Section 29.1

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.

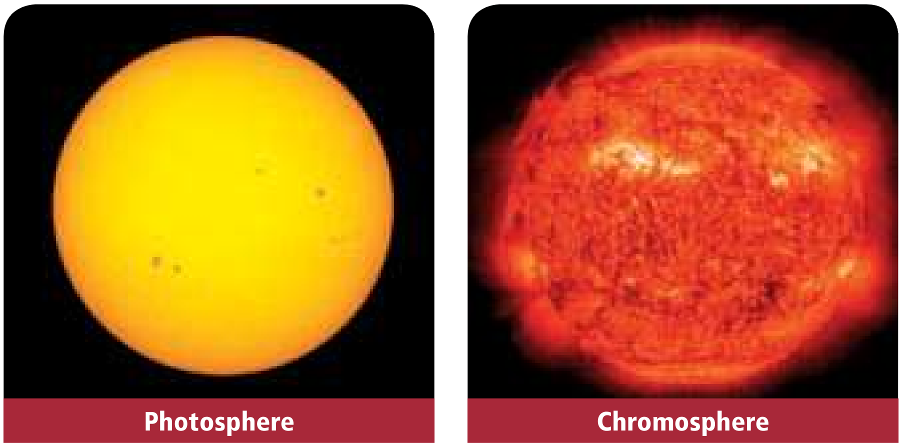
Unlike lead, which is a solid, the Sun's interior is gaseous throughout because of its high temperature—about 1×10^7 K in the center. At this temperature, all of the gases are completely ionized, meaning the interior is composed only of atomic nuclei and electrons. This state of matter is known as plasma. 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

Concepts In Motion — **Interactive Table** To explore more about the Sun, visit glencoe.com.

	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/m^3)	1.4×10^3	5.5×10^3	1.3×10^3

(tl)Kent Wood/Photo Researchers, (tc)SOHO (ESA & NASA), (br)Fred Espenak/Photo Researchers



■ **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.

■ **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.

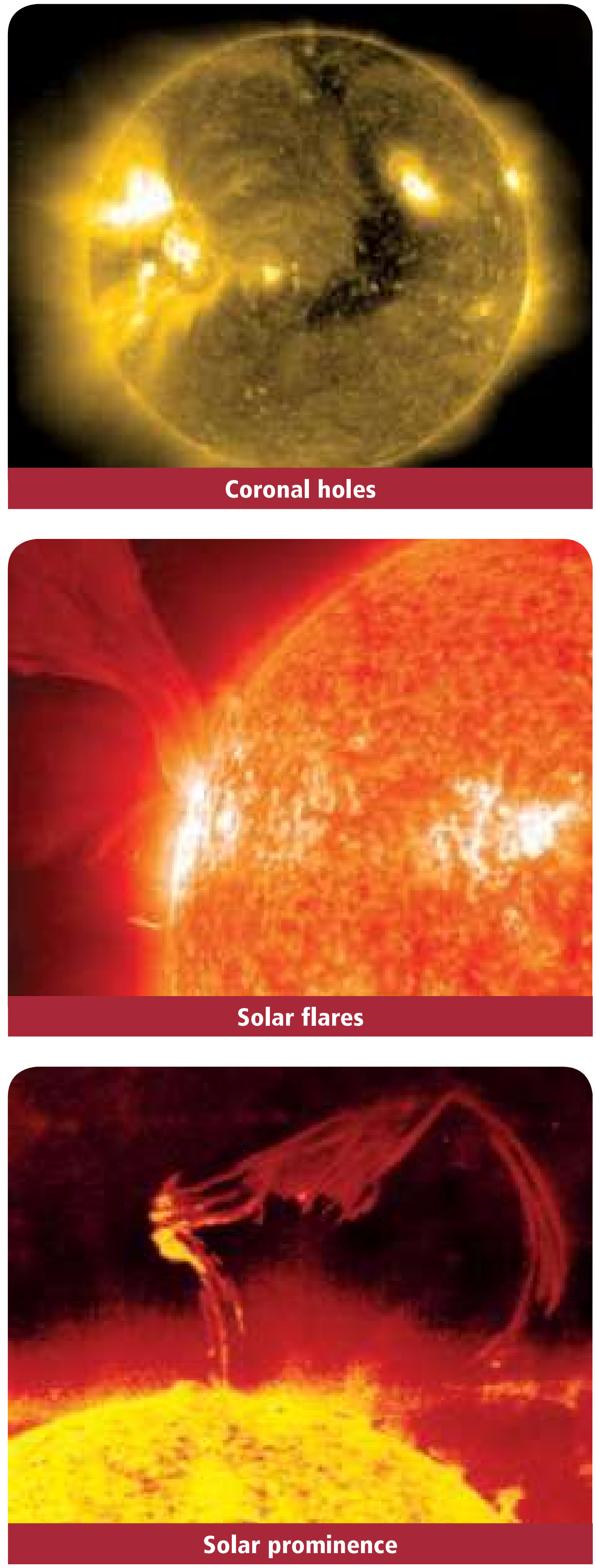
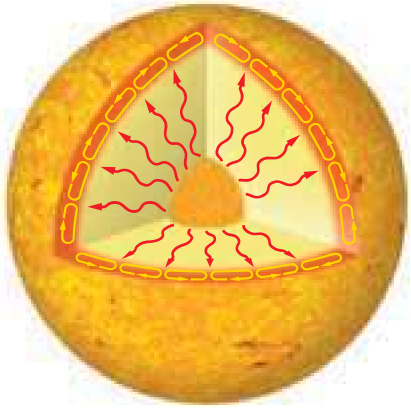


Figure 29.5 Features of the Sun's surface include coronal holes into the surface and solar flares and prominences that erupt from the surface.



■ **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.

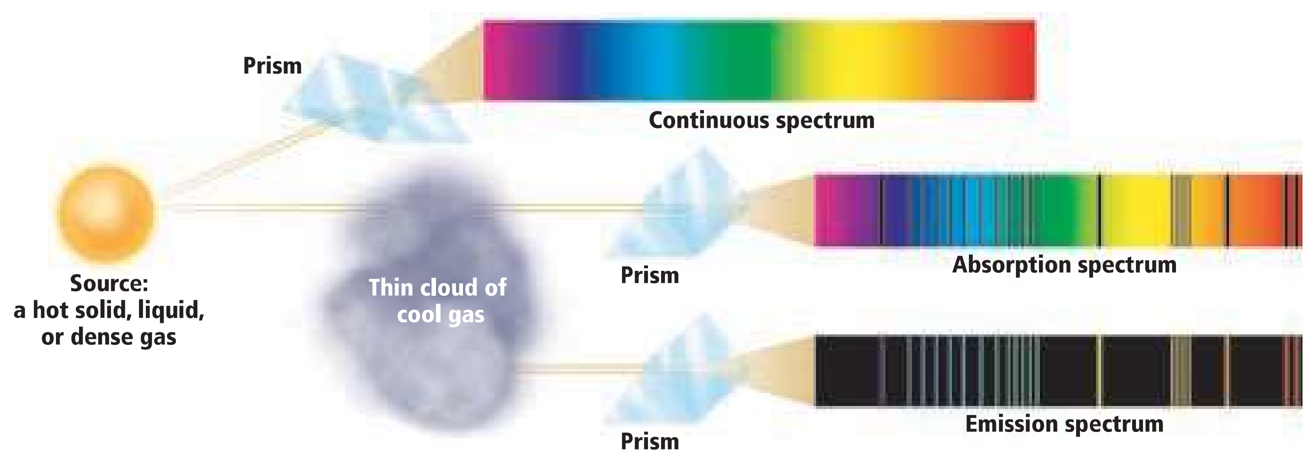
The Solar Interior

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.*



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 m^2/s (1354 W/m^2). In other words, 13 100-W lightbulbs could be operated with the solar energy that strikes a 1-m^2 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.

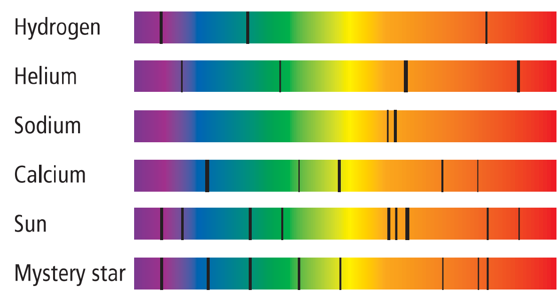
A spectrum produced from the Sun's light shows a series of dark bands. These dark spectral lines are caused by different chemical elements that absorb light at specific wavelengths. This is called an absorption spectrum, and the lines are called absorption lines. Absorption is caused by a cooler gas 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.



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.

*James B. Kaler. Professor Emeritus of Astronomy. University of Illinois. 1998.

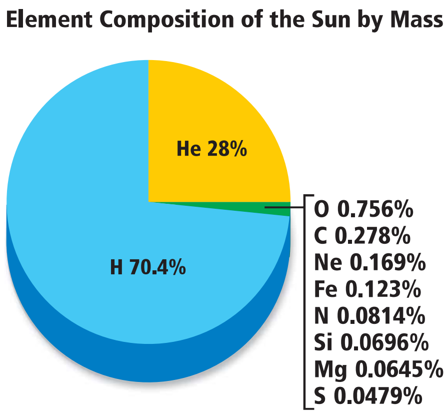


Figure 29.8 The Sun is composed primarily of hydrogen and helium with small amounts of other gases.

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