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

**Electromagnetic Radiation**

The vast majority of our information about the universe is obtained from the study of the light emitted from stars and other bodies in space. Although visible light is most familiar to us, it makes up only a small part of the different types of energy known as electromagnetic radiation. Electromagnetic radiation includes gamma rays, X-rays, ultraviolet light, visible light, infrared radiation, microwaves, and radio waves. The arrangement of these waves according to their wavelengths and frequencies is called the electromagnetic spectrum. Figure 1 shows the electromagnetic spectrum. All energy, regardless of wavelength, travels through the vacuum of space at the speed of light, or 300,000 kilometers per second. Over a 24-hour day, this equals a staggering 26 billion kilometers.
**Nature of Light**  
Experiments have shown that light can be described in two ways. In some instances light behaves like waves, and in others like particles. In the wave sense, light can be thought of as swells in the ocean. This motion is characterized by a property known as wavelength, which is the distance from one wave crest to the next. Wavelengths vary from several kilometers for radio waves to less than a billionth of a centimeter for gamma rays, as shown in Figure 1. Most of these waves are either too long or too short for our eyes to see.

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

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

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

---

**Table 1 Colors and Corresponding Wavelengths**

<table>
<thead>
<tr>
<th>Color</th>
<th>Wavelength (nanometers*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Violet</td>
<td>380–440</td>
</tr>
<tr>
<td>Blue</td>
<td>440–500</td>
</tr>
<tr>
<td>Green</td>
<td>500–560</td>
</tr>
<tr>
<td>Yellow</td>
<td>560–590</td>
</tr>
<tr>
<td>Orange</td>
<td>590–640</td>
</tr>
<tr>
<td>Red</td>
<td>640–750</td>
</tr>
</tbody>
</table>

*One nanometer is 10⁻⁹ meter.

---

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

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

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

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

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

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

What is spectroscopy?

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

Purpose
Students will observe how a spectrometer breaks light into the wavelengths that compose it.

Materials
empty paper towel, cardboard tube, diffracting grating (about 5 cm x 5 cm), piece of black paper (about 9 cm x 9 cm), tape, rubber band, razor blade, bright light

Procedure
Tape the diffracting grating over one end of the cardboard tube. Cover the opposite end of the tube with black paper. Secure the black paper over the end of the tube with a rubber band. Carefully cut a narrow slit in the center of the black paper. The slit should be about two-thirds the width of the opening. Point the slit toward a bright light and slowly rotate the tube until you see the spectrum. Allow students to use the spectrometer to view the spectrum.

Safety
Do not allow students to use this spectrometer to directly view the sun.

Expected Outcome
The diffraction grating works like a prism and breaks visible light into its basic colors. Students will be able to use this simple spectrometer to see bright light broken into its component colors or wavelengths.

Visual, Kinesthetic
The Doppler Effect

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

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

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

**Figure 4 The Doppler Effect**

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

### Section 24.1 Assessment

**Reviewing Concepts**

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

**Critical Thinking**

5. Sequence the components of visible light according to wavelength, beginning with the shortest wavelength.

6. **Applying Concepts** Based on what you know about prisms and visible light, how do you think rainbows form in Earth’s atmosphere?

**Writing in Science**

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

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**The Doppler Effect**

**Integrate Physics**

**A Sonic Boom** The Doppler effect and a sonic boom are similar phenomena. When an object such as an airplane is traveling near the speed of sound, the compression waves bunch up near the nose of the aircraft. When the aircraft exceeds the speed of sound, a loud explosion is heard known as a sonic boom. The sonic boom occurs because some of the sound wavefronts arrive at the same instant. Have students research how a sonic boom and a Mach cone are created. Have students make posters showing how each of these phenomena occurs.

**Verbal**

**ASSESS**

**Evaluate Understanding**

Have students write one question on each of the following topics: electromagnetic radiation, spectroscopy, and the Doppler effect. Have groups of students ask one another their questions.

**Reteach**

Use Figure 3 on p. 676 to review the different types of spectrums.

**Sample questions:** In which circumstances does light behave like a wave? When does it behave like a stream of particles? Who developed the theories? If time permits, have students research the answers to their questions.

---

**Answer to . . .**

*Spectroscopy is the study of the properties of light that depend on wavelength.*

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**Studying the Sun 677**

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5. violet, blue, green, yellow, orange, and red
6. Visible light is bent when it encounters water droplets in the atmosphere and is separated into its component colors.
Section 24.2

24.2 Tools for Studying Space

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

Vocabulary
- refracting telescope
- reflecting telescope
- radio telescope

Reading Strategy
Comparing and Contrasting
Copy the Venn diagram. As you read, complete it to show the differences between refracting and reflecting telescopes.

Refracting Telescopes
Reflecting Telescopes

Now that we’ve examined the nature of light, let’s turn our attention to the tools astronomers use to intercept and study the energy emitted by distant objects in the universe. Because the basic principles of detecting radiation were originally developed through visual observations, the astronomical tools we’ll explore first will be optical telescopes. An example is shown in Figure 5. To create an image that is a great distance away, a telescope must collect as much light as possible. Optical telescopes contain mirrors, lenses, or both to accomplish this task.

Refracting Telescopes
Galileo is considered to be the first person to have used telescopes for astronomical observations. Having learned about the newly invented instrument, Galileo built one of his own that was capable of magnifying objects 30 times. Because this early instrument, like its modern counterparts, used a lens to bend or refract light, it is known as a refracting telescope.
**Focus** The most important lens in a refracting telescope, the objective lens, produces an image by bending light from a distant object so that the light converges at an area called the focus (focus = central point). A star appears as a point of light. For nearby objects, the image appears inverted.

You can easily demonstrate the latter case by holding a lens in one hand and, with the other hand, placing a white card behind the lens. Now vary the distance between them until an image from a window appears on the card. The distance between the focus (where the image appears) and the lens is called the focal length of the lens.

Astronomers usually study an image from a telescope by first photographing the image. However, if a telescope is used to examine an image directly, a second lens, called an eyepiece, is required. The eyepiece magnifies the image produced by the objective lens. In this respect, it is similar to a magnifying glass. The objective lens produces a very small, bright image of an object, and the eyepiece enlarges the image so that details can be seen. Figure 6 shows the parts of a refracting telescope.

**Chromatic Aberration** Although used extensively in the nineteenth century, refracting telescopes suffer a major optical defect. A lens, like a prism, bends the shorter wavelengths of light more than the longer ones. Consequently, when a refracting telescope is in focus for red light, blue and violet light are out of focus. The troublesome effect, known as chromatic (chroma = color) aberration (aberrare = to go astray), weakens the image and produces a halo of color around it. When blue light is in focus, a reddish halo appears. When red light is in focus, a bluish halo appears. Although this effect cannot be eliminated completely, it is reduced by using a second lens made of a different type of glass.

*What is chromatic aberration?*

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**Use Community Resources**

Invite an astronomer to talk to your class about telescopes. Ask if he or she could bring small telescopes to use for demonstrations. If possible, see if the astronomer could come at night and have a moon-gazing or star-gazing party.

*Verbal, Interpersonal*

**Making a Simple Refracting Telescope**

**Purpose** Students will observe the simple concepts behind a refracting telescope.

**Materials** 2 magnifying lenses

**Procedure** Observe an object in the distance with one of the magnifying lenses. Move the lens back and forth until you get a sharp image. Place the second magnifying lens in front of your eye. Move the second lens back and forth until you get a clear image. The image should appear larger. Pass the lenses around the classroom to give students an opportunity to view an image.

**Expected Outcome** Students will see that a simple refracting telescope consists of two lenses. In this example, it consists of two convex lenses. A convex lens is thicker in the middle and thinner around the edges.

*Visual, Kinesthetic*

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**Customize for Inclusion Students**

**Learning Disabled** For students with difficulty absorbing concepts by reading, use Figures 6, 7, and 8 as visual aids as you describe how each of these telescopes works. Be sure students understand the differences among these telescopes.

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**Answer to . . .**

Chromatic aberration is a troublesome effect associated with refracting telescopes that weakens an image and produces a halo of color around it.
Reflecting Telescopes

Newton was bothered by chromatic aberration so he built telescopes that reflected light from a shiny surface—a mirror. Because reflected light is not dispersed into its component colors, the chromatic aberration is avoided. Reflecting telescopes use a concave mirror that focuses the light in front of a mirror, rather than behind it, like a lens. The mirror, called the objective, is generally made of glass that is finely ground and coated with a highly reflective material, usually an aluminum compound.

Because the focus of a reflecting telescope is in front of the mirror, an observer must be able to view the image without blocking too much incoming light. Figure 7A shows a viewing cage for the observer within the telescope. Figures 7B and 7C show how secondary mirrors can be used to view the image from outside the telescope.

Advantages of Reflecting Telescopes As you might guess, it’s a huge task to produce a large piece of high-quality, bubble-free glass for refracting telescopes. Most large optical telescopes are reflectors. Light does not pass through a mirror so the glass for a reflecting telescope does not have to be of optical quality. In addition, a lens can be supported only around the edge, so it sags. But mirrors can be supported fully from behind. One disadvantage of most reflecting telescopes is that the secondary mirror blocks some light entering the telescope. Thus, a reflecting telescope with a 10-inch opening will not collect as much light as a 10-inch refractor.

Properties of Optical Telescopes Both refracting and reflecting telescopes have three properties that aid astronomers in their work: 1) light-gathering power, 2) resolving power, and 3) magnifying power. Light-gathering power refers to the telescope’s ability to intercept more light from distant objects, thereby producing brighter images. Telescopes with large lenses or mirrors “see” farther into space than do those with small ones.

Another advantage of telescopes with large objectives is their greater resolving power, which allows for sharper images and finer detail. For example, with the naked eye, the Milky Way appears as a vague band of light in the night sky. But even a small telescope is capable of resolving, or separating it into, individual stars. Lastly, telescopes have magnifying power, which is the ability to make an image larger. Magnification is calculated by dividing the focal length of the objective by the focal length of the eyepiece. Thus, the magnification of a telescope can be changed by simply changing the eyepiece.

What is light-gathering power?
Detecting Invisible Radiation

Radio Telescopes

As you learned earlier, sunlight is made up of more than just the radiation that is visible to our eyes. Gamma rays, X-rays, ultraviolet radiation, infrared radiation, and radio waves are also produced by stars. Photographic film that is sensitive to ultraviolet and infrared radiation has been developed. This extends the limits of our vision. However, most of this radiation cannot penetrate our atmosphere, so balloons, rockets, and satellites must transport cameras “above” the atmosphere to record it.

A narrow band of radio waves is able to penetrate the atmosphere. Measurement of this radiation is important because we can map the galactic distribution of hydrogen. Hydrogen is the main material from which stars are made.

Radio Telescopes

The detection of radio waves is accomplished by big dishes called radio telescopes, shown in Figure 8A. In principle, the dish of one of these telescopes operates in the same manner as the mirror of an optical telescope. A radio telescope focuses the incoming radio waves on an antenna, which absorbs and transmits these waves to an amplifier, just like a radio antenna.

Because radio waves are about 100,000 times longer than visible radiation, the surface of the dish doesn’t need to be as smooth as a mirror. Except for the shortest radio waves, a wire mesh is a good reflector. However, because radio signals from celestial sources are very weak, large dishes are necessary to intercept an adequate signal.

Radio telescopes have poor resolution, making it difficult to pinpoint the radio source. Pairs or groups of telescopes reduce this problem. When several radio telescopes are wired together, as shown in Figure 8B, the resulting network is called a radio interferometer.

Detecting Invisible Radiation

Build Science Skills

Inferring

Explain to students that radio waves are able to penetrate Earth’s atmosphere and are used to map the distribution of hydrogen in the galaxy.

Ask: The largest radio telescope is 300 m (1,000 ft) in diameter. Why is a radio telescope this large an advantage? (Radio signals from celestial sources are very weak. This telescope is able to collect a larger number of signals because of its size.) This radio telescope was built in a depression in the landscape. Why was this location chosen? (This depression blocks human-made radio signals from the telescope.)

Verbal, Logical

Facts and Figures

The Very Large Array consists of 27 radio antennas set up in a Y-shaped configuration. The site is located on the Plains of San Augustin 50 miles west of Socorro, New Mexico. Each antenna measures 25 m in diameter. When the antennas are combined electronically, they give an equivalent resolution of an antenna 36 km in diameter. The combination of the antennas has the sensitivity of a dish that is 130 m in diameter.

Answer to . . .

Figure 8 a radio interferometer

Light-gathering power refers to the telescope’s ability to intercept more light from distant objects, thereby producing brighter images.
Advantages of Radio Telescopes

Radio telescopes have some advantages over optical telescopes. They are much less affected by turbulence in the atmosphere, clouds, and the weather. No protective dome is required, which reduces the cost of construction. "Viewing" is possible 24 hours a day. More important, radio telescopes can "see" through interstellar dust clouds that obscure visible wavelengths. Radio telescopes can also detect clouds of gases too cool to emit visible light. These cold gas clouds are important because they are the sites of star formation.

Radio telescopes are, however, hindered by human-made radio interference. While optical telescopes are placed on remote mountaintops to reduce interference from city lights, radio telescopes are often hidden in valleys to block human-made radio interference.

Radio telescopes have revealed such spectacular events as the collision of two galaxies. They also discovered intense and distant radio sources called quasars.

Space Telescopes

Have you ever seen a blurring effect caused by the movement of air on a hot summer day? That blurring effect also distorts the images produced by most telescopes on Earth. On a night when the stars twinkle, viewing a star clearly through a telescope is difficult because the air is moving rapidly. This causes the image to move about and blur.

One way to get around the distorting effects of Earth’s atmosphere—send telescopes into space. Space telescopes orbit above Earth’s atmosphere and thus produce clearer images than Earth-based telescopes.

Hubble Space Telescope

The first space telescope, built by NASA, was the Hubble Space Telescope, shown in Figure 9. Hubble was put into orbit around Earth in April 1990. This 2.4-meter space telescope has 10 billion times more light-gathering power than the human eye. Hubble has given us many spectacular images. It has provided data about planets that orbit other stars, the birth of stars, objects known as black holes, and the age of the universe.

Hubble and many Earth-based telescopes have detected more than 140 extrasolar planets. An extrasolar planet is a planet in orbit around a star other than the sun. How do astronomers detect an extrasolar planet? A planet’s gravity causes a Doppler shift in light emitted by the planet’s star. By measuring the Doppler shift in the star’s emission spectrum, astronomers can infer that a planet is present. Most known extrasolar planets are thought to be gas giants larger than Jupiter.
Special Purpose Telescopes
Space telescopes have been designed for a variety of special purposes. Like radio telescopes, these space telescopes often reveal surprising features of the objects they study. They are often designed to observe objects in space at wavelengths outside the visible spectrum. Data from space telescopes enable astronomers to classify these objects. They can also study the processes that formed the objects.

Several space telescopes have been designed for special purposes. To study X-rays, NASA uses the Chandra X-Ray Observatory. One of Chandra’s main missions is to gather data about black holes—objects whose gravity is so strong that visible light cannot escape them. Another space telescope, the Compton Gamma-Ray Observatory, was used to study both visible light and gamma rays emitted by black holes and other objects in space. For example, it observed exploding stars that give off powerful bursts of gamma radiation. In 2013, NASA plans to launch the James Webb Space Telescope to study infrared radiation. This telescope will be able to detect infrared radiation from stars and galaxies that formed early in the history of the universe.

Electromagnetic Radiation Recall the different types of electromagnetic radiation. Based on what you’ve learned in this section, would you recommend sending a telescope into space to study radio waves? Why or why not?

Studying the Sun

ASSESS

Evaluate Understanding

Have students write down the following types of telescopes: refracting, reflecting, and radio. Then, have students write down three facts about each telescope. Have students share their facts with the class.

Reteach

Use Figures 6, 7, and 8 to review how each of the these telescopes works.

Connecting Concepts

Sample answer: Radio waves can easily pass through Earth’s atmosphere. Therefore, there is little advantage in sending a radio telescope into space.

Section 24.2 Assessment

Reviewing Concepts
1. How does a refracting telescope work?
2. How does a reflecting telescope differ from a refracting telescope?
3. Why are most large optical telescopes reflecting telescopes?
4. How do radio telescopes gather data?
5. Why do space telescopes obtain clearer images than Earth-based telescopes?

Critical Thinking
6. Calculating If a telescope has an objective with a focal length of 50 centimeters and an eyepiece with a focal length of 25 millimeter, what will be the magnification?

7. Applying Concepts Using the numbers from the previous question, would an eyepiece with a greater focal length increase or decrease magnification? Explain.

Electromagnetic Radiation

Recall the different types of electromagnetic radiation. Based on what you’ve learned in this section, would you recommend sending a telescope into space to study radio waves? Why or why not?

Section 24.2 Assessment

1. The objective lens produces an image by bending light from a distant object so that the light converges at an area called the focus.
2. A reflecting telescope uses a concave mirror to produce an image. A refracting telescope uses a lens to bend or refract light.
3. Because light does not pass through a mirror, the glass for a reflecting telescope does not have to be of optical quality. In addition, a lens can be supported only around the edge, so it sags. Mirrors, on the other hand, can be supported fully from behind. Finally, with mirrors there is no chromatic aberration.
4. A radio telescope focuses the incoming radio waves on an antenna, which absorbs and transmits the waves to an amplifier.
5. Space telescopes orbit above Earth’s atmosphere and thus produce clearer images than Earth-based telescopes. There is no blurring of images and no interference from city lights.
6. Magnification is calculated by dividing the focal length of the objective by the focal length of the eyepiece. In this example, 500 mm / 25 mm = 20; magnification would be 20 times.
7. An eyepiece with a greater focal length, such as 50 mm, would decrease magnification because 500 mm / 50 mm = 10 times magnification.
The sun is one of the 400 billion stars that make up the Milky Way galaxy. It is Earth's primary source of energy. Everything—from the fossil fuels we burn in our automobiles to the food that we eat—is ultimately derived from solar energy. The sun is also important to astronomers, since until just a few years ago it was the only star whose surface we could study. Even with the largest telescopes, most other stars appear only as points of light.

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

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

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

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

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

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

**Customize for English Language Learners**

Encourage English language learners to make a science glossary as they read the section. Suggest that they start with the vocabulary terms and then add any other new words they encounter. Encourage students to write brief definitions of each term and draw an illustration that helps them understand the term.

**Address Misconceptions**

Many students may think that since the sun is an enormous ball of gas it does not have a surface. The visible surface of the sun, the photosphere, is a layer of gas about 500 km thick. Most of the sunlight that we receive is from this layer. Although more light is emitted from the layer below the photosphere, that light is absorbed in the overlying layers of gas. Above the photosphere, the gas is less dense and thus unable to radiate much light. The photosphere is the layer that is dense enough to emit ample light yet has a density low enough to allow light to escape. Since the photosphere emits most of the light we see, it appears as the outermost surface of the sun.

**Verbal**

**Describe** Describe the movement of gases in the convection zone.

**Figure 13** Gases rise to the surface of the sun, cool, then sink back into the interior.
Chromosphere

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

Corona

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

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

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

Earth and Solar Winds

Purpose Students will observe how Earth is protected from solar winds.

Materials bar magnet, 2 sheets of notebook paper, iron filings, drinking straw

Procedure Cover the magnet with a sheet of paper. Fold the other sheet of paper in half. Sprinkle iron filings in the fold. Hold the paper about 15 cm from the magnet. Blow through the straw, directing the stream of air at the iron filings. The iron filings should be attracted to the magnet.

Expected Outcome Students will observe how a magnetic field attracts charged particles. The solar wind is composed of ionized or charged particles. Just as the iron filings are drawn to the magnet, the solar wind is attracted to Earth's magnetic field. Earth's magnetic field prevents the solar wind from reaching Earth's surface and bombarding it.

Visual, Logical

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

Corona

The corona is visible only when the brilliant photosphere is covered. This envelope of ionized gases normally extends a million kilometers from the surface of the sun and produces a glow about half as bright as the full moon.

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What is the solar wind?

Facts and Figures

The high temperature of the corona is probably caused by sound waves generated by the convection motion of the photosphere. Just as boiling water makes noise, the energetic sound waves generated in the photosphere are believed to be absorbed by the gases of the corona and thereby raise their temperatures.
The Active Sun

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

Sunspots

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

In the nineteenth century, an accurate record of sunspot occurrences was kept. The sunspot data revealed that the number of sunspots observable varies in an 11-year cycle. First, the number of sunspots increases to a maximum, with perhaps a hundred or more visible at a given time. Then their numbers gradually decline to a minimum, when only a few or even none are visible.

Figure 15 Sunspots

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

Facts and Figures

An interesting characteristic of sunspots was discovered by astronomer George Hale, for whom the Hale telescope is named. Hale found that the large sunspots are strongly magnetized, and when they occur in pairs, they have opposite magnetic poles. Also, every pair located in the same hemisphere is magnetized in the same manner. However, all pairs in the other hemisphere are magnetized in the opposite manner. At the beginning of each sunspot cycle, the polarity reverses. The cause of this change in polarity is not fully understood.

Answer to . . .

streams of protons and electrons that flow from the corona
Prominences

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

Solar Flares

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

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

What are solar flares?
The Solar Interior

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

Nuclear Fusion

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

\[ E = mc^2 \]

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

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

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

**Reading Checkpoint**

What happens during the process of nuclear fusion?

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**Figure 18 Nuclear Fusion**

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

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**Go Online NSTA SCILINKS**

For: Links on nuclear fusion in the sun
Visit: www.SciLinks.org
Web Code: cjn-7243

**The Solar Interior Use Visuals**

Using nuclear fusion as an electrical energy source could provide a limitless supply of electrical power. Constructing practical fusion reactors has proven to be difficult. Have students research nuclear fusion as a renewable energy source and prepare a report to present to the class. The report should contain promising techniques that scientists are currently investigating.

**Integrate Physics**

**Nuclear Fusion as an Energy Source**

Using nuclear fusion as an electrical energy source could provide a limitless supply of electrical power. Constructing practical fusion reactors has proven to be difficult. Have students research nuclear fusion as a renewable energy source and prepare a report to present to the class. The report should contain promising techniques that scientists are currently investigating.

**Verbal**

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**Answer to . . .**

**Reading Checkpoint**

Solar flares are brief outbursts that normally last an hour or so, and appear as a sudden brightening of the region above a sunspot cluster.

Some matter is converted to energy, and energy is released.
Section 24.3 Assessment

Reviewing Concepts

1. What is the structure of the sun?
2. Which layer of the sun can be thought of as its surface?
3. Describe some characteristics of features on the sun.
4. Are the same number of sunspots always present on the sun? Explain.
5. How does the sun produce energy?
6. How much longer will the sun likely exist in its present state?
7. Relating Cause and Effect Why do sunspots appear dark?
8. Applying Concepts What is the effect on Earth’s atmosphere of a strong solar flare?
9. Of the 6 x 10^8 tons of hydrogen the sun consumes each second, about 4 x 10^6 tons are converted to energy. What percentage of the total energy consumed per second is converted to energy?

Critical Thinking

4. No, because the number of sunspots varies in an 11-year cycle.
5. Deep in its interior, the sun produces energy by a process known as nuclear fusion, wherein four hydrogen nuclei are converted into the nucleus of a helium atom and tremendous energy is released.
6. The sun is estimated to last easily another 5 billion years.
7. Sunspots are somewhat cooler than the surrounding surface.
8. During a solar flare, fast-moving particles are ejected from the sun, increasing the solar wind. The ejected particles reach Earth and disturb long-distance radio communication. They also produce auroras.
Some people believe that changes in solar activity relate to climatic change. The effect of such changes would seem direct and easily understood: Increases in solar output would cause the atmosphere to warm, and reductions would result in cooling. This notion is appealing because it can be used to explain climatic changes of any length or intensity.

Still, there is at least one major drawback: No major long-term variations in the total intensity of solar radiation have yet been measured. Such measurements were not even possible until satellite technology became available. Now that it is possible, we will need many years of records before we begin to sense how variable the sun really is.

**Sunspot Cycles**

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

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

**Conflicting Evidence**

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

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

**Figure 21** Mean Annual Sunspot Numbers

A National Aeronautics and Space Administration (NASA) computer climate model suggests that low solar activity from the 1400s to the 1700s could have triggered the “Little Ice Age” in North America and Europe. Changes in the sun’s energy were one of the biggest factors influencing climatic changes during this time period. While solar activity primarily influenced temperature variations during the Middle Ages, this is not true today. The accumulation of greenhouse gases in the atmosphere, caused by human activities, is the primary catalyst for temperature changes today.

**Teaching Tip**

Have students research information available from NASA, National Oceanic and Atmospheric Administration (NOAA), and other reliable sources on the relationship between Earth temperature and solar activity. Students should write a short report detailing the information they have found.

**Verbal**