Chapter 29 The Sun

Chapter Outline

Why It Matters

The sun provides Earth with more than just heat. All living things on Earth depend, either directly or indirectly, on the sun as a source of energy to permit and sustain life processes.

Inquiry Lab

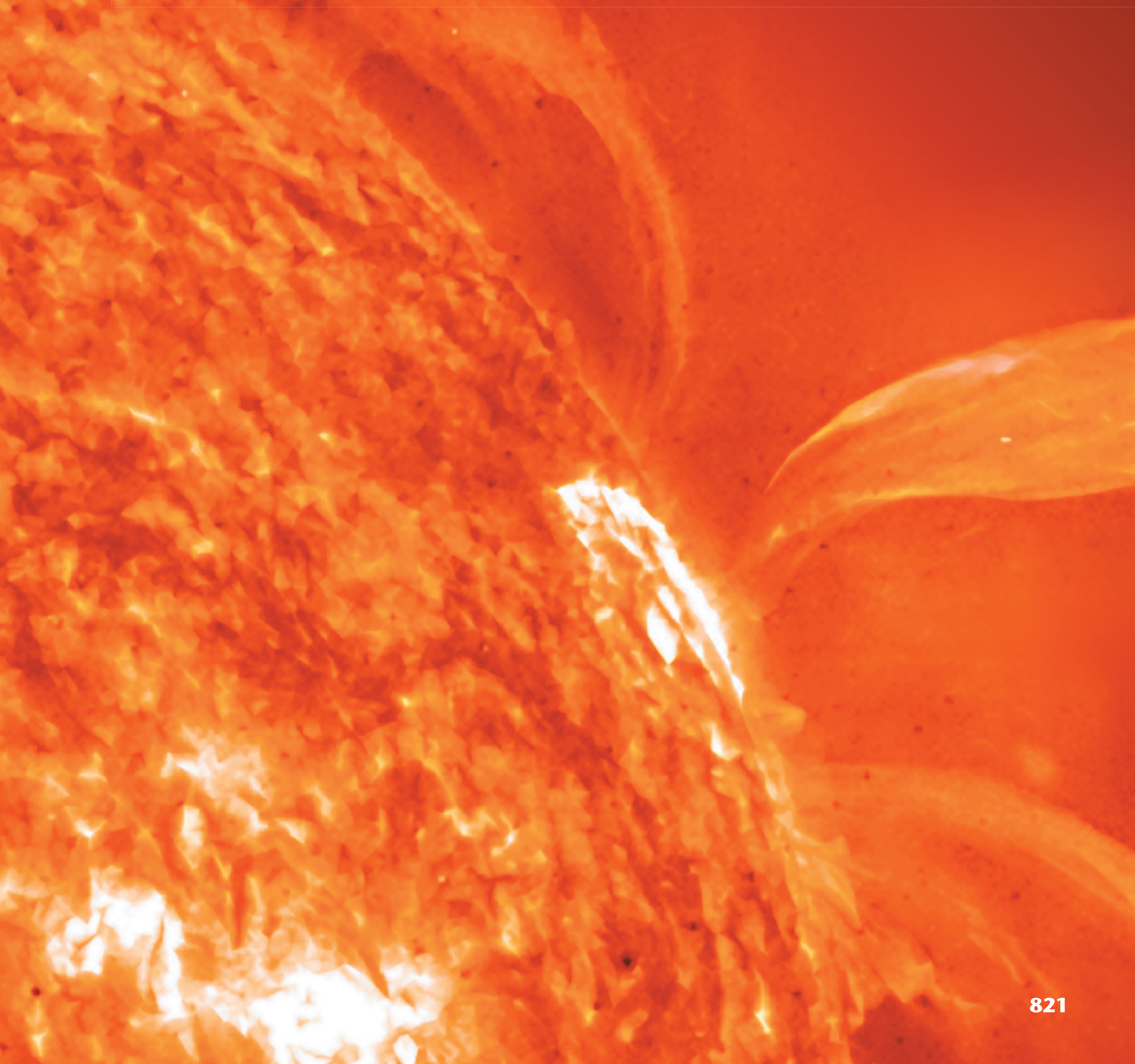
Making a Spectrum

15 min

Fill a **shallow dish** or basin about halfway with **water**. Lean a **flat mirror** against one side of the dish so that the mirror is on an angle. Make sure that part of the mirror is submerged in the water. Darken the classroom, and shine a **flashlight** at the mirror. Observe the reflected image. What do you see?

Questions to Get You Started

1. Why do you see colors even though you started with white light?
2. What would you see if you placed a red filter over the flashlight?



READING TOOLBOX

These reading tools will help you learn the material in this chapter.

Word Parts

Suffixes The suffix *-ive* changes nouns and verbs to adjectives and adds the meaning "relating or tending to." For example, *supportive* is an adjective formed from the noun *support*. It means "tending to give support." The suffix *-tion* changes verbs to nouns, or nouns to other nouns, and adds the meaning "the act or state of." For example, *connection* is a noun formed from the verb *connect*. It means "the state of joining."

Your Turn Make a table like the one below. In Section 1, there are two key terms with the suffix *-ive* and an italicized word with the suffix *-tion*. Add them to your table, along with other *-ive* or *-tion* words.

Word	Suffix	Related noun or verb	Definition of word
reaction	-tion	react	a response to something

Generalizations

Signal Words Generalizations are statements applied to a large group of things. Generalizations may be signaled by words such as *commonly, usually, normally,* or *generally*. Sometimes they are signaled by words such as *most, mostly,* and *much,* and by phrases such as *in general* and *for the most part*. Many generalizations, however, are not signaled by a word or phrase.

Your Turn As you read Section 2, look for sentences that are generalizations. Make a table like the one below to list the generalizations that you find.

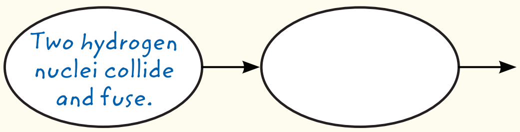
Sentence	Word or phrase that signals generalization	Why sentence is a generalization
Many other solar activities are affected by the sunspot cycle.	many	The statement applies to many, but not all, solar activities.

Graphic Organizers

Chain-of-Events Chart A chain-of-events chart shows the order in which steps occur.

Your Turn As you read Section 1, complete the chain-of-events chart that outlines each step in the process of nuclear fusion.

1. The first step in the process is written in the first box.
2. The second step in the process is written in the second box, and an arrow shows the order of the first and second steps.
3. Continue adding boxes and arrows until the process of nuclear fusion is complete.



For more information on how to use these and other tools, see **Appendix A.**

SECTION 1 Structure of the Sun

Key Ideas	Key Terms	Why It Matters
❯ Explain how the sun converts matter into energy in its core. ❯ Compare the radiative and convective zones of the sun. ❯ Describe the three layers of the sun's atmosphere.	**nuclear fusion** **radiative zone** **convective zone** **photosphere** **chromosphere** **corona**	Scientists hope that their research will one day result in the technology to create safe, controlled nuclear fusion reactions on Earth, which could then be used as a source of plentiful, reliable energy.

Throughout much of human history, people thought that the sun's energy came from fire. People knew that burning a piece of coal or wood produced energy as heat and light. They assumed that the sun, too, burned some type of fuel to produce its energy. But less than 100 years ago, scientists discovered that the source of the sun's energy is quite different from fire.

The Sun's Energy

The sun appears to the unaided eye as a dazzling, brilliant ball that has no distinct features. Because the sun's brightness can damage your eyes if you look directly at the sun, astronomers look at the sun only through special filters. Astronomers often use other specialized scientific instruments to study the sun.

Composition of the Sun

Scientists break up the sun's light into a spectrum by using a device called a *spectrograph*. Dark lines form in the spectra of stars when gases in the stars' outer layers absorb specific wavelengths of the light that passes through the layers. Because each element produces a unique pattern of spectral lines, astronomers can match the spectral lines of starlight to those of Earth's elements, as shown in **Figure 1**, and identify the elements in the star's atmosphere.

About 75% of the sun's mass is hydrogen, and hydrogen and helium together make up about 99% of the sun's mass. The sun's spectrum reveals, however, that the sun contains traces of almost all other chemical elements.

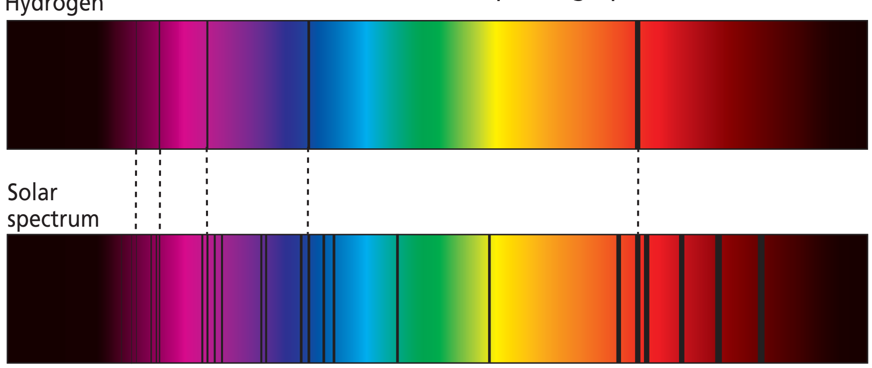


Figure 1 When light passes through hydrogen gas and then through a slit in a prism, dark lines appear in the spectrum. Hydrogen and lines from other elements in the solar spectrum are shown in the bottom spectrograph.

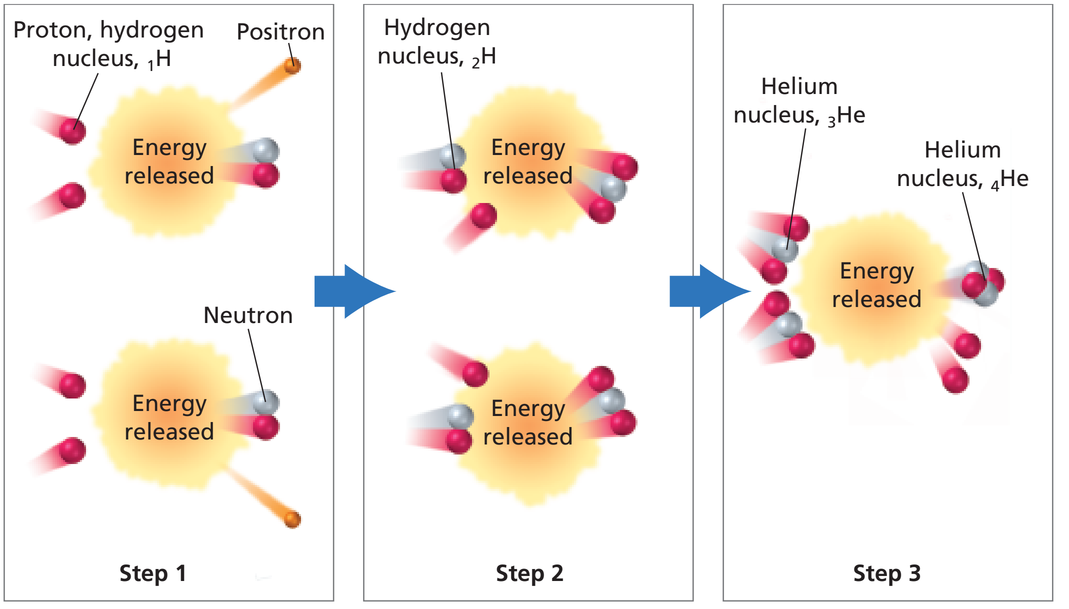


Figure 2 In the core of the sun, the nuclei of hydrogen atoms fuse to form helium. The fusion process converts some of the mass into energy.

THINK central
INTERACT ONLINE
Keyword: HQXSUNF2

nuclear fusion the process by which nuclei of small atoms combine to form a new, more massive nucleus; the process releases energy

Nuclear Fusion

A powerful atomic process known as nuclear fusion occurs inside the sun. **Nuclear fusion** is the process of combining nuclei of small atoms to form more-massive nuclei. Fusion releases huge amounts of energy. Nuclei of hydrogen atoms are the primary fuel for the sun's fusion. A hydrogen atom, the simplest of all atoms, commonly consists of only one electron and one proton. Inside the sun, however, electrons are stripped from the protons by the sun's intense heat.

Nuclear fusion produces most of the sun's energy and consists of three steps, as shown in **Figure 2.** In the first step, two hydrogen nuclei, or *protons*, collide and fuse. In this step, the positive charge of one of the protons is neutralized as a particle called a *positron* is emitted. As a result, the proton becomes a neutron and the original two protons become a proton-neutron pair. In the second step, another proton combines with this proton-neutron pair to produce a nucleus made up of two protons and one neutron, a rare type of helium. In the third step, two nuclei made up of two protons and one neutron collide and fuse. As this fusion happens, two protons are released. The remaining two protons and two neutrons are fused together as a helium nucleus of the common type. During each step of the reaction, energy is released.

READING TOOLBOX

Generalizations
As you read Section 1, look for sentences that contain generalizations, and list them in a table. Remember that some generalizations are not signaled by a word or phrase.

The Final Product

One of the final products of the fusion of hydrogen in the sun is always a helium nucleus. The helium nucleus has about 0.7% less mass than the hydrogen nuclei that combined to form it do. The lost mass is converted into energy during the series of fusion reactions that forms helium. The energy released during the three steps of nuclear fusion causes the sun to shine and gives the sun its high temperature.

Academic Vocabulary

convert (cohn VUHRT) change from one form to another

Mass Changing into Energy

The sun's energy comes from fusion, and the mass that is lost during fusion becomes energy. In 1905, the physicist Albert Einstein, then an unknown patent-office worker, proposed that a small amount of matter yields a large amount of energy. At the time, the existence of nuclear fusion was unknown. In fact, scientists had not yet discovered the nucleus of the atom. Einstein's proposal was part of his special theory of relativity. This theory included the equation $E = mc^2$. In this equation, E represents energy produced; m represents the mass, or the amount of matter, that is changed; and c represents the speed of light, which is about 300,000 km/s. Einstein's equation can be used to calculate the amount of energy produced from a given amount of matter.

By using Einstein's equation, astronomers were able to explain the huge quantities of energy produced by the sun. The sun changes about 4 million tons of mass into energy every second. Yet this amount of mass is small compared with the total mass of the sun.

During fusion, a type of subatomic particle called a *neutrino* is given off. Neutrinos escape the sun and reach Earth in about eight minutes. Studies of these particles confirm that the sun is fueled by the fusion of hydrogen into helium. One apparatus that collects these particles is shown in **Figure 3.** Elements other than hydrogen can fuse, too. In stars that are hotter than the sun, energy is produced by fusion reactions of the nuclei of carbon, nitrogen, and oxygen.

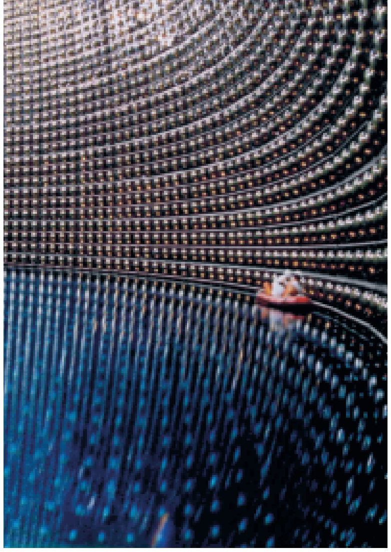


Figure 3 In Japan, this giant tank of pure water, which was only partly filled when the photo was taken, captures subatomic particles that fly out of the sun during nuclear fusion.

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Topic: The Sun
Code: **HQX1477**

Reading Check **How did the equation $E = mc^2$ help scientists understand the energy of the sun?** (See Appendix G for answers to Reading Checks.)

Quick Lab — Modeling Fusion

10 min

Procedure

1. Mark **six coins** by using a **marker** or **wax pencil.** Put a *P* for "proton" on the head side of each coin and an *N* for "neutron" on the tail side of the coins.
2. Place two coins P-side up. These two protons each represent hydrogen's simplest isotope, H. Model the fusion of these two H nuclei by placing them such that their edges touch. When they touch, flip one of them to be N-side up. This flip represents a proton becoming a neutron during fusion. The resulting nucleus, which consists of one proton and one neutron, represents the isotope hydrogen-2, ^{2}H.
3. To model the next step of nuclear fusion, place a third coin, P-side up, against the ^{2}H nucleus from step 2. This forms the isotope helium-3, or ^{3}He.
4. Repeat steps 2 and 3 to form a second ^{3}He nucleus.
5. Next, model the fusion of two ^{3}He nuclei. Move the two ^{3}He nuclei formed in step 3 so that their edges touch. When the two ^{3}He nuclei touch, move two of the protons in the two ^{3}He nuclei away from the other four particles. These four particles form a new nucleus: helium-4, or ^{4}He.

Analysis

1. Large amounts of energy are released when nuclei combine. How many energy-producing reactions did you model?
2. Create a diagram that shows the formation of ^{4}He.

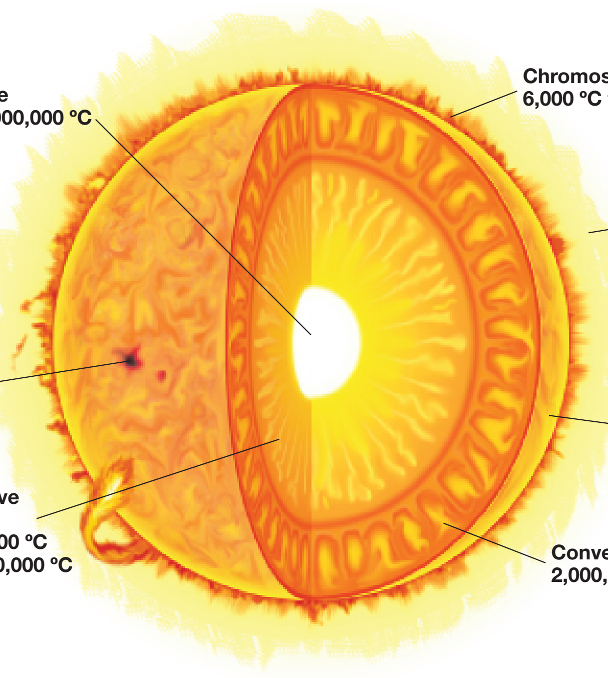


Figure 4 Energy released by fusion reactions in the core slowly works its way through the layers of the sun by the processes of radiation and convection.

The Sun's Interior

Scientists can't see inside the sun. But computer models have revealed what the invisible layers may be like. In recent years, careful studies of motions on the sun's surface have supplied more detail about what is happening inside the sun. The parts of the sun are shown in **Figure 4.**

The Core

At the center of the sun is the core. The core makes up 25% of the sun's total diameter of 1,390,000 km. The temperature of the sun's core is about 15,000,000 °C. No liquid or solid can exist at such a high temperature. The core, like the rest of the sun, is made up entirely of ionized gas. The mass of the sun is 300,000 times the mass of Earth. Because of the sun's large mass, the pressure from the sun's material is so great that the center of the sun is more than 10 times as dense as iron.

The enormous pressure and high temperature of the sun's core cause the atoms to separate into nuclei and electrons. On Earth, atoms generally consist of a nucleus surrounded by one or more electrons. Within the core of the sun, however, the energy and pressure strip electrons away from the atomic nuclei. The nuclei have positive charges, so they tend to push away from each other. But the high temperature and pressure force the nuclei close enough to fuse. The most common nuclear reaction that occurs inside the sun is the fusion of hydrogen into helium.

Quick Lab 20 min

The Size of Our Sun

Procedure

1. Using a **compass,** draw a large circle near the edge of a piece of **butcher paper** to represent the sun.
2. Measure the diameter (*D*) of your "sun."
3. Calculate the size of Earth and Jupiter, and compare the sizes with the size of the sun in step 1 by using the following values:
   D (sun) = 1.4×10^9 m
   D (Jupiter) = 1.4×10^8 m
   D (Earth) = 1.3×10^7 m
4. Now, draw Earth and Jupiter to scale on your model.

Analysis

The diameter of the sun's core is about 175,000,000 m. How does the size of the core compare with that of Earth and Jupiter?

The Radiative Zone

Before reaching the sun's atmosphere, the energy produced in the core moves through two zones of the sun's interior. The zone surrounding the core is called the **radiative zone.** The temperature in this zone ranges from about 2,000,000 ºC to 7,000,000 ºC. In the radiative zone, energy moves outward in the form of electromagnetic waves, or radiation.

radiative zone the zone of the sun's interior that is between the core and the convective zone and in which energy moves by radiation

convective zone the region of the sun's interior that is between the radiative zone and the photosphere and in which energy is carried upward by convection

photosphere the visible surface of the sun

The Convective Zone

Surrounding the radiative zone, comprising the outer 30 percent of the sun, is the **convective zone,** where temperatures are about 2,000,000 ºC. Energy produced in the core moves through this zone by convection. *Convection* is the transfer of energy by moving matter. On Earth, boiling water carries energy upward by convection. In the sun's convective zone, hot gases carry energy to the sun's surface. As the hot gases move outward and expand, they lose energy. The cooling gases become denser than the other gases and sink to the bottom of the convective zone. There, the cooled gases are heated by the energy from the radiative zone and rise again. Thus, energy is transferred to the sun's surface as the gases rise and sink.

The Sun's Atmosphere

Surrounding the convective zone is the sun's atmosphere. Although the sun is made of gases, the term *atmosphere* refers to the uppermost region of solar gases. This region has three layers—the photosphere, the chromosphere, and the corona.

The Photosphere

The innermost layer of the solar atmosphere is the **photosphere.** *Photosphere* means "sphere of light." The photosphere is made of gases that have risen from the convective zone. The temperature in the photosphere is about 6,000 ºC. Much of the energy given off from the photosphere is in the form of visible light. The layers above the photosphere are transparent, so the visible light is the light that is seen from Earth. A photo of the sun's photosphere is shown in **Figure 5.** The dark spots are cool areas of about 3,800 ºC and are called *sunspots*.

Reading Check **What layers make up the sun's atmosphere?**

Figure 5 The photosphere is referred to as the sun's surface because this layer is the visible surface of the sun. Sunspots are cooler regions in the photosphere.

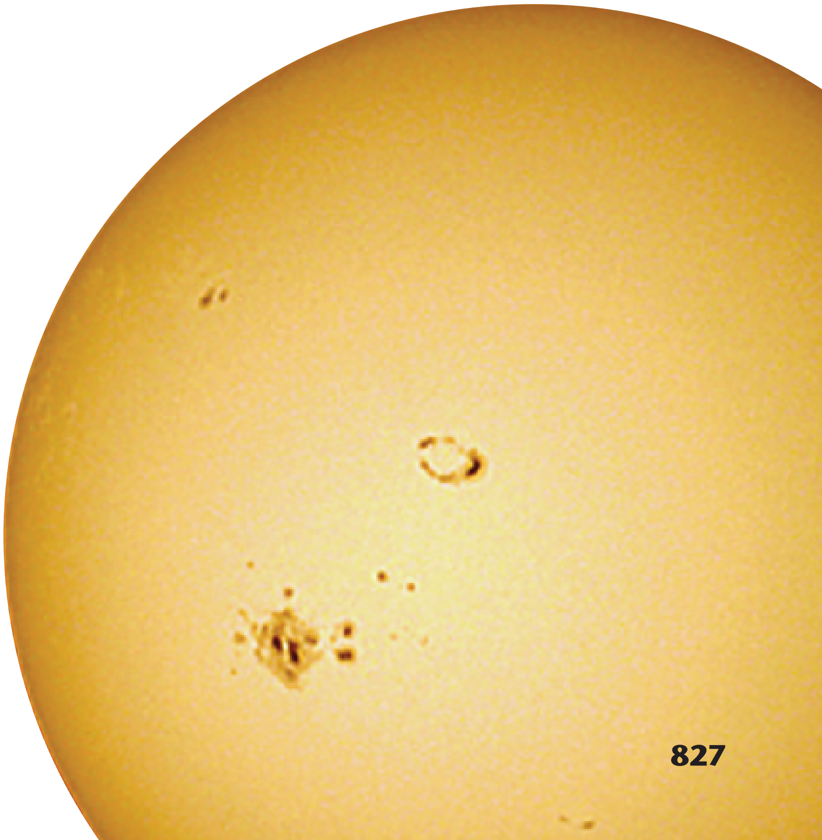


Figure 6 The corona of the sun becomes visible during a total solar eclipse. The black disk is the silhouette of the moon, which is blocking the photosphere.

The Chromosphere

Above the photosphere lies the **chromosphere,** or color sphere. This is a thin layer of gases that glows with reddish light that is typical of the color given off by hydrogen. The chromosphere's temperature ranges from 6,000°C to 50,000°C. The gases of the chromosphere move away from the photosphere. In an upward movement, gas regularly forms narrow jets of hot gas that shoot outward to form the chromosphere and then fade away within a few minutes. Some of these jets reach heights of 16,000 km.

Spacecraft study the sun from above Earth's atmosphere. These spacecraft can detect small details on the sun. They can also measure wavelengths of light that are blocked by Earth's atmosphere. Movies made from these spacecraft images show how features on the sun rise, change, and sometimes twist.

chromosphere the thin layer of the sun that is just above the photosphere and that glows a reddish color during eclipses

corona the outermost layer of the sun's atmosphere

The Sun's Outer Parts

Just above the chromosphere is a thin zone called the transition region where the temperature rises dramatically. The outermost layer of the sun's atmosphere is the **corona** (kuh ROH nuh), or crown. The corona is a huge region of gas with a temperature above 1,000,000 °C. The corona is not very dense, but its magnetic field can stop most subatomic particles from escaping into space. However, electrons and electrically charged particles called *ions* do stream out into space as the corona expands. These particles make up the *solar wind*, which flows outward from the sun to the rest of the solar system.

The chromosphere and the corona are normally not seen from Earth because the sky during the day is too bright. Occasionally, however, the moon moves between Earth and the sun and blocks out the light of the photosphere. The sky darkens, and the corona becomes visible, as shown in **Figure 6.**

Section 1 Review

Key Ideas

1. **Describe** how scientists use spectra to determine the composition of stars.
2. **Identify** the two elements that make up most of the sun.
3. **Identify** the end products of the nuclear fusion process that occurs in the sun.
4. **Explain** how the sun converts matter into energy in its core.
5. **Compare** the radiative and convective zones of the sun.
6. **Describe** the three layers of the sun's atmosphere.
7. **Explain** why the sun's corona can be seen during an eclipse but not at other times.

Critical Thinking

8. **Making Inferences** Describe whether the amount of hydrogen in the sun will increase or decrease over the next few million years. Explain your reasoning.
9. **Analyzing Ideas** Why does fusion occur in the sun's core but not in other layers?
10. **Predicting Consequences** What might happen to the solar wind if the sun lost its corona?

Concept Mapping

11. Use the following terms to create a concept map: *sun, hydrogen, helium, nuclear fusion, core, radiative zone,* and *convective zone.*

SECTION 2

Solar Activity

Key Ideas	Key Terms	Why It Matters
❯ Explain how sunspots are related to powerful magnetic fields on the sun. ❯ Compare prominences, solar flares, and coronal mass ejections. ❯ Describe how the solar wind can cause auroras on Earth.	**sunspot** **prominence** **solar flare** **coronal mass ejection** **aurora**	Solar flares and coronal mass ejections can cause geomagnetic storms on Earth that disrupt communications technologies such as radio, television, and cellular telephones.

The gases that make up the sun's interior and atmosphere are in constant motion. The energy produced in the sun's core and the force of gravity combine to cause the continuous rising and sinking of gases. The gases also move because the sun rotates on its axis. Because the sun is a ball of hot gases rather than a solid sphere, not all locations on the sun rotate at the same speed. Places close to the equator on the surface of the sun take 25.3 Earth days to rotate once. Points near the poles take 33 days to rotate once. On average, the sun rotates once every 27 days.

sunspot a dark area of the photosphere of the sun that is cooler than the surrounding areas and that has a strong magnetic field

Sunspots

The movement of gases within the sun's convective zone and the movements caused by the sun's rotation produce magnetic fields. These magnetic fields cause convection to slow in parts of the convective zone. Slower convection causes a decrease in the amount of gas that is transferring energy from the core of the sun to these regions of the photosphere. In some places, the magnetic field is thousands of times stronger than it is in other places. Because less energy is being transferred, these regions of the photosphere are up to 3,000 °C cooler than surrounding regions.

Although they still shine brightly, these cooler areas of the sun appear darker than the areas that surround them do. These cool, dark areas of gas within the photosphere are called **sunspots.** The rest of the photosphere has a grainy appearance called *granulation*. The area around the sunspots shown in **Figure 1** has visible granulation. A large sunspot can have a diameter of more than 100,000 km, which is more than seven times the diameter of Earth.

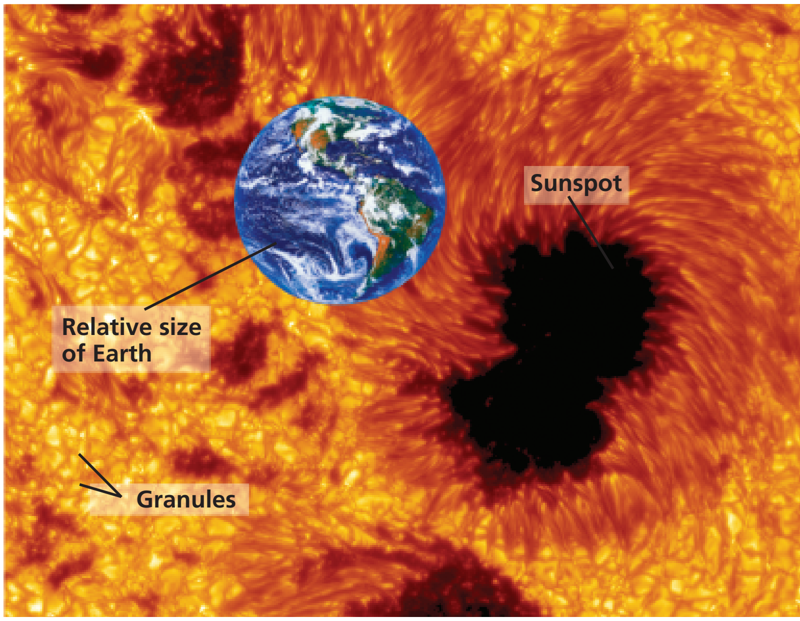


Figure 1 The diameter of this large sunspot is bigger than Earth's diameter. This image also shows the granulation on the sun's surface.

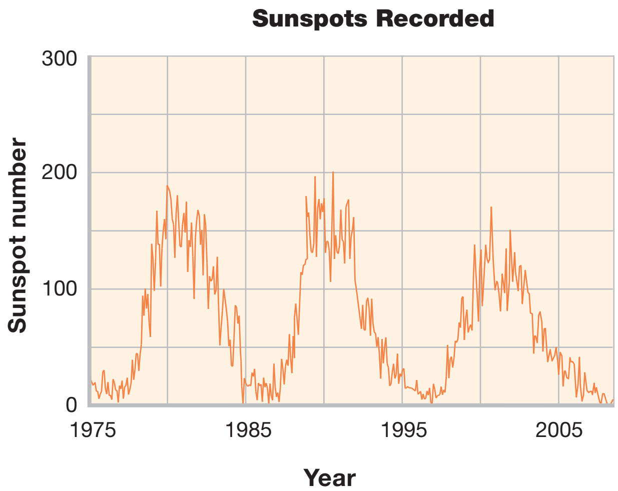


Figure 2 The sunspot cycle lasts an average of 11 years. ***When will the next high point in the cycle occur?***

The Sunspot Cycle

Astronomers have carefully observed sunspots for hundreds of years. Observations of sunspots showed astronomers that the sun rotates. Later, astronomers observed that the numbers and positions of sunspots vary in a cycle that lasts about 11 years.

A sunspot cycle begins when the number of sunspots is very low but begins to increase. Sunspots initially appear in groups about midway between the sun's equator and poles. The number of sunspots increases over the next few years until it reaches a peak of 100 or more sunspots. Then, sunspots at higher latitudes slowly disappear, and new ones appear closer to the sun's equator. **Figure 2** shows that after the peak, the number of sunspots begins to decrease until it reaches a minimum. Another 11-year cycle begins when the number of sunspots begins to increase again.

READING TOOLBOX

Suffixes
In Section 2, one key term and two italicized words contain the suffix *-tion*. Find and add these words to your table.

Solar Eruptions

Many other solar activities are affected by the sunspot cycle. The *solar-activity cycle* is caused by the changing solar magnetic field. This cycle is characterized by increases and decreases in various types of solar activity, including solar eruptions. Solar eruptions are events in which the sun lifts substantial material above the photosphere and emits atomic or subatomic particles. These events include prominences, solar flares, and coronal mass ejections.

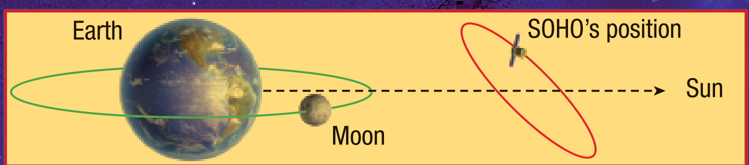
Why It Matters

SOHO, So Helpful

SCIENCE & SOCIETY

On November 4, 2003, the most violent solar flare ever recorded ejected billions of tons of hot gases and particles from the sun's surface at 2,700 km/s. Had Earth been in its direct path, we would have had only 17 hours warning. Without the Solar and Heliospheric Observatory (SOHO), we might not have seen it coming. SOHO images the sun in visible, X-ray, and (as shown here) UV frequencies. Initially planned for two years, the mission has been extended at least three times.

In addition to its sun-related duties, SOHO has discovered more than 1,000 new comets.



YOUR TURN
ONLINE RESEARCH
When was the last major solar flare that affected Earth?

Prominences

The magnetic fields that cause sunspots also create other disturbances in the sun's atmosphere. Great clouds of glowing gases, called **prominences,** form huge arches that reach high above the sun's surface. Each solar prominence follows curved magnetic field lines from a region of one magnetic polarity to a region of the opposite magnetic polarity. Some prominences may last for several weeks, while others may erupt and disappear in hours. The gas in prominences is very hot and is commonly associated with the chromosphere.

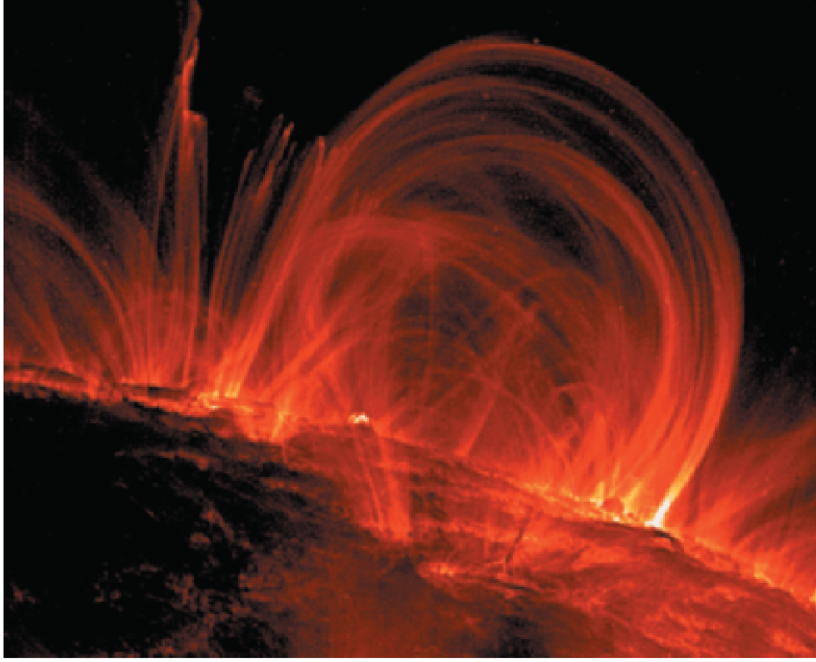


Figure 3 A coronal loop, shown here curving from left to right, can arch more than 500,000 km above the sun's surface.

Solar Flares

The most violent of all solar disturbances is a **solar flare,** a sudden outward eruption of electrically charged particles, such as electrons and protons. The trigger for these eruptions is unknown. However, scientists know that solar flares release the energy stored in the strong magnetic fields of sunspots. This release of energy can lead to the formation of coronal loops, such as the ones shown in **Figure 3.**

Solar flares may travel upward thousands of kilometers within minutes, but few eruptions last more than an hour. During a peak in the sunspot cycle, 5 to 10 solar flares may occur each day. The temperature of the gas in solar flares may reach 20,000,000 °C. Some of the particles from a solar flare escape into space. These particles increase the strength of the solar wind.

Coronal Mass Ejections

Particles also escape into space as **coronal mass ejections,** or parts of the corona that are thrown off the sun. As the gusts of particles strike Earth's *magnetosphere*, or the space around Earth that contains a magnetic field, the particles can generate a sudden disturbance in Earth's magnetic field. These disturbances are called *geomagnetic storms*. Although several small geomagnetic storms may occur each month, the average number of severe storms is less than one per year.

Geomagnetic storms have been known to interfere with radio communications on Earth. The high-energy particles that circulate in Earth's outer atmosphere during geomagnetic storms can also damage satellites. They can also lead to blackouts when power lines become overloaded. Not all solar activity is so dramatic, but the activity of the sun affects Earth every day.

Reading Check **How do coronal mass ejections affect communications on Earth?**

prominence a loop of relatively cool, incandescent gas that extends above the photosphere and above the sun's edge as seen from Earth

solar flare an explosive release of energy that comes from the sun and that is associated with magnetic disturbances on the sun's surface

coronal mass ejection coronal gas that is thrown into space from the sun

Math Skills

Magnetic Fields

Solar magnetic field densities at the sun's poles are 0.001 teslas (T); those near sunspots are up to 0.3 T. How many times the field densities at the poles are field densities near sunspots?

Figure 4 Auroras, such as these over Finland, can fill the entire sky. The different colors in an aurora result from high-energy particles from the sun colliding with atoms of different elements in Earth's atmosphere.

Academic Vocabulary

interaction (IN tuhr AK shuhn) the action or influence between things

aurora colored light produced by charged particles from the solar wind and from the magnetosphere that react with and excite the oxygen and nitrogen of Earth's upper atmosphere; usually seen in the sky near Earth's magnetic poles

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Topic: Solar Activity
Code: **HQX1413**

Auroras

On Earth, a spectacular effect of the interaction between the solar wind and Earth's magnetosphere is the appearance in the sky of bands of light called **auroras** (aw RAWR uhz). **Figure 4** shows an example of an aurora. Auroras are usually seen close to Earth's magnetic poles because electrically charged particles are guided toward Earth's magnetic poles by Earth's magnetosphere. The electrically charged particles strike the atoms and gas molecules in the upper atmosphere and produce colorful sheets of light. Depending on which pole they are near, auroras are called *northern lights*—or *aurora borealis* (aw RAWR uh BAWR ee AL is)—or *southern lights*—or *aurora australis*.

Auroras normally occur between 100 and 1,000 km above Earth's surface. They are most frequent just after a peak in the sunspot cycle, especially after solar flares occur. Across the northern contiguous United States, auroras are visible about five times per year. In Alaska, however, people can see auroras almost every clear, dark night. Astronauts in orbit can also look down on Earth and see auroras. But Earth is not the only planet that has auroras. Spacecraft have imaged auroras on Jupiter and Saturn.

Section 2 Review

Key Ideas

1. **Explain** why sunspots are cooler than surrounding areas on the sun's surface.
2. **Identify** the number of sunspots that are on the sun during the peak of the sunspot cycle.
3. **Summarize** how the latitude of sunspots varies during the sunspot cycle.
4. **Explain** how prominences are different from solar flares.
5. **Summarize** the cause of auroras on Earth.

Critical Thinking

6. **Identifying Relationships** How can a sunspot be bright but look dark?
7. **Analyzing Ideas** Why doesn't the whole sun rotate at the same rate?

Concept Mapping

8. Use the following terms to create a concept map: *sunspot, prominence, solar flare, solar-activity cycle,* and *coronal mass ejection.*

REAL WORLD

Seasonal Sunlight

Visible light makes up a small fraction of the sun's total energy and is the only part of its energy that your eyes can detect. But this tiny "sliver" of the electromagnetic spectrum helps to feed the world, guide animals on their yearly migrations, and even let you know when it's time to wake up. Earth's green plants and other producers use about 2% of the solar energy that reaches Earth for photosynthesis, generating between 150 and 200 billion tons of organic matter each year. This is the matter that we use for food, fuel, and countless other applications.

Sunlight motivates us to go outside and helps keep our bodies fit. Our skin uses sunlight to make vitamin D, which we need for strong bones and a healthy immune system.

In winter, when there is less natural light available, some people experience seasonal affective disorder (SAD) and use methods known as light therapy to help them cope.

Some migratory animals, such as butterflies and birds, use the sun to help them determine direction when they travel. Fish use patterns of reflected sunlight for the same purpose.

YOUR TURN

UNDERSTANDING CONCEPTS
What are three ways that people depend on sunlight?

CRITICAL THINKING
In what other ways do organisms rely on sunlight?

Skills Practice Lab

90 min

Energy of the Sun

Objectives

- **Estimate** the sun's energy output.
- **Evaluate** the differences between known values and experimental values.

Materials

aluminum foil, 8 cm × 64 cm
clay, modeling
desk lamp with 100 W bulb
jar, glass, with lid
paint or magic marker, black, flat finish
pencil
ruler, metric
tape, masking
thermometer, Celsius

Safety

The sun is, on average, 150 million kilometers away from Earth. Scientists use complex astronomical instruments to measure the size and energy output of the sun. However, it is possible to estimate the sun's energy output by using simple instruments and the knowledge of the relationship between the sun's size and its distance from Earth. In this lab, you will collect energy from sunlight and estimate the amount of energy produced by the sun.

Procedure

1. Construct a solar collector in the following way.
   a. Carefully punch a hole in the jar lid, or use a lid that is already prepared by your teacher.
   b. Cut an 8 cm × 64 cm piece of aluminum foil. Place the piece of foil with the shorter (8 cm) edge in front of you. Fold the strip over three times. Then rotate the foil 90°, and fold it over two times. The resulting foil strip is now 2 cm × 8 cm. Wrap the strip snugly around at least half the bulb of the thermometer. Bend the edges out so that they form "wings," as shown in the photo. **CAUTION** Thermometers are fragile. Do not squeeze the bulb of the thermometer too tight or let the thermometer strike any solid object. Bend the remaining foil outward to collect as much sunlight as possible.
   c. Paint the wings black using a marker or flat black paint.
   d. Slip the top of the thermometer through the hole in the jar's lid. On the top and bottom of the lid, mold the clay around the thermometer to hold the thermometer steady. Place the lid on the jar. Adjust the thermometer so that the aluminum-foil wings are centered in the jar. Then, secure the thermometer and clay to the lid with masking tape.
2. Place the solar collector in sunlight. Tilt the jar so that the sun shines directly on the metal wings. Carefully hold the jar in place. You may want to prop the jar up carefully with books.
3. Watch the temperature reading on the thermometer until it reaches a maximum value or until 5 min have elapsed. Record this value. Allow the collector to cool for 2 min.

4. Place the lamp or heat lamp at the end of a table. Remove any reflector or shade from the lamp.
5. Place the collector about 30 cm from the lamp, and turn the collector toward the lamp.
6. Turn on the lamp, and wait 1 min. Then, gradually move the collector toward the lamp in 2 cm increments. Watch the temperature carefully. At each position, let the collector sit until the temperature reading stabilizes. Stop moving the collector when the temperature reaches the maximum temperature that was achieved in sunlight.
7. Once the temperature has stabilized at the same level reached in sunlight, record the distance between the center of the lamp and the thermometer bulb.

Analysis

1. **Analyzing Results** Because the collector reached the same temperature in both trials, the collector absorbed as much energy from the sun at a distance of 150 million km as it did from the light bulb at the distance that you measured. Using 1.5×10^{13} cm as the distance to the sun, calculate the power of the sun in watts by using the equation that follows. The power of the lamp is equal to the wattage of the light bulb.

$$\frac{power_{sun}}{(distance_{sun})^2} = \frac{power_{lamp}}{(distance_{lamp})^2}$$

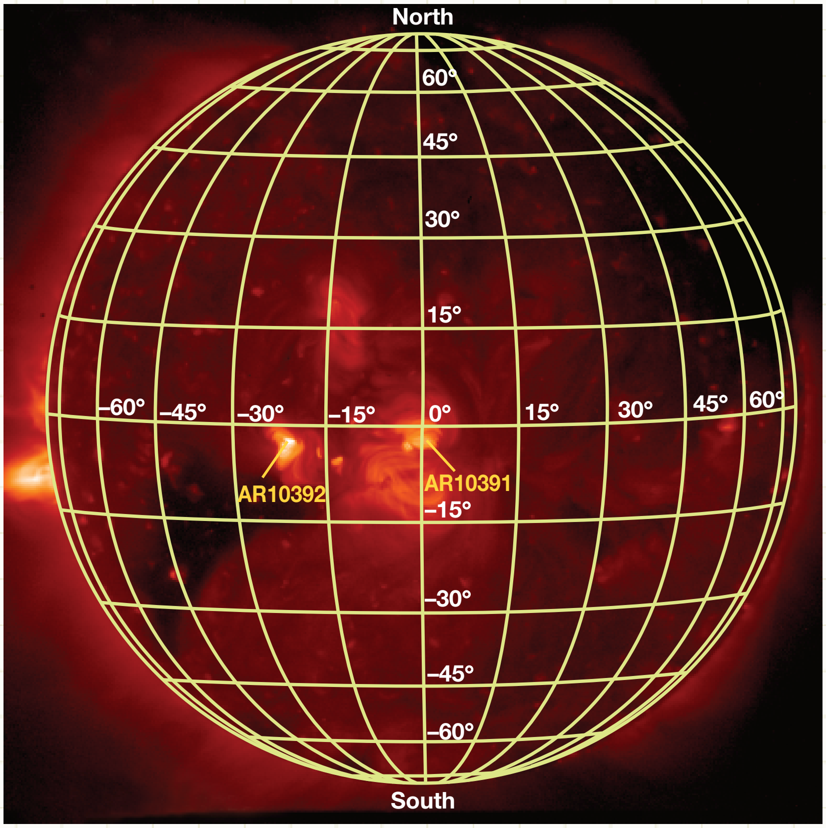
2. **Evaluating Models** The sun's power is generally given as 3.7×10^{26} W. Calculate your experimental percentage error by first subtracting your experimental value from the accepted value. Divide this difference by the accepted value, and multiply by 100. Describe two possible sources for your calculated error.

Extension

Evaluating Models How would using a fluorescent bulb instead of an incandescent bulb in the experiment affect the results of the experiment? Explain your answer.

MAPS in Action

XRT Composite Image of the Sun



Map Skills Activity

This map is an X-ray telescope (XRT) image of the sun that includes latitude and longitude lines. Yellow represents the strongest X-ray radiation. Red represents moderate X-ray radiation. Black represents the weakest X-ray radiation. Active regions (AR) are numbered. Use the map to answer these questions.

1. **Analyzing Data** What is the latitude and longitude of the active region numbered 10392?
2. **Analyzing Data** How would you describe the intensity of the X-ray radiation in the region at 15° north latitude and –15° west longitude?
3. **Inferring Relationships** Why do the lines of solar longitude appear to be close to each other near the left side and the right side of the map?
4. **Interpreting Data** Dark regions of the corona that are visible in X-ray images are called *coronal holes*. They are the source of the solar wind. What is the range of longitudes covered by the coronal hole in the southwestern quadrant of the map?
5. **Analyzing Relationships** Sunspots emit large amounts of X-ray radiation. Where on this map would you expect to find sunspots?

Chapter 29 Summary

THINK central
SUPER SUMMARY
Keyword: HQXSUNS

Key Ideas | **Key Terms**

Section 1

Structure of the Sun

- The sun's core converts matter into energy through the process of nuclear fusion. In nuclear fusion, four hydrogen nuclei are combined to form one helium nucleus, releasing much energy.
- Energy produced by nuclear fusion moves from the sun's core through the hotter radiative zone (in the form of electromagnetic waves) and then the cooler convective zone (in the form of gaseous convection currents) before it enters the sun's atmosphere.
- The sun's atmosphere is composed of three layers: the photosphere (the inner layer, but the layer that is visible to us on Earth), the hotter chromosphere, and the much hotter and much larger corona (the outer layer).

Key Terms

nuclear fusion, p. 824
radiative zone, p. 827
convective zone, p. 827
photosphere, p. 827
chromosphere, p. 828
corona, p. 828

Section 2

Solar Activity

- Sunspots are regions of the photosphere that have stronger magnetic fields than the regions that surround them. They are cooler than the surrounding regions because less energy is being transferred to them from the core.
- Prominences are loops of relatively cool gas that extend above the photosphere. They are usually associated with the chromosphere. Solar flares are explosive releases of the energy stored in the magnetic fields of sunspots. Coronal mass ejections cause disturbances in Earth's magnetosphere called geomagnetic storms.
- Auroras are colorful sheets of light that occur in Earth's polar regions when charged particles from the interaction between the solar wind and Earth's magnetosphere collide with atoms and molecules in the atmosphere.

Key Terms

sunspot, p. 829
prominence, p. 831
solar flare, p. 831
coronal mass ejection, p. 831
aurora, p. 832

Chapter 29 Review

1. **Chain-of-Events Chart** Create a chain-of-events chart to show how the solar wind interacts with Earth's magnetosphere to form auroras.

READING TOOLBOX

USING KEY TERMS

Use each of the following terms in a separate sentence.

2. *photosphere*
3. *solar flare*
4. *solar wind*
5. *sunspot cycle*

For each pair of terms, explain how the meanings of the terms differ.

6. *chromosphere* and *corona*
7. *photosphere* and *core*
8. *solar flare* and *prominence*
9. *aurora* and *solar wind*

UNDERSTANDING KEY IDEAS

10. According to Einstein's theory of relativity, in the formula $E = mc^2$, the c stands for
    a. corona.
    b. core.
    c. the speed of light.
    d. the length of time.
11. A nuclear reaction in which atomic nuclei combine is called
    a. fission. **c.** magnetism.
    b. fusion. **d.** granulation.
12. The part of the sun in which energy moves from atom to atom in the form of electromagnetic waves is called the
    a. radiative zone.
    b. convective zone.
    c. solar wind.
    d. chromosphere.
13. The number of hydrogen atoms that fuse to form a helium atom is
    a. two. **c.** six.
    b. four. **d.** eight.
14. The part of the sun that is normally visible from Earth is the
    a. core. **c.** corona.
    b. photosphere. **d.** solar nebula.
15. Sunspots are regions of
    a. intense magnetism.
    b. the core.
    c. high temperature.
    d. lighter color.
16. The sunspot cycle repeats about every
    a. month. **c.** 11 years.
    b. 5 years. **d.** 19 years.
17. Sudden outward eruptions of electrically charged particles from the sun are called
    a. prominences. **c.** sunspots.
    b. coronas. **d.** solar flares.
18. Gusts of solar wind can cause
    a. rotation.
    b. magnetic storms.
    c. nuclear fission.
    d. nuclear fusion.
19. *Northern lights* and *southern lights* are other names for
    a. prominences.
    b. auroras.
    c. granulations.
    d. total solar irradiance.

SHORT ANSWER

20. What is the outermost layer of the sun?
21. How is the solar activity cycle related to the sunspot cycle?
22. What is unusual about the magnetic field in a sunspot?
23. From what process does the sun gets its energy? What steps does this process follow?
24. Compare two types of solar activity.
25. Describe the corona, and identify when it is visible from Earth.
26. How does the transfer of energy in the radiative zone differ from the transfer of energy in the convective zone?

CRITICAL THINKING

27. Making Comparisons How is the transfer of energy in a pan of hot water similar to the transfer of energy in the sun's convective zone?

28. Making Comparisons Explain how the radiative zone in the sun is similar to the region between the sun and Earth.

29. Making Predictions Predict what would happen to the number of sunspots if parts of the sun's magnetic field suddenly increased in strength.

30. Drawing Conclusions If Earth's magnetosphere shifted so that solar wind was not deflected toward the poles but was deflected toward the equator, what would happen to the area where auroras are most often visible?

31. Analyzing Relationships Magnetic fields create electric currents that can damage electric power grids and interrupt the flow of electricity. How does this information help explain why strong magnetic storms can knock out power in cities?

32. Predicting Consequences How do scientists predict magnetic storms? List two ways that scientists on Earth could help people prepare for a very large magnetic storm.

CONCEPT MAPPING

33. Use the following terms to create a concept map: *sun, nuclear fusion, core, radiative zone, convective zone, photosphere,* and *corona.*

MATH SKILLS

34. Making Calculations On average, Earth is 1.5×10^8 km from the sun. A coronal mass ejection, or CME, can have a speed of 7×10^6 km/h. At this speed, how long would a CME take to reach Earth?

35. Applying Information A peak of the sunspot cycle occurred in the years 2000–2001. In what years will the next two peaks occur?

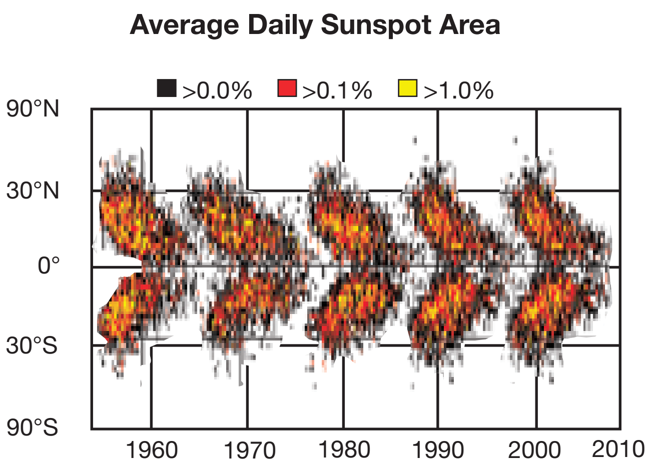
WRITING SKILLS

36. Creative Writing Write a short story that describes an imaginary trip to the center of the sun. Describe each layer and zone through which you would pass.

37. Writing from Research Research the northern lights. Write a short travel brochure that describes when and where to go to see the most spectacular and frequent displays of the auroras.

INTERPRETING GRAPHICS

The graph below shows how the latitudes of sunspots vary over time. Use the graph to answer the questions that follow.



38. How many complete sunspot cycles are illustrated by the graph?

39. How does the range of latitudes of sunspots change over time? How is this change related to the sunspot cycle?

40. According to the graph, how many sunspots were located at the sun's north pole?

Chapter 29 Standardized Test Prep

Understanding Concepts

Directions (1–5): For each question, write on a separate sheet of paper the letter of the correct answer.

1. What is the source of the sun's energy?
- **A.** nuclear fission reactions that break down massive nuclei to form lighter atoms
- **B.** nuclear fusion reactions that combine smaller nuclei to form more massive ones
- **C.** reactions that strip away electrons to form lighter atoms
- **D.** reactions that strip away electrons to form more massive ones

2. What do electrically charged particles from the sun strike in Earth's magnetosphere to lead to the production of sheets of light known as auroras?
- **F.** gas molecules
- **G.** dust particles
- **H.** water vapor
- **I.** ice crystals

3. Which layer of the sun has the densest material?
- **A.** the corona
- **B.** the convective zone
- **C.** the radiative zone
- **D.** the core

4. Which of the following is the correct sequence of layers of the sun's interior, from inner to outer?
- **F.** convective zone, radiative zone, core
- **G.** core, corona, photosphere
- **H.** core, radiative zone, convective zone
- **I.** core, convective zone, radiative zone

5. The solar activity cycle occurs regularly every
- **A.** 5 years.
- **B.** 11 years.
- **C.** 16 years.
- **D.** 29 years.

Directions (6–7): For each question, write a short response.

6. In which part of the sun's interior is energy carried to the sun's surface by moving matter?

7. What is the term for the innermost layer of the sun's atmosphere?

Reading Skills

Directions (8–10): Read the passage below. Then, answer the questions.

Studying the Sun

Sunlight that has been focused, especially through a magnifying glass, can produce a great amount of thermal energy—enough to start a fire. Imagine focusing the sun's rays by using a magnifying glass that has a diameter of 1.6 m. The resulting heat could easily melt metal. If a conventional telescope were pointed directly at the sun, some of its parts could melt and become useless.

The McMath-Pierce telescope uses a 1.6-m mirror to produce an image of the sun. First, a flat mirror directs the sun's rays down a long, diagonal shaft to a curved 1.6-m diameter mirror, which is located 50 m underground. This second mirror focuses the sunlight. Because the focal length is so long, the solar image is so large that no part of it is strong enough to melt anything. The focused sunlight is reflected by another flat mirror, which in turn directs the light to an observing room and instrument shaft. This system, while complex, not only protects the sensitive and expensive telescopic equipment but also protects the scientists that use it as well.

8. According to the information in the passage, which of the following statements about solar telescopes is true?
- **F.** Solar telescopes allow scientists to safely observe the sun.
- **G.** Solar telescopes do not need mirrors to focus the sun's rays.
- **H.** All solar telescopes are built 50 m underground.
- **I.** All solar telescopes are built with a diameter of 1.6 m.

9. Which of the following statements can be inferred from the information in the passage?
- **A.** Focusing sunlight can help avoid a meltdown.
- **B.** Unfocused sunlight produces little energy.
- **C.** A curved mirror can focus sunlight to produce a great amount of thermal energy.
- **D.** Mirrors greatly increase the intensity and danger of studying sunlight.

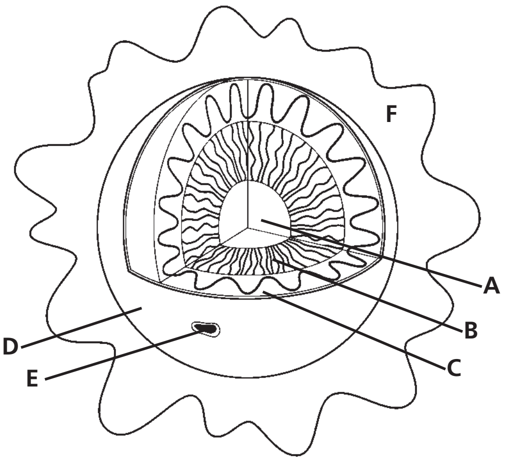
10. Why do scientists have to use specialized equipment to study the sun?

Interpreting Graphics

Directions (11–13): For each question below, record the correct answer on a separate sheet of paper.

The graphic below shows the structure of the sun. Use this diagram to answer questions 11 and 12.

Structure of the Sun



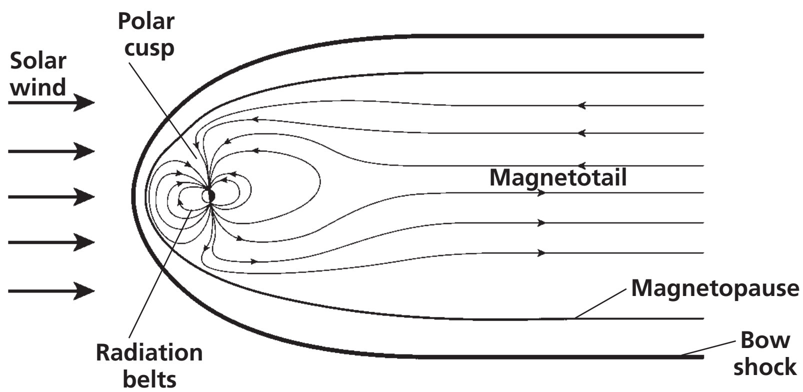
11. Fusion reactions provide power for the stars, such as the sun. In which part of the sun do these fusion reactions take place?

F. layer A
G. layer B
H. layer C
I. layer D

12. What is the term for the dark, cool regions of the sun, which are represented by the letter E on the diagram?

The diagram below shows what happens when Earth's magnetic field interacts with the solar wind. Use this graphic to answer question 13.

Earth's Magnetosphere



13. How does the solar wind affect humans and other living things on Earth, despite the protection provided by the magnetosphere? Use examples to explain your answer.

Test Tip

Choose the best possible answer for each question, even if you think there is another possible answer that is not given.