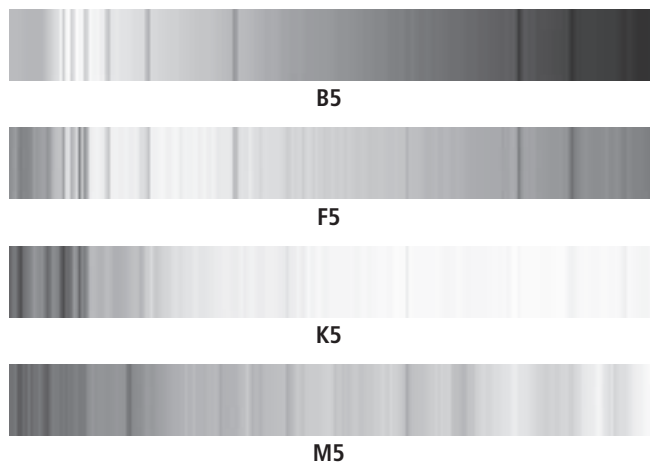
■ **Figure 29.16** These are typical absorption spectra of a class B5 star, class F5 star, class K5 star, and a class M5 star. The black stripes are absorption lines telling us each star's element composition.

MiniLab

Model Parallax

How does parallax angle change with distance? If a star is observed at six-month intervals in its orbit, it will appear to have moved because Earth is 300 million km away from the location of the first observation. The angle to the star is different and the apparent change in position of the star is called parallax.
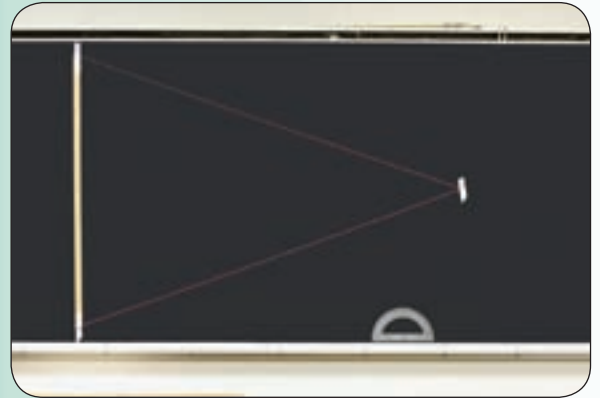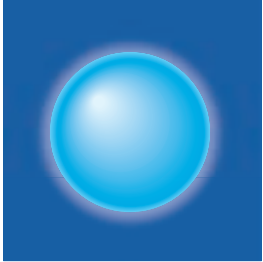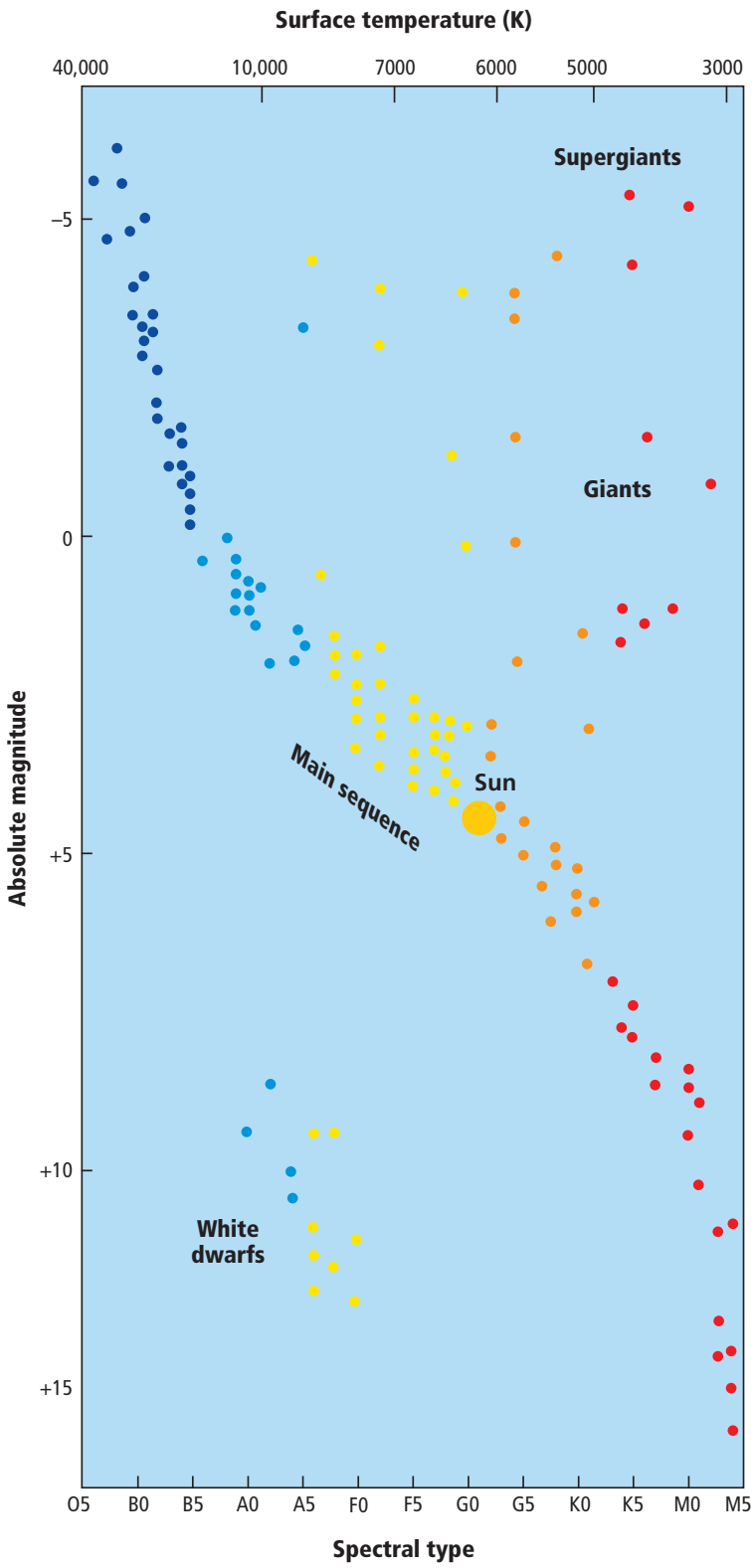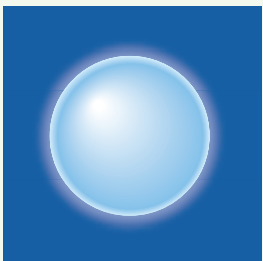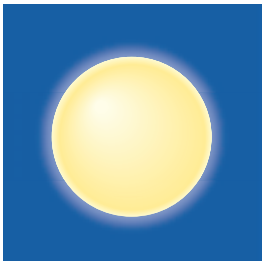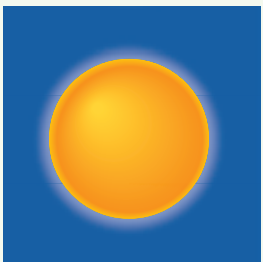

Procedure
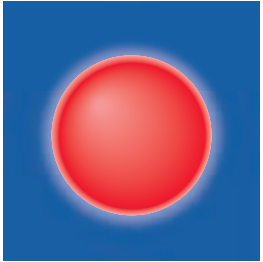
1. Read and complete the lab safety form.
2. Place a **meterstick** at a fixed position and attach a **4-m piece of string** to each end.
3. Stand away from the meterstick and hold the two strings together to form a triangle. Be sure to hold the strings taut. Measure your distance from the meterstick. Record your measurement.
4. Measure the angle between the two pieces of string with a **protractor.** Record your measurement of the angle.
5. Repeat Steps 3 and 4 for different distances from the meterstick by shortening or lengthening the string.
6. Make a graph of the angles versus their distance from the meterstick.

Analysis

1. **Interpret** what the length of the meterstick represents. What does the angle represent?
2. **Analyze** what the graph shows. How does parallax angle depend on distance?
3. **Explain** how the angles that you measured are similar to actual stellar parallax angles.

Table 29.2	Relationships of Spectral Types of Stars

Color of Star	Spectral Type	H-R diagram
	O5	
	B5	
	F5	
	G5	
	M5	

Surface temperature (K)

Supergiants

Giants

Main sequence

Sun

White dwarfs

Absolute magnitude

Spectral type

Composition All stars, including the Sun, have nearly identical compositions, despite the differences in their spectra, shown in **Table 29.2.** The differences in the appearance of their spectra are almost entirely a result of temperature differences. Hotter stars have fairly simple visible spectra, while cooler stars have spectra with more lines. The coolest stars have bands in their spectra due to molecules such as titanium oxide in their atmospheres. Typically, about 73 percent of a star's mass is hydrogen (H), about 25 percent is helium (He), and the remaining 2 percent is composed of all the other elements. While there are some variations in the composition of stars, particularly in the final 2 percent, all stars have this general composition.

H-R diagrams The properties of mass, luminosity, temperature, and diameter are closely related. Each class of star has a specific mass, luminosity, magnitude, temperature, and diameter. These relationships can be demonstrated on a graph called the **Hertzsprung-Russell diagram** (H-R diagram) on which absolute magnitude is plotted on the vertical axis and temperature or spectral type is plotted on the horizontal axis, as shown in **Table 29.2.** Spectroscopists first plotted this graph in the early twentieth century. An H-R diagram with luminosity plotted on the vertical axis looks similar to the one in **Table 29.2** and is used to calculate the evolution of stars.

Most stars occupy the region in the diagram called the **main sequence,** which runs diagonally from the upper-left corner, where hot, luminous stars are represented, to the lower-right corner, where cool, dim stars are represented. **Table 29.3** shows some properties of main-sequence stars.

Concepts in Motion

Interactive Table To explore more about main-sequence star properties, visit **glencoe.com**.

Table 29.3	Properties of Main-Sequence Stars			
Spectral Type	Mass*	Surface Temperature (K)	Luminosity*	Radius*
O5	40.0	40,000	5×10^5	18.0
B5	6.5	15,500	800	3.8
A5	2.1	8500	20	1.7
F5	1.3	6580	2.5	1.2
G5	0.9	5520	0.8	0.9
K5	0.7	4130	0.2	0.7
M5	0.2	2800	0.008	0.3

* These properties are relative to the Sun.

Main sequence About 90 percent of stars, including the Sun, fall along a broad strip of the H-R diagram called the main sequence. While stars are in the main sequence, they are fusing hydrogen in their cores. The interrelatedness of the properties of these stars indicates that all these stars have similar internal structures and functions. As stars evolve off the main sequence, they begin to fuse helium in their cores and burn hydrogen around the core edges.

The Sun lies near the center of the main sequence, being of average temperature and luminosity. A star's mass determines almost all its other properties, including its main-sequence lifetime. The more massive a star is, the higher its central temperature and the more rapidly it burns its hydrogen fuel. This is due primarily to the ratio of radiation pressure to gravitational pressure. Higher pressures cause the fuels to burn faster. As a consequence, the star runs out of hydrogen faster than a lower-mass star.

Red giants and white dwarfs The stars plotted at the upper right of the H-R diagram in **Table 29.2** are cool, yet luminous. Because cool surfaces emit much less radiation per square meter than hot surfaces do, these cool stars must have large surface areas to be so bright. For this reason, these larger, cool, luminous stars are called red giants. Red giants are so large—more than 100 times the size of the Sun in some cases—that Earth would be swallowed up if the Sun were to become a red giant! Conversely, the dim, hot stars plotted in the lower-left corner of the H-R diagram must be small, or they would be more luminous. These small, dim, hot stars are called white dwarfs. A white dwarf is about the size of Earth but has a mass about as large as the Sun's. You will learn how all the different stars are formed in Section 29.3.

Section 29.2 Assessment

Section Summary

▶ Stars exist in clusters held together by their gravity.

▶ The simplest cluster is a binary.

▶ Parallax is used to measure distances to stars.

▶ The brightness of stars is related to their temperature.

▶ Stars are classified by their spectra.

▶ The H-R diagram relates the basic properties of stars: class, temperature, and luminosity.

Understand Main Ideas

1. **MAIN Idea** **Relate** the stellar temperature to the classification of a star.

2. **Explain** the difference between apparent and absolute magnitudes.

3. **Explain** how parallax is used to measure the distance to stars.

4. **Compare and contrast** luminosity and magnitude.

5. **Contrast** the apparent magnitude and the absolute magnitude of a star.

6. **Compare** a light-year and a parsec.

Think Critically

7. **Design** a model to explain parallax.

8. **Explain** the relationship between radius and mass using **Table 29.3**.

MATH in Earth Science

9. Compare Orion's brightest stars, Rigel (O class) and Betelguise (M class), by mass, temperature, luminosity, and radius, using **Table 29.3** as a reference.

Earth Science Online **Self-Check Quiz** glencoe.com

Review Vocabulary

evolution: a radical change in composition over a star's lifetime

New Vocabulary

nebula
protostar
neutron star
pulsar
supernova
black hole

Stellar Evolution

MAIN ‹Idea The Sun and other stars follow similar life cycles, leaving the galaxy enriched with heavy elements.

Real-World Reading Link A campfire glows brightly as long as it has fuel to burn. When the fuel is depleted, the light becomes dimmer, and the fire extinguishes. Unlike a campfire, stars shine because of nuclear reactions in their interior. Stars also die out when their nuclear fuel is gone.
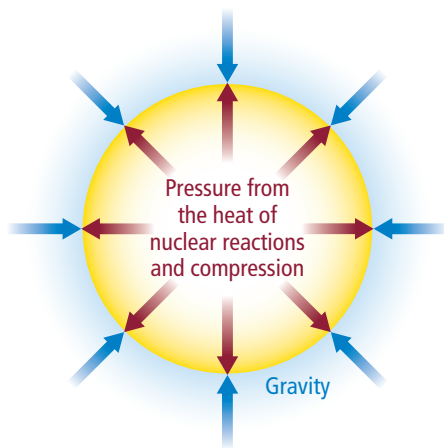
Basic Structure of Stars

Mass governs a star's temperature, luminosity, and diameter. In fact, astronomers have discovered that the mass and the composition of a star determine nearly all its other properties.

Mass effects The more massive a star is, the greater the gravity pressing inward, and the hotter and more dense the star must be inside to balance its own gravity. The temperature inside a star governs the rate of nuclear reactions, which in turn determines the star's energy output—its luminosity. The balance between gravity squeezing inward and outward pressure is maintained by heat due to nuclear reactions and compression. This balance is called hydrostatic equilibrium and it must hold for any stable star, as illustrated in **Figure 29.17,** otherwise the star would expand or contract. This balance is governed by the mass of a star.

Fusion Inside a star, conditions vary in much the same way that they do inside the Sun. The density and temperature increase toward the center, where energy is generated by nuclear fusion. Stars on the main sequence produce energy by fusing hydrogen into helium, as the Sun does. Stars that are not on the main sequence either fuse elements other than hydrogen in their cores or do not undergo fusion at all.

Pressure from the heat of nuclear reactions and compression

Gravity

■ **Figure 29.17** When the pressure from radiation and fusion is balanced by gravity, a star is stable and will not expand or contract.

Stellar Evolution

A star changes as it ages because its internal composition changes as nuclear-fusion reactions in the star's core convert one element into another. With a change in the core composition, the star's density increases, its temperature rises, and its luminosity increases. As long as the star is stable and converting hydrogen to helium, it is considered a main-sequence star. Eventually, when the nuclear fuel runs out, the star's internal structure and mechanism for producing pressure must change to counteract gravity. The changes a star undergoes during its evolution begin with its formation.
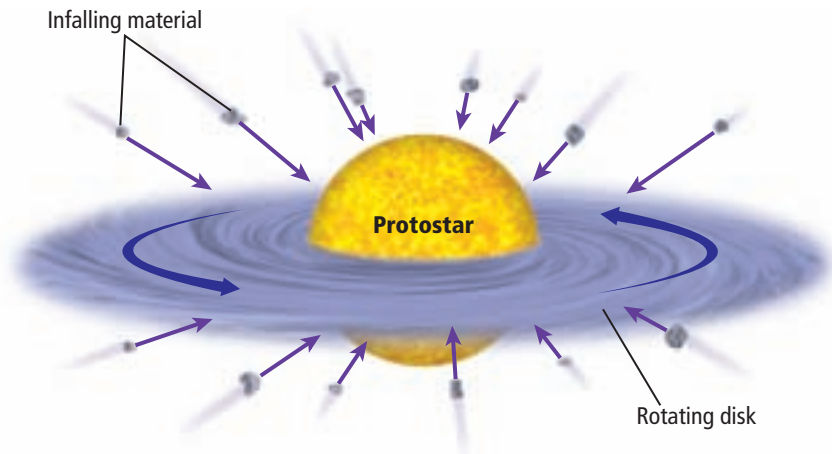
■ **Figure 29.18** Temperatures will continue to build as gravity pulls the infalling matter to the center of the rotating disk. The center region is a protostar until fusion initiates and a star ignites.

Infer *what happens to the remaining material in the disk.*

Concepts **in M**O**tion**

Interactive Figure To see an animation of star formation, visit **glencoe.com**.

Star formation All stars form in much the same manner as the Sun did. The formation of a star begins with a cloud of interstellar gas and dust, called a **nebula** (plural, nebulae), which collapses on itself as a result of its own gravity. As the cloud contracts, its rotation forces it into a disk shape with a hot, condensed object at the center, called a **protostar,** as illustrated in **Figure 29.18.** Friction from gravity continues to increase the temperature of the protostar, until the condensed object reaches the ignition temperature for nuclear reactions and becomes a new star. A protostar is brightest at infrared wavelengths.

✔ **Reading Check** **Infer** what causes the disk shape to form.

Fusion begins When the temperature inside a protostar becomes hot enough, nuclear fusion reactions begin. The first reaction to ignite is always the conversion of hydrogen to helium. Once this reaction begins, the star becomes stable because it then has sufficient internal heat to produce the pressure needed to balance gravity. The object is then truly a star and takes its place on the main sequence according to its mass. A new star often illuminates the gas and dust surrounding it, as shown in **Figure 29.19.**

Life Cycles of Stars Like the Sun

What happens next during a star's life cycle depends on its mass. For example, as a star like the Sun converts hydrogen into helium in its core, it gradually becomes more luminous because the core density and temperature rise slowly and increase the reaction rate. It takes about 10 billion years for a star with the mass of the Sun to convert all of the hydrogen in its core into helium. Thus, such a star has a main-sequence lifetime of 10 billion years. From here, the next step in the life cycle of a small mass star is to become a red giant.

■ **Figure 29.19** Using the Spitzer telescope's infrared wavelengths, protostars are imaged inside the Elephant Trunk nebula.

NASA/Photo Researchers

Red giant Only about the innermost 10 percent of a star's mass can undergo nuclear reactions because temperatures outside of this core never become hot enough for reactions to occur. Thus, when the hydrogen in its core is gone, a star has a helium center and outer layers made of hydrogen-dominated gas. Some hydrogen continues to react in a thin layer at the outer edge of the helium core, as illustrated in **Figure 29.20.** The energy produced in this layer forces the outer layers of the star to expand and cool. The star then becomes a red giant because its luminosity increases while its surface temperature decreases due to the expansion.

While the star is a red giant, it loses gas from its outer layers. The star is so large that its surface gravity is low, and thus the outer layers can be released by small expansions and contractions, or pulsations, of the star due to instability. Meanwhile, the core of the star becomes hot enough, at 100 million K, for helium to react and form carbon. The star contracts back to a more normal size, where it again becomes stable for awhile. The helium-reaction phase lasts only about one-tenth as long as the earlier hydrogen-burning phase. Afterward, when the helium in the core is depleted, the star is left with a core made of carbon.

The final stages A star with the same mass as the Sun never becomes hot enough for carbon to fuse, so its energy production ends. The outer layers expand again and are expelled by pulsations that develop in the outer layers. This shell of gas is called a planetary nebula. In the center of a planetary nebula, shown in **Figure 29.21,** the core of the star becomes exposed as a small, hot object about the size of Earth. The star is then a white dwarf made of carbon.

Internal pressure in white dwarfs A white dwarf is stable despite its lack of nuclear reactions because it is supported by the resistance of electrons being squeezed together, and does not require a source of heat to be maintained. This pressure counteracts gravity and can support the core as long as the mass of the remaining core is less than about 1.4 times the mass of the Sun. The main-sequence lifetime of such a star is much longer, however, because low-mass stars are dim and do not deplete their nuclear fuel rapidly.

Life Cycles of Massive Stars

For stars more massive than the Sun, evolution is different. A more massive star begins its life in the same way, with hydrogen being converted to helium, but it is much higher on the main sequence. The star's lifetime in this phase is short because the star is very luminous and uses up its fuel quickly. The electron pressure does not require ongoing reactions, so it can last indefinitely. The white dwarf gradually cools, eventually losing its luminosity and becoming an undetectable black dwarf.

Helium core

Hydrogen fusing in a shell
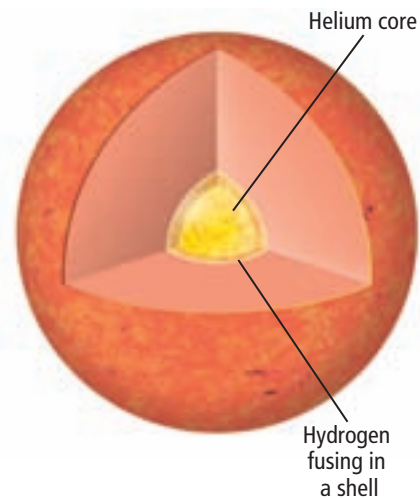
■ **Figure 29.20** In a red giant's central region, helium is converted to carbon. In the spherical shell just outside, hydrogen continues to be converted to helium. The low temperature of the outer atmosphere due to expansion and cooling causes the red color.

Concepts In Motion

Interactive Figure To see an animation of the helium core, visit **glencoe.com**.

■ **Figure 29.21** The star at the center of the Eskimo nebula, now a white dwarf, was the source of the remnant gases surrounding it.

■ Figure 29.22 A massive star can have many shells fusing different elements. These stars are the source of heavier elements in the universe.

Inside the figure:
H → He
He → C, O
C → Ne, Mg
Ne → O, Mg
O → Si, S
Si → Fe, Ni
Fe/Ni

Core
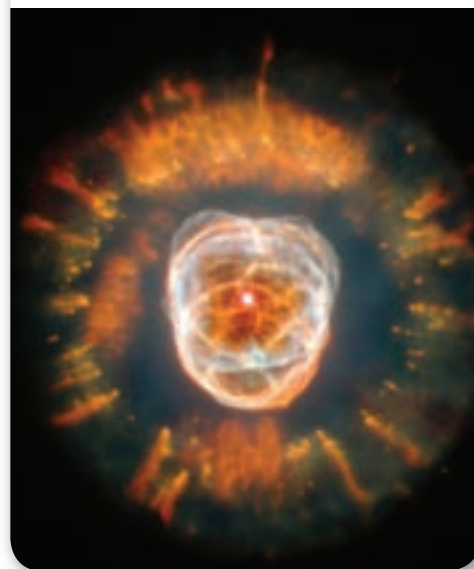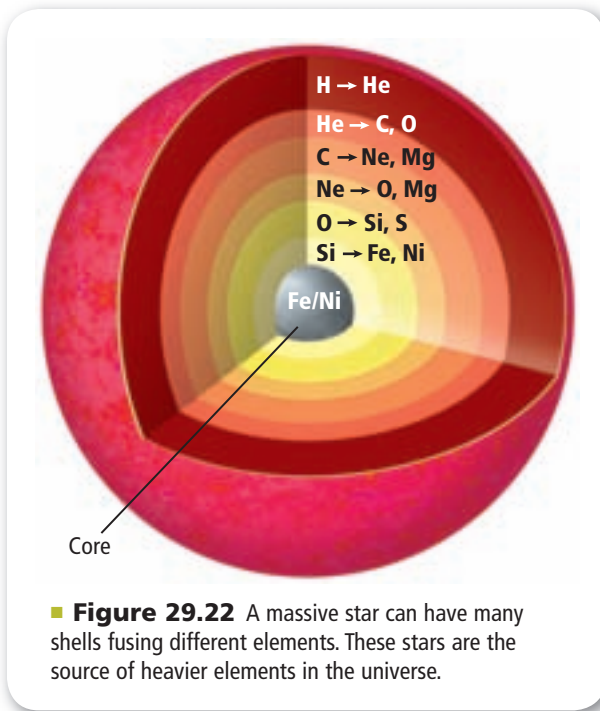
Supergiant A massive star undergoes many more reaction phases and thus produces a rich stew of many elements in its interior. The star becomes a red giant several times as it expands following the end of each reaction stage. As more shells are formed by the fusion of different elements, illustrated in **Figure 29.22,** the star expands to a larger size and becomes a supergiant, such as Betelgeuse in the Orion constellation.

Supernova formation A star that begins with a mass between about 8 and 20 times the Sun's mass will end up with a core that is too massive to be supported by electron pressure. Such a star comes to a violent end. Once reactions in the core of the star have created iron, no further energy-producing reactions can occur, and the core of the star violently collapses in on itself, as illustrated in **Figure 29.23.** Protons and electrons in the core merge to form neutrons. Like electrons, a neu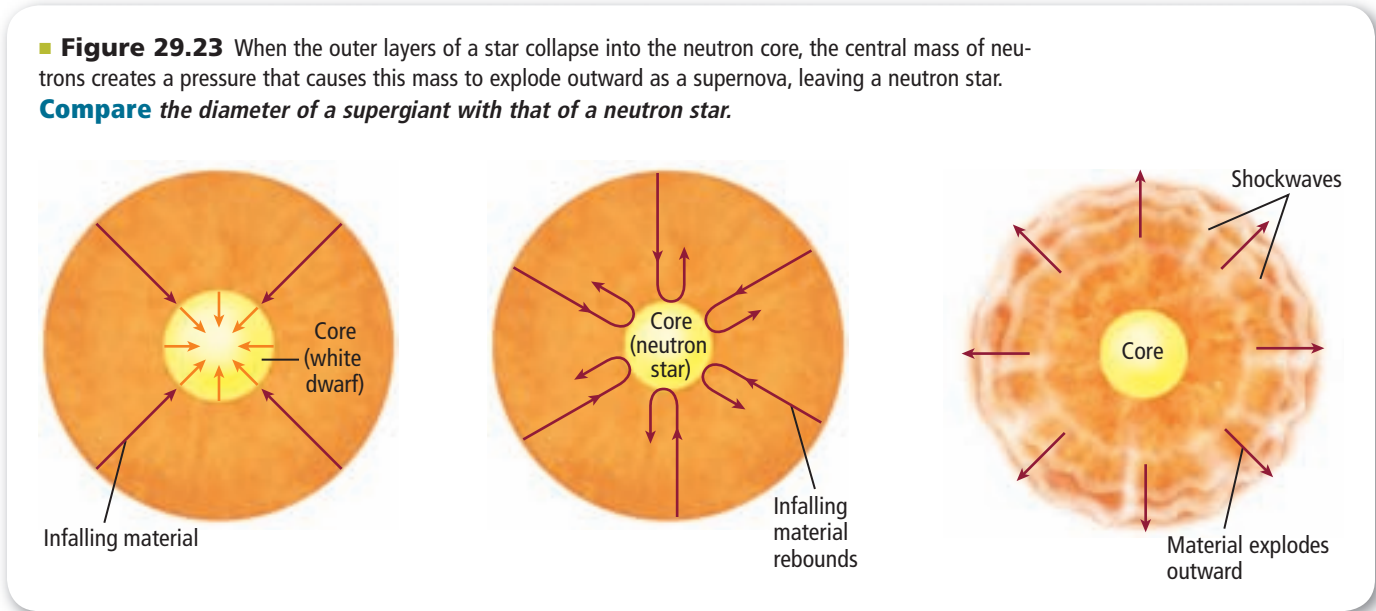tron's resistance to being squeezed close together creates a pressure that halts the collapse of the core, and the core becomes a collapsed star remnant—a **neutron star.** A neutron star has a mass of 1.5 to 3 times the Sun's mass but a radius of only about 10 km. Its density is extremely high—about 100 trillion times the density of water—and is comparable to that of an atomic nucleus.

Pulsar Some neutron stars are unique in that they have a pulsating pattern of light. The magnetic fields of these stars focus the light they emit into cones. Then as these stars rotate on their axes, the light from each spinning neutron star is observed as a series of pulses of light, as each of the cones sweeps out a path in Earth's direction. This pulsating star is known as a **pulsar.**

■ Figure 29.23 When the outer layers of a star collapse into the neutron core, the central mass of neutrons creates a pressure that causes this mass to explode outward as a supernova, leaving a neutron star.
Compare *the diameter of a supergiant with that of a neutron star.*

Core (white dwarf)

Infalling material

Core (neutron star)

Infalling material rebounds

Shockwaves

Core

Material explodes outward

Supernova A neutron star forms quickly while the outer layers of the star are still falling inward. This infalling gas rebounds when it strikes the hard surface of the neutron star and explodes outward. The entire outer portion of the star is blown off in a massive explosion called a **supernova** (plural, supernovae). This explosion creates elements that are heavier than iron and enriches the universe. **Figure 29.24** shows photos of before and during a supernova explosion. A distant supernova explosion might be brighter than the galaxy in which it is found.

Black holes Some stars are too massive to form neutron stars. The pressure from the resistance of neutrons being squeezed together cannot support the core of a star if the star's mass is greater than about three times the mass of the Sun. A star that begins with more than 20 times the Sun's mass will end up above this mass limit, and it cannot form a neutron star. The resistance of neutrons to being squeezed is not great enough to stop the collapse and the core of the star continues to collapse, compacting matter into a smaller volume. The small, extremely dense object that remains is called a **black hole** because its gravity is so immense that nothing, not even light, can escape it. Astronomers cannot observe what goes on inside a black hole, but they can observe the X-ray-emitting gas that spirals into it.

Before supernova

During supernova

■ **Figure 29.24** The region of sky in the Large Magellanic Cloud seemed ordinary before one of its stars underwent a supernova explosion.

Section 29.3 Assessment

Section Summary

▶ The mass of a star determines its internal structure and its other properties.

▶ Gravity and pressure balance each other in a star.

▶ If the temperature in the core of a star becomes high enough, elements heavier than hydrogen can fuse together.

▶ A supernova occurs when the outer layers of the star bounce off the neutron star core, and explode outward.

Understand Main Ideas

1. **MAIN Idea** **Explain** how mass determines a star's evolution.

2. **Infer** how the diameter of a star is determined by mass.

3. **Determine** how the lifetimes of stars depend on their masses.

4. **Determine** why only the most massive stars are important contributors in enriching the galaxy with heavy elements.

Think Critically

5. **Explain** how the universe would be different if massive stars did not explode at the end of their lives.

6. **Distinguish** whether there is a balance between pressure and gravity in main-sequence stars, white dwarfs, neutron stars, and black holes.

WRITING in Earth Science

7. Write a description of an observation of a supernova in another galaxy.

EARTH SCIENCE AND TECHNOLOGY

SPACE WEATHER AND EARTH SYSTEMS

Powerful hurricanes and tornadoes can cause millions of dollars worth of damage to homes and other structures. These types of strong storms can be responsible for loss of human life and the disruption of major electrical and communication systems in an area. There are also weather conditions in space. What effects do solar storms have on Earth?

Space weather Solar flares and coronal mass ejections create powerful solar storms that release billions of high-energy particles into space that travel at speeds of up to 2000 km/s. Some of these particles slam into Earth's magnetosphere—over which particles from space normally flow—much like water flows around a large rock in the middle of a river. Earth's magnetosphere normally deflects particles from the Sun, but during intense solar storms, highly charged particles cause disruptions in many of Earth's communication and electrical systems.

Monitoring space weather Two U.S. government agencies, NASA and NOAA, monitor and provide daily updates on space weather, including predictions about solar flare and solar storm occurrences. Power companies, the Federal Aviation Administration, and the U.S. Department of Defense use the data to help minimize the damage to sensitive equipment caused by solar storms.

Communication Communication satellites, locating systems, and military signals rely on radio waves that are bounced off Earth's ionosphere. The ionosphere is a layer of highly charged particles which is especially vulnerable to highly energized particles from the Sun.
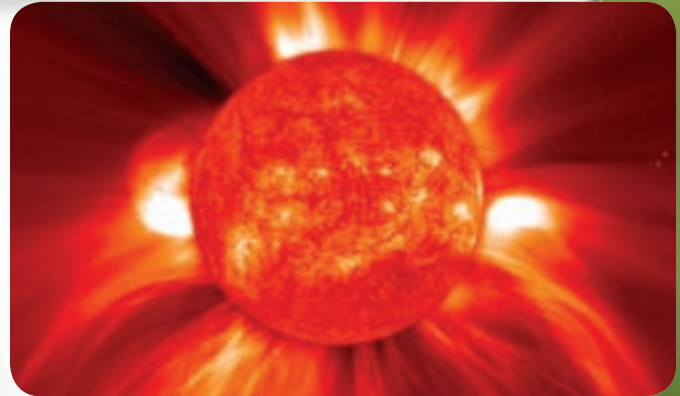
SOHO (ESA & NASA)

A widespread coronal mass ejection blasts more than a billion tons of matter into space at millions of kilometers per hour. Fortunately one this large is rare.

These high-energy particles can interfere with radio signals and disrupt transmissions.

Satellites Solar storms can cause satellites to fall out of orbit due to temperature and density changes in Earth's upper atmosphere. They must be moved to higher orbits in response to this phenomenon. Communication satellites can also be knocked out by electric particle buildup as well.

Electricity Power companies routinely receive information about possible solar storms in order to avoid service disruption to customers. Solar storms can knock out power by inducing currents in electrical lines. In 1989, in Quebec, Canada, a solar storm caused a nine-hour blackout that affected 6 million people and cost the power company over 10 million dollars in repairs.

WRITING in Earth Science

Pamphlet Research more information about space weather and create a pamphlet that answers frequently asked questions about it. Include information about the causes and why it is important to monitor space weather. To learn more about space weather, visit glencoe.com.

GEOLAB

IDENTIFY STELLAR SPECTRAL LINES

Background: An astronomer studying a star or other type of celestial object often starts by identifying the lines in the object's spectrum. The identity of the spectral lines gives information about the chemical composition of the distant object, along with data on its temperature and other properties.

Question: *How can you identify stellar spectral lines based on two previously identified lines?*

Materials
ruler

Procedure
1. Read and complete the lab safety form.
2. Find the difference between the two labeled spectral line values on Star 1.
3. Accurately measure the distance between the two labeled spectral lines.
4. Set up a conversion scale by dividing the spectral difference by the measured distance.
   For example: 1 mm = 12 nm
5. Measure the distance from one of the labeled spectral lines to each of the unlabeled spectral lines.
6. Convert these distances to nm. Add or subtract your value to the original spectral line value. If the labeled line is to the right of the line measured, then subtract. Otherwise, add. This is the value of the wavelength.

| Possible Elements and Wavelengths	
Element/Ion	**Wavelength (nm)**
H	383.5, 388.9, 397.0, 410.2, 434.1, 486.1, 656.3
He	402.6, 447.1, 492.2, 587.6, 686.7
He$^+$	420.0, 454.1, 468.6, 541.2, 656.0
Na	475.2, 498.3, 589.0, 589.6
Ca$^+$	393.4, 480.0, 530.7

7. Compare your wavelength measurements to the table of wavelengths emitted by elements, and identify the elements in the spectrum.
8. Repeat this procedure for Star 2.

Analyze and Conclude
1. **Identify** Can you see any clues in the star's spectrum about which elements are most common in the stars? Explain.
2. **Explain** Do both stars contain the same lines for all the elements in the table?
3. **Evaluate** How do the thicker absorption lines of some elements in a star's spectrum affect the accuracy of your measurements? Is there a way to improve your measurements? Explain.

INQUIRY EXTENSION

Design Your Own Obtain spectra from various sources, such as sunlight, fluorescent, and incandescent light. Compare their emission lines to those from this lab. What elements are common to each?
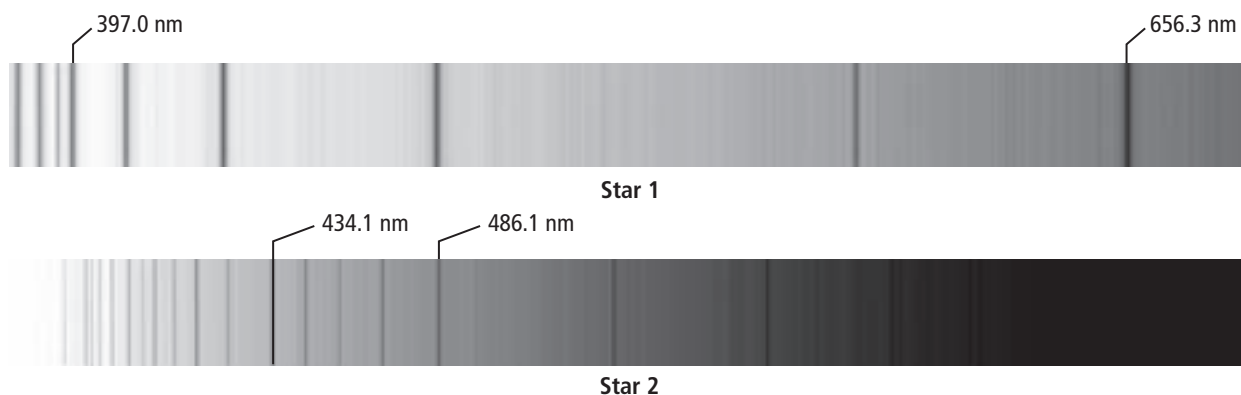
397.0 nm   656.3 nm

Star 1

434.1 nm   486.1 nm

Star 2

Study Guide

BIG Idea The life cycle of every star is determined by its mass, luminosity, magnitude, temperature, and composition.

Vocabulary	Key Concepts
Section 29.1 The Sun	
• chromosphere (p. 831) • corona (p. 831) • fission (p. 834) • fusion (p. 834) • photosphere (p. 831) • prominence (p. 833) • solar flare (p. 833) • solar wind (p. 832) • sunspot (p. 832)	**MAIN Idea** The Sun contains most of the mass of the solar system and has many features typical of other stars. • Most of the mass in the solar system is found in the Sun. • The Sun's average density is approximately equal to that of the gas giant planets. • The Sun has a layered atmosphere. • The Sun's magnetic field causes sunspots and other solar activity. • The fusion of hydrogen into helium provides the Sun's energy and composition. • The different temperatures of the Sun's outer layers produce different spectra.
Section 29.2 Measuring the Stars	
• absolute magnitude (p. 842) • apparent magnitude (p. 842) • binary star (p. 838) • constellation (p. 837) • Hertzsprung-Russell diagram (p. 845) • luminosity (p. 842) • main sequence (p. 845) • parallax (p. 841) • parsec (p. 840)	**MAIN Idea** Stellar classification is based on measurement of light spectra, temperature, and composition. • Stars exist in clusters held together by their gravity. • The simplest cluster is a binary. • Parallax is used to measure distances to stars. • The brightness of stars is related to their temperature. • Stars are classified by their spectra. • The H-R diagram relates the basic properties of stars: class, temperature, and luminosity.
Section 29.3 Stellar Evolution	
• black hole (p. 851) • nebula (p. 848) • neutron star (p. 850) • protostar (p. 848) • pulsar (p. 850) • supernova (p. 851)	**MAIN Idea** The Sun and other stars follow similar life cycles, leaving the galaxy enriched with heavy elements. • The mass of a star determines its internal structure and its other properties. • Gravity and pressure balance each other in a star. • If the temperature in the core of a star becomes high enough, elements heavier than hydrogen can fuse together. • A supernova occurs when the outer layers of the star bounce off the neutron star core, and explode outward.

Earth Science Online **Vocabulary PuzzleMaker glencoe.com**

Vocabulary Review

Match the definitions below to the correct vocabulary term on the Study Guide.

1. the top layer of the Sun's atmosphere, having a temperature of about 1 million K

2. combining of lightweight nuclei such as hydrogen into heavier nuclei

3. dark spots where the surface is cooler on the photosphere of the Sun

4. the arrangement of electromagnetic energy according to wavelengths

5. the outward flow of charged particles from the Sun's corona flowing throughout the solar system

6. two stars that are gravitationally bound and orbit a common center of mass

7. the power or energy output from the surface of a star in units per second

8. an explosion that blows away the outer portion of a star

*Distinguish between the following pairs of terms.*

9. eclipsing binary, spectroscopic binary

10. giant stars, main-sequence stars

11. apparent magnitude, absolute magnitude

12. black hole, neutron star

13. fission, fusion

Define these terms in your own words.

14. constellation

15. prominence

16. main sequence

17. nebula

18 supernova

19. black hole

20. protostar

Understand Key Concepts

Use the diagram below to answer Question 21.
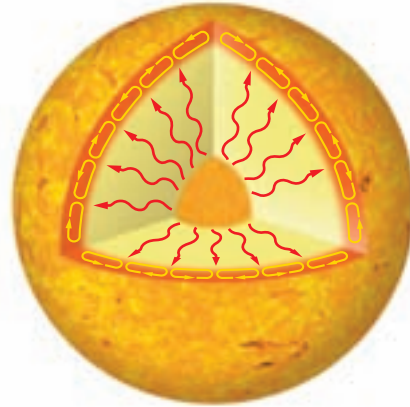
21. Starting at the center, which is the correct order of solar layers?
    A. chromosphere, corona, photosphere, solar wind
    B. photosphere, chromosphere, solar wind, corona
    C. photosphere, chromosphere, corona, solar wind
    D. solar wind, chromosphere, corona, photosphere

22. Why do sunspots appear dark?
    A. They are cooler than their surroundings.
    B. They are holes in the interior of the Sun.
    C. They do not have strong magnetic fields.
    D. They are hotter than their surroundings.

23. Why is the Sun's composition similar to that of the gas giant planets?
    A. They all formed at the same time.
    B. They both lost heavy elements.
    C. They all formed from the same interstellar cloud.
    D. They both gained heavy elements.

24. How is the Sun's magnetic behavior associated with its activity cycle?
    A. The magnetic field turns off when the activity cycle turns on.
    B. The activity cycle is coordinated with the peak number of sunspots.
    C. The activity cycle is independent of the number of solar flares.
    D. Solar flares are not coordinated with magnetic storms on Earth.

25. Which is NOT true about binary stars?
   A. They usually appear as one star.
   B. They move about a common center of mass.
   C. They are the most common stars in a galaxy.
   D. They are always of equal brightness.

*Use the diagram below to answer Question 26.*
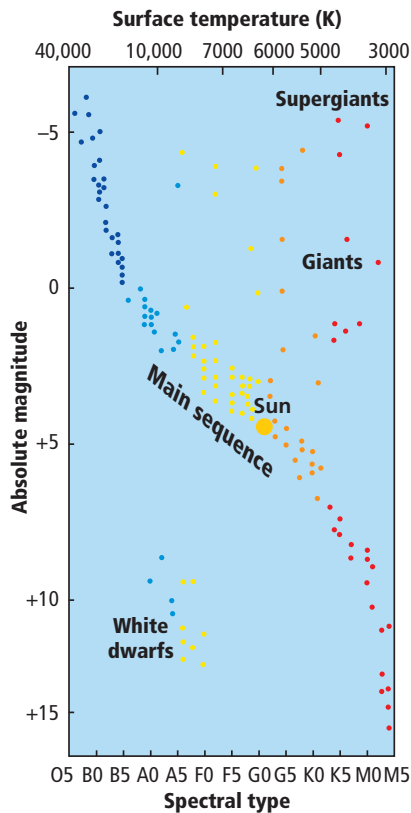
26. Which is true about the spectral classification system of stars?
   A. An A star is cooler than an M star but hotter than an F star.
   B. An O star is cooler than a B star yet hotter than an F star.
   C. A K star is hotter than both a G star and an M star.
   D. A G star is cooler than a B star and hotter than a K star.

27. Which two key stellar properties determine all the other stellar properties?
   A. radius and diameter
   B. mass and radius
   C. composition and mass
   D. diameter and composition

28. Which are in the proper time order?
   A. main-sequence star, red giant, white dwarf, planetary nebula
   B. planetary nebula, red giant, white dwarf, main-sequence star
   C. main-sequence star, white dwarf, planetary nebula, red giant
   D. planetary nebula, main-sequence star, white dwarf, red giant

Constructed Response

29. **CAREERS IN EARTH SCIENCE** Deduce what astronomers can tell about how stars of different masses evolve, by observing stars in clusters.

30. **Detail** how, if Earth's orbit were twice the diameter it is now, that would affect stellar parallax and our ability to measure distances.

31. **Explain** why we say the solar cycle lasts 22 years and not 11.

*Use the image below to answer Questions 32 and 33.*
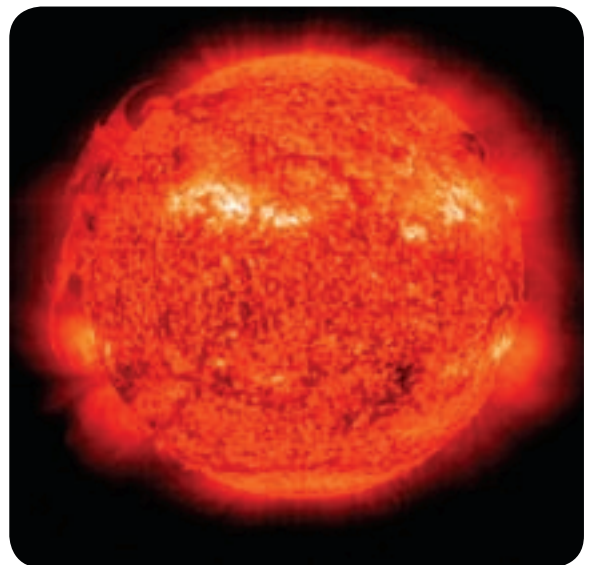
32. **Identify** the visible layers of the Sun in this photo.

33. **Identify** the light and dark areas of the Sun's surface in the photo.

34. **Explain** the relationship between the solar prominences and the Sun's magnetic field.

Chapter Test glencoe.com

Think Critically

35. **Deduce** why it is hotter at the center of the Sun than on the surface.

36. **Predict** the layering and composition of stars other than the Sun.

37. **Explain** how the density of the Sun is so great and yet is still in the gaseous state.

Use the diagram below to answer Questions 38 and 39.

January   **July**
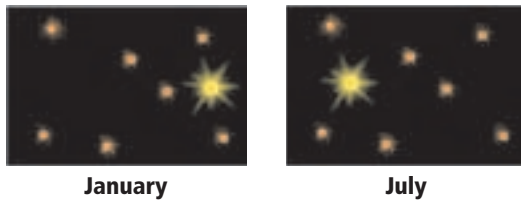
38. **Draw** the relative positions of Earth, the Sun, and the star in March and November, based upon the observation in the diagram.

39. **Infer** how parallax helps scientists determine magnitude and luminosity.

40. **Infer** why the parsec has become the standard unit for expressing distance to the stars rather than the AU or light-year.

41. **Compare** a B5 star to the Sun using the H-R diagram.

42. **Compare** a supernova, a neutron star, and a pulsar.

43. **Explain** the difference between a planetary nebula and a supernova.

Concept Mapping

44. Make a concept map linking the terms *fusion, luminosity, protostar*, and one other vocabulary term.

Challenge Question

45. **Organize** a procedure for discovering whether a star is binary.

## Additional Assessment

46. *WRITING in* **Earth Science** The person who developed the modern system of spectral classification was Annie J. Cannon. Research her work and write about her role in forging new pathways for women in science.

🄳🄱🄠 Document–Based Questions

Data obtained from: Massey, P., et al. 2002. Orbits of four very massive binaries in the R136 cluster. *The Astrophysical Journal* 565:982–993.

Binary stars rotate around one another. The radial velocity is the rate of the stars in a binary pair moving toward and away from an observer. Subtract the lowest velocity from the highest velocity for each star, and divide by two to find the average velocity.
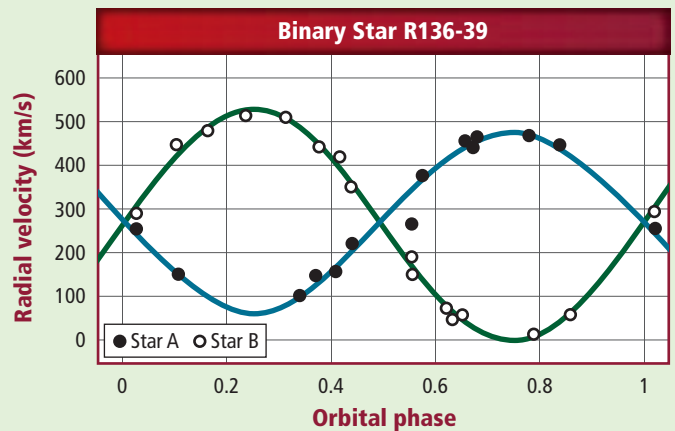
47. If the star with the larger mass has a lower average velocity, which star has the greater mass?

48. When the paths of the stars cross, there is an eclipse for the observer. At what points in the orbital phase are there eclipses?

Cumulative Review

49. Which of the mineral groups is most abundant in Earth's crust? **(Chapter 4)**

50. Briefly describe how air masses form. **(Chapter 12)**

51. What structures are formed by magmas that intrude the crust but do not erupt at the surface? **(Chapter 18)**

52. What makes an interstellar cloud collapse to start the star-formation process? **(Chapter 28)**

Standardized Test Practice

Multiple Choice

1. In December, the south pole is tilted closer to the Sun than at any other time of the year, and the north pole is tilted its farthest from the Sun. What is the northern hemisphere experiencing at that time?
  A. the winter solstice
  B. the summer solstice
 C. the vernal equinox
  D. the autumnal equinox

Use the diagram below to answer Questions 2 and 3.
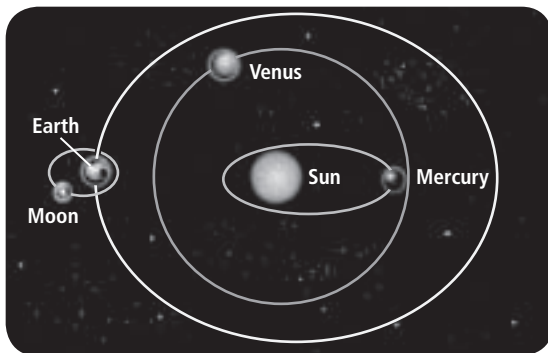
2. Which planet is located at aphelion in its orbit?
  A. Mercury
  B. Venus
  C. Earth
  D. the Sun

3. Which orbit shown has an eccentricity that is closest to 0?
  A. Mercury
  B. Venus
  C. Earth
  D. the Moon

4. A bed of sedimentary rock is formed by sediments that were deposited at a rate of 1 cm/year. If the bed is 350 m thick, how long did it take for the whole bed to be deposited?
  A. 350 years
  B. 3500 years
  C. 35,000 years
  D. 350,000 years

5. Which gas giant is the largest?
  A. Jupiter   C. Uranus
  B. Saturn   D. Neptune

6. Which energy source does not come from the Sun?
  A. wind   C. geothermal
 B. water   D. ocean

Use the graph below to answer Questions 7–9.
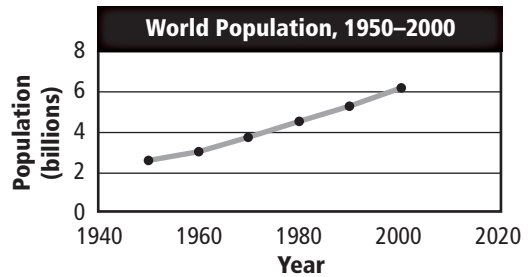
7. Which can you conclude from the graph?
  A. In 80 years, it will not be possible to feed the population.
  B. World population increases at a rate of 1 billion people every 10 years.
  C. There were approximately 2.5 billion people in the world in 1940.
  D. At the present rate of growth, the population will exceed 7 billion before 2020.

8. Based on this graph, what can be assumed about the carrying capacity of the world?
  A. The world is in a state of equilibrium.
  B. The world has not reached its carrying capacity.
  C. The world has reached its carrying capacity.
  D. The world has exceeded its carrying capacity.

9. On the graph, what is the year considered?
  A. the constant
  B. the dependent variable
  C. the independent variable
  D. the variable

10. What causes sunspots on the Sun?
  A. intense magnetic fields poking through the photosphere
  B. charged particles flowing into the solar system
  C. spots on the surface of the photosphere, which are hotter than the surrounding areas
  D. areas of low density in gas of the Sun's corona

Earth Science Online   **Standardized Test Practice glencoe.com**

Short Answer

Use the illustration below to answer Questions 11–13.
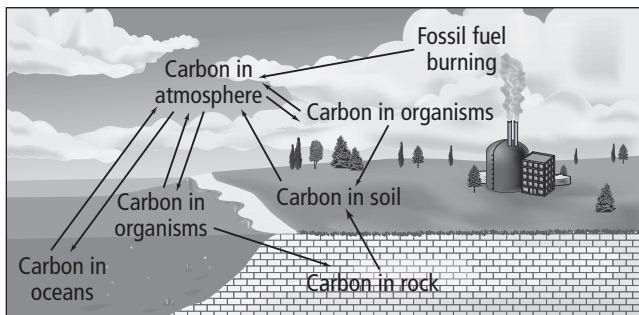
11. Describe the process shown above.

12. Why is burning fossil fuels an important part of this process?

13. Why are there two arrows between carbon in the atmosphere and carbon in organisms?

14. Describe how Earth's atmosphere would be different if there were no life on Earth.

15. Why would a minor temperature increase caused by global warming pose a threat to Earth?

16. Why is an express lane for cars with multiple passengers a good form of energy conservation?

Reading for Comprehension

The Sun's Impact on Climate

Sunspots alter the amount of energy Earth gets from the Sun, but not enough to impact global climate change, a new study suggests. The Sun's role in global warming has long been a matter of debate and is likely to remain a contentious topic.

Scientists have pondered the link between the Sun and Earth's climate since the time of Galileo. There has been an intuitive perception that the Sun's variable degree of brightness—the coming and going of sunspots for instance—might have an impact on climate. Most climate models already incorporate the effects of the Sun's waxing and waning power on Earth's weather. The number of spots cycles over time, reaching a peak every 11 years, but sunspot-driven changes to the Sun's power are too small to account for the climatic changes observed in historical data. The difference in brightness between the high point of a sunspot cycle and its low point is less than 0.1 percent of the Sun's total output.

Article obtained from: Handwerk, B. Don't blame Sun for global warming, study says. *National Geographic News.* September 13, 2006.

17. What can be inferred from this passage?
    A. Sunspots on the Sun do not affect global climate change.
    B. Sunspots greatly alter the amount of energy Earth gets from the Sun.
    C. It has long been thought that sunspots change Earth's climate.
    D. The amount of energy output from a sunspot changes drastically during its cycle.

18. Approximately how much does a sunspot cycle change the energy output of the Sun?
    A. 11 percent
    B. 1.0 percent
    C. 0.1 percent
    D. 0.01 percent

19. While a sunspot does change the amount of energy Earth gets from the Sun, why does it not impact climate?

NEED EXTRA HELP?																
If You Missed Question . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Review Section . . .	27.3	28.1	28.1	6.1	28.3	25.2	26.1	26.1	1.2	29.1	24.3	24.3	24.3	22.3	25.3	25.3