

Chapter 26

Studying Space

Chapter Outline

1 Viewing the Universe

The Value of Astronomy

Characteristics of the Universe

Observing Space

Telescopes

Space-Based Astronomy

2 Movements of Earth

The Rotating Earth

The Revolving Earth

Constellations and Earth's Motion

Measuring Time

The Seasons



Why It Matters

In our efforts to study space, we have developed many technologies, from simple telescopes to the International Space Station. Human interest in the regions beyond Earth has impacted life on the surface of the planet, as well as above it, in many ways.



Inquiry Lab

 20 min

A Model Telescope

Ask a partner to hold up this **textbook** 1 m away from you. Use a pair of **hand lenses** to form your model telescope. Hold one lens close to your eye. Hold the second lens in the other hand, and move it back and forth until you can see a clear image of the book cover. Use a **meterstick** to measure the distance between the two lenses. Have your partner hold the book at different distances, and find the lens arrangement with the clearest image. Then switch roles.

Questions to Get You Started

1. How did you make the textbook image clearer when it was closer to you and farther from you?
2. How could you redesign the telescope so you would not have to hold the lenses?



Frequency

Always, Sometimes, Never Many statements include a word that tells you about the frequency of the information in the statement. Examples include words such as *always*, *sometimes*, *often*, and *never*. Words such as *some*, *many*, and *most* are examples of words that tell you about frequency in number.

Your Turn As you read this chapter, record examples of statements that contain frequency words. In each statement, underline the word that tells you about the frequency of the information in the statement or about frequency in number in the statement. Here is one example:

To measure distances in the solar system, astronomers often use astronomical units.

Describing Space

Using Spatial Language Spatial language is used to describe space and the universe. It can be used to describe

- the shape of objects
- the location of objects
- distance
- orientation
- direction of motion

Your Turn As you read this chapter, complete a table like the one below. Add words or phrases that use spatial language to describe something.

Shape	Location	Distance	Orientation	Direction
spherical	in the core	a long way	vertical	outward
cube	at the North Pole	kilometer	tilt	south

FoldNotes

Key-Term Fold The key-term fold can help you learn key terms from this chapter.

Your Turn Create a key-term fold for Section 1, as described in **Appendix A**.

- 1 Write one key term on the front of each tab.
- 2 Write a definition or description for each term under its tab.

- 3 Use this FoldNote to help you review the key terms.



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

Viewing the Universe

Key Ideas

- Describe characteristics of the universe in terms of time, distance, and organization.
- Identify the visible and nonvisible parts of the electromagnetic spectrum.
- Compare refracting telescopes and reflecting telescopes.
- Explain how telescopes for nonvisible electromagnetic radiation differ from light telescopes.

Key Terms

astronomy
galaxy
astronomical unit
electromagnetic spectrum
telescope
refracting telescope
reflecting telescope

Why It Matters

Technologies that are developed for space exploration also have spinoffs that allow us to treat illnesses, develop new building materials, predict the weather, and communicate with others around the world.

People studied the sky long before the telescope was invented. For example, farmers observed changes in daylight and the visibility of groups of stars throughout the year to track seasons and to predict floods and droughts. Sailors focused on the stars to navigate through unknown territory. Today, most interest in studying the sky comes from a curiosity to discover what lies within the universe and how the universe changes. This scientific study of the universe is called **astronomy**. Scientists who study the universe are called *astronomers*.

The Value of Astronomy

In the process of observing the universe, astronomers have made exciting discoveries, such as new planets, stars, black holes, and nebulae, such as the one shown in **Figure 1**. By studying these objects, astronomers have been able to learn more about the origin of Earth and the processes involved in the formation of our solar system and other objects in the universe.

Studying the universe is also important for the potential benefits to humans. For example, studies of how stars shine may one day lead to improved or new energy sources on Earth. Astronomers may also learn how to protect us from potential catastrophes, such as collisions between asteroids and Earth. Because of these and other contributions, astronomical research is supported by federal agencies, such as the National Science Foundation and NASA. Private foundations and industry also fund research in astronomy.

Figure 1 A nebula is a large cloud of gas and dust in space. This nebula is called the Eskimo nebula. It formed as a result of the outer layers of the central star being blown away. Astronomers predict that our sun will reach this state in about 5 billion years.

astronomy the scientific study of the universe

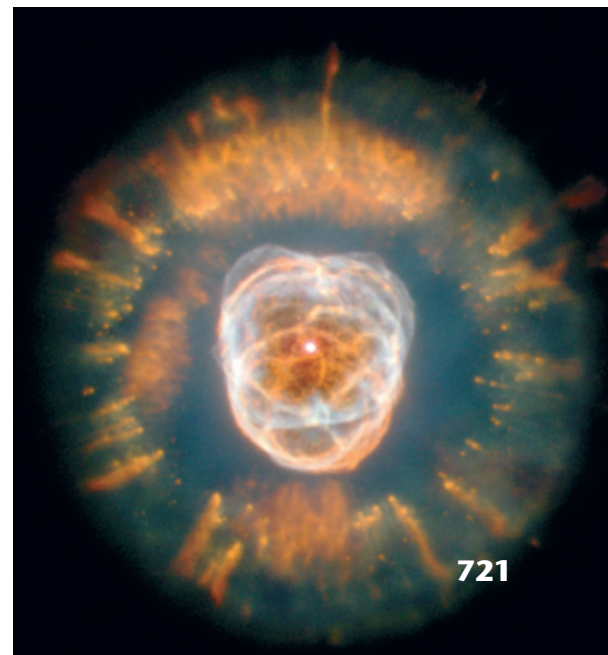




Figure 2 The Whirlpool galaxy, M51 (above), is 31 million light-years from the Milky Way. Abell 2218 (right) is one of the most massive galaxy clusters known. The cluster's mass has distorted the light from even farther objects into the giant arcs shown here.



Characteristics of the Universe

The study of the origin, properties, processes, and evolution of the universe is called *cosmology*. Astronomers have determined that the universe began about 13.7 billion years ago in one giant explosion, called the *big bang*. Since that time, the universe has continued to expand. In fact, it is expanding faster and faster. The universe is very large, and the objects within it are extremely far apart. Telescopes are used to study distant objects. However, astronomers also commonly use computer and mathematical models to study the universe.

Math Skills

Astronomical Unit

An astronomical unit is the average distance between the sun and Earth, or about 150 million km. Venus orbits the sun at a distance of 0.7 AU. Venus is how many kilometers from the sun?

galaxy a collection of stars, dust, and gas bound together by gravity

astronomical unit the average distance between Earth and the sun; approximately 150 million kilometers (symbol, AU)

Organization of the Universe

The nearest part of the universe to Earth is our solar system. The solar system includes the sun, Earth, the other planets, and many smaller objects such as dwarf planets, asteroids, and comets. The solar system is part of a **galaxy**, which is a large collection of stars, dust, and gas bound together by gravity. The galaxy in which the solar system resides is called the *Milky Way galaxy*. Beyond the Milky Way galaxy, there are billions of other galaxies, dozens of which are shown in **Figure 2**.

Measuring Distances in the Universe

Because the universe is so large, the units of measurement used on Earth are too small to represent the distance between objects in space. To measure distances in the solar system, astronomers often use astronomical units. An **astronomical unit** (symbol, AU) is the average distance between Earth and the sun, which is 149,597,870.691 km or about 150 million km.

Astronomers also use the speed of light to measure distance. Light travels at 300,000 km/s. In one year, light travels 9.46×10^{12} km. This distance is known as a *light-year*. Aside from the sun, the closest star to Earth is 4.22 light-years away.

Observing Space

Light enables us to see the world around us and to make observations. When people look at the night sky, they see stars and other objects in space because of the light these objects emit. This visible light is only a small amount of the energy that comes from these objects. By studying other forms of energy, astronomers are able to learn more about the universe. Recall that planets do not emit light. Rather, they reflect the light from stars.

Electromagnetic Spectrum

Visible light is a form of energy that is part of the electromagnetic spectrum. The **electromagnetic spectrum** is all the wavelengths of electromagnetic radiation. Light, radio waves, and X rays are examples of electromagnetic radiation. The radiation is composed of traveling waves of electric and magnetic fields that have fixed wavelengths and therefore fixed frequencies.

electromagnetic spectrum all of the frequencies or wavelengths of electromagnetic radiation

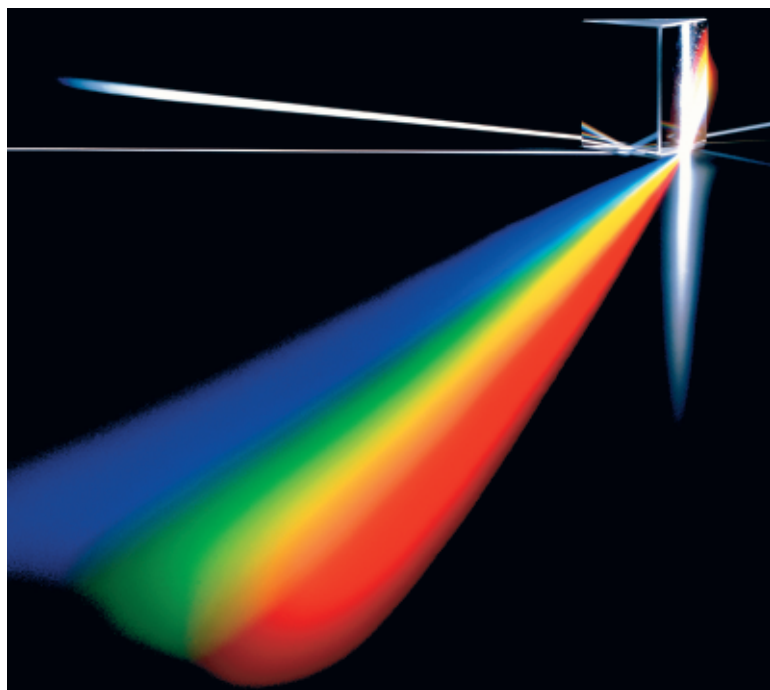
Visible Electromagnetic Radiation

The human eye can see only radiation of wavelengths in the visible light range of the spectrum. When white light passes through a prism, the light is refracted (bent), and a continuous set of colors, as shown in **Figure 3**, results. Every rainbow formed in the sky and any spectrum formed by a prism always has the same colors in the same order. The different colors result because each color of light has a characteristic wavelength that refracts at a different angle when it passes from one medium, such as air, into another, such as a glass prism. For example, the shortest wavelengths of visible light are blue and violet, while the longest wavelengths are orange and red.

Electromagnetic radiation that has wavelengths that are shorter than the wavelengths of violet light or longer than the wavelengths of red light cannot be seen by humans. But these wavelengths can be detected by instruments that are designed to detect electromagnetic radiation that cannot be seen by human eyes. These invisible wavelengths include infrared waves, microwaves, and radio waves (at longer wavelengths than red), as well as ultraviolet rays, X rays, and gamma rays (at shorter wavelengths than blue).

Reading Check Which type of electromagnetic radiation can be seen by humans? (See Appendix G for answers to Reading Checks.)

Figure 3 When white light (shown here coming from the upper left) passes from air, through a prism (top right), and then back into air, the light is separated into its different colors.



Invisible Electromagnetic Radiation

If you place a thermometer in any wavelength of the visible spectrum, the temperature reading on the thermometer will rise. In 1800, the scientist William Herschel placed a thermometer just beyond the red end of the visible spectrum. Even though he could not see any light shining on the thermometer, the temperature reading on the thermometer still increased. Herschel had discovered infrared, which means “below the red.” Infrared is electromagnetic radiation that has wavelengths that are longer than those of visible light. Other scientists later discovered radio waves, which have even longer wavelengths than infrared.

The ultraviolet wavelengths, which are invisible to humans, are shorter than the wavelengths of violet light. *Ultraviolet* means “beyond the violet.” The X-ray wavelengths are shorter than the ultraviolet wavelengths are. The shortest wavelengths are the gamma-ray wavelengths.

Telescopes

Our eyes can see detail, but some things are too small or too far away to see. Our ability to see the detail of distant objects in the sky began with the Italian scientist Galileo. In 1609, he heard of a device that used two lenses to make distant objects appear closer. He built one of the devices and turned it toward the sky. For the first time, he could see that there are craters on the moon and that the Milky Way is made of stars. Later, Isaac Newton invented another kind of telescope. An example of one of these early devices is shown in **Figure 4**.

A **telescope** is an instrument that collects electromagnetic radiation from the sky and concentrates it for better observation. While modern telescopes are able to collect and use invisible electromagnetic radiation, the first telescopes that were developed collected only visible light. Telescopes that collect only visible light are called *optical telescopes*. The two types of optical telescopes are refracting telescopes and reflecting telescopes.

Academic Vocabulary

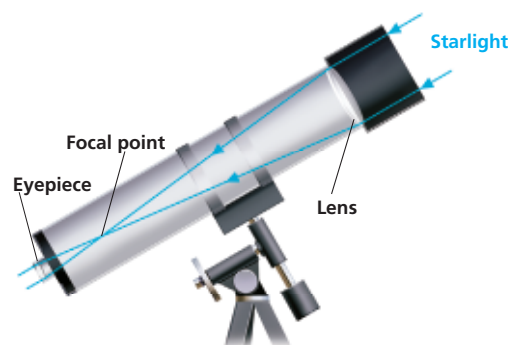
device (di VIES) a piece of equipment made for a specific use

telescope an instrument that collects electromagnetic radiation from the sky and concentrates it for better observation

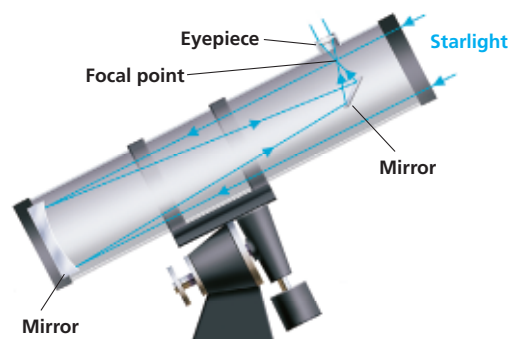
Figure 4 An early model of one of the first reflecting telescopes, which was invented by Isaac Newton, can be seen at the Royal Society in London, England.



Figure 5 Refracting and Reflecting Telescopes



Refracting telescopes use lenses to gather and focus light from distant objects.



Reflecting telescopes use mirrors to gather and focus light from distant objects.

Refracting Telescopes

Lenses are clear objects shaped to bend light in special ways. The bending of light by lenses is called *refraction*. Telescopes that use a set of lenses to gather and focus light from distant objects are called **refracting telescopes**. Refracting telescopes have an objective lens that bends light that passes through the lens and focuses the light to be magnified by an eyepiece, as shown in **Figure 5**.

One problem with refracting telescopes is that the lens focuses different colors of light at different distances. For example, if an object is in focus in red light, the object will appear out of focus in blue light. Another problem with refracting telescopes is that it is difficult to make very large lenses of the required strength and clarity. The amount of light collected from distant objects is limited by the size of the objective lens.

Reflecting Telescopes

In the mid-1600s, Isaac Newton solved the problem of color separation that resulted from the use of lenses. He invented the **reflecting telescope**, which used a curved mirror to gather and focus light from distant objects, as shown in **Figure 5**. When light enters a reflecting telescope, the light is reflected by a large curved mirror to a second mirror. The second mirror reflects the light to the eyepiece, which is a lens that magnifies and focuses the image.

Unlike objective lenses in refracting telescopes, mirrors in reflecting telescopes can be made very large without affecting the quality of the image. Thus, reflecting telescopes can be much larger and can gather more light than refracting telescopes can. The largest reflecting telescopes that can point anywhere in the sky are a pair called the Keck Telescopes in Hawaii and a slightly larger one in the Canary Islands. Each telescope is 10 m in diameter. Astronomers are tentatively planning to build an ELT (Extremely Large Telescope) that would be about 50 m in diameter and an OWL (Overwhelmingly Large Telescope) that would be 100 m in diameter.

refracting telescope a telescope that uses a set of lenses to gather and focus light from distant objects

reflecting telescope a telescope that uses a curved mirror to gather and focus light from distant objects

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Reading Check What are the problems with refracting telescopes?



Figure 6 Radio telescopes, such as this one (of 27) at the National Radio Astronomy Observatory in New Mexico, provide scientists with information about objects in space.

Telescopes for Invisible Electromagnetic Radiation

Each type of electromagnetic radiation provides scientists with information about objects in space. Scientists have developed telescopes that detect invisible radiation. For example, a radio telescope, such as the one shown in **Figure 6**, detects radio waves. There are also telescopes that detect gamma rays, X rays, and infrared rays.

One problem with using telescopes to detect invisible electromagnetic radiation is that Earth's atmosphere acts as a shield against many forms of electromagnetic radiation. Atoms and molecules in the atmosphere prevent short wavelengths like gamma rays, X rays, and most ultraviolet rays from reaching Earth's surface. Water vapor blocks infrared rays, so ground-based telescopes that are used to study infrared work best at high elevations, where the air is thin and dry. But the only way to study many forms of radiation is from space.

Space-Based Astronomy

While ground-based telescopes have been critical in helping astronomers learn about the universe, valuable information has also come from spacecraft. Spacecraft that contain telescopes and other instruments have been launched to investigate planets, stars, and other distant objects. In space, Earth's atmosphere cannot interfere with the detection of electromagnetic radiation.

Reading Check Why do scientists launch spacecraft beyond Earth's atmosphere?

Why It Matters

The Interstellar Playlist

Telescopes gather data from outer space for us to study on Earth. The two Voyager probes carry data in the opposite direction. They carry the Golden Record, which stores 115 images, greetings in 55 languages, sounds from nature, and music from different cultures and eras.



The Golden Record has coded instructions to explain its use and origin. The image at right is one of the images stored on the recording.



The Voyager probes were launched in 1977 and are still traveling out of the solar system. Their power will last until at least 2025.

YOUR TURN

CRITICAL THINKING

If you were to make a new Golden Record, what would you put on it? Why?





Figure 7 The *Hubble Space Telescope* is in orbit around Earth, where the telescope can detect visible and nonvisible electromagnetic radiation without the obstruction of Earth's atmosphere.

READING TOOLBOX

Frequency

Compare your list of frequency-word statements with the lists made by other students. Add to your list if there are any statements that you missed.

Space Telescopes

The *Hubble Space Telescope*, shown in **Figure 7**, is an example of a telescope that has been launched into space to collect electromagnetic radiation from objects in space. Another example, the *Chandra X-ray Observatory*, makes remarkably clear images using X rays from objects in space, such as the remnants of exploded stars. The *Swift* spacecraft detects gamma rays and X rays from explosions and collisions of objects such as black holes. The *Spitzer Space Telescope* detects infrared radiation. The *James Webb Space Telescope* is scheduled to be launched in 2013. When deployed in space, this telescope will be used to detect near- and mid-range infrared radiation from objects in space.

Other Spacecraft

Since the early 1960s, spacecraft have been sent out of Earth's orbit to study other planets. Launched in 1977, the space probes *Voyager 1* and *Voyager 2* investigated Jupiter, Saturn, Uranus, and Neptune. These two spacecraft collected images of these planets and their moons. The *Galileo* spacecraft was in orbit around Jupiter and its moons from 1995 to 2003. This space probe gathered information about the composition of Jupiter's atmosphere and storm systems, which are several times larger than Earth's storm systems. The *Cassini* spacecraft began orbiting Saturn in 2004. In December 2004, the *Huygens* probe detached from the *Cassini* orbiter to study the atmosphere and surface of Titan, Saturn's largest moon. The twin Mars rovers *Spirit*, shown in **Figure 8**, and *Opportunity* landed on Mars in January 2004. They confirmed that water had once been present on Mars. In 2008, the *Phoenix* lander found ice on Mars.

Figure 8 The Mars rover *Spirit* and its twin, *Opportunity*, have transmitted thousands of images of the red planet to scientists on Earth. The mission was originally planned to last only three months, but the rovers continued to operate for several years.





Figure 9 Astronaut Doug Wheelock installs a truss that supports a set of solar panels on the International Space Station.

Human Space Exploration

Spacecraft that carry only instruments and computers are described as *robotic*. These spacecraft can explore space and travel beyond the solar system. Crewed spacecraft, or those that carry humans, have never gone beyond Earth's moon.

The first humans went into space in the 1960s. Between 1969 and 1972, NASA landed 12 people on the moon. Now, crewed spaceflights only orbit Earth. Flights, such as those aboard the space shuttles, allow people to release or repair satellites, to perform scientific experiments, or to live and work on the International Space Station, as shown in **Figure 9**.

Eventually, NASA would like to send people to explore Mars. However, such a voyage would be expensive, difficult, and dangerous. The loss of two space shuttles and their crews, the *Challenger* in 1986 and the *Columbia* in 2003, have focused public attention on the risks of human space exploration. NASA is planning first to send astronauts back to the moon.

Spinoffs of the Space Program

Space programs have brought benefits to areas outside the field of astronomy. Satellites in orbit provide information about weather all over Earth. This information helps scientists make accurate weather predictions days in advance. Other satellites broadcast television signals from around the world or allow people to navigate cars and airplanes. Inventing ways to make objects smaller and lighter so that they can go into space has also led to improved electronics. These technological developments have been applied to radios, televisions, and other equipment. Even medical equipment has benefited from space programs. For example, heart pumps have been improved based on NASA's research on the flow of fluids through rockets.

Section 1 Review

Key Ideas

1. **Describe** characteristics of the universe in terms of time, distance, and organization.
2. **Identify** the parts of the electromagnetic spectrum, both visible and invisible.
3. **Explain** how astronomers use electromagnetic radiation to study space.
4. **Compare** reflecting telescopes and refracting telescopes.
5. **Explain** how a radio telescope differs from an optical telescope.
6. **Identify** two examples of space telescopes and two examples of space probes.

Critical Thinking

7. **Identifying Relationships** Using the development of reflecting telescopes as an example, explain how scientific inquiry leads to advances in technology.
8. **Analyzing Processes** Human space exploration is expensive and dangerous. Explain why NASA should or should not continue doing it.

Concept Mapping

9. Use the following terms to create a concept map: *electromagnetic radiation, reflecting telescope, refracting telescope, telescope, probe, astronomy, universe, Voyager, and Cassini*.

Movements of Earth

Key Ideas

- Describe two lines of evidence for Earth's rotation.
- Explain how the change in apparent positions of constellations provides evidence of Earth's rotation and revolution around the sun.
- Summarize how Earth's rotation and revolution provide a basis for measuring time.
- Explain how the tilt of Earth's axis and Earth's movement cause seasons.

Key Terms

rotation
revolution
perihelion
aphelion
equinox
solstice

Why It Matters

Earth's rotation and revolution are responsible for natural events such as day and night, weather patterns, and the seasons. We also measure and tell time based on Earth's movements.

Understanding the basic motions of Earth helps scientists understand the motions of other bodies in the solar system and the universe. These movements of Earth are also responsible for the seasons and the changes in weather.

The Rotating Earth

The spinning of Earth on its axis is called **rotation**. Each complete rotation takes one day. The most observable effects of Earth's rotation on its axis are day and night. As Earth rotates from west to east, the sun appears to rise in the east in the morning. The sun then appears to cross the sky and set in the west. At any given moment, the part of Earth that faces the sun experiences daylight. At the same time, the part of Earth that faces away from the sun experiences nighttime.

rotation the spin of a body on its axis

The Foucault Pendulum

In the 19th century, the scientist Jean-Bernard-Leon Foucault provided evidence of Earth's rotation by using a pendulum. He created a long, heavy pendulum that rocks back and forth by attaching a wire to the ceiling and then attaching a weight, called a *bob*, to the wire. Throughout the day, the bob would swing back and forth. The path of the pendulum appeared to change over time. However, it was the floor that was moving while the pendulum's path stayed constant. Because the floor was attached to Earth, one can conclude that Earth rotates. A Foucault pendulum is shown in **Figure 1**.

Figure 1 The 12 ft arc of this Foucault pendulum in Spokane, Washington, appears to change throughout the day. However, the actual path of the pendulum does not change. Instead, it is the floor that moves as Earth rotates under the pendulum.



A Model Pendulum

Procedure

- 1 Use a **yo-yo**, or tie a **small object** to one end of a **length of string** to make a pendulum.
- 2 Hold the end of the string in your fingers, and swing the pendulum.
- 3 Twist the string in your fingers as you allow the pendulum to continue swinging.

Analysis

1. Does the direction in which the yo-yo swings change?
2. Does the yo-yo twist around with the string?
3. How does this experiment differ from the operation of a Foucault pendulum?

revolution the motion of a body that travels around another body in space; one complete trip along an orbit

perihelion in the orbit of a planet or other body in the solar system, the point that is closest to the sun

aphelion in the orbit of a planet or other body in the solar system, the point that is farthest from the sun

Figure 2 As Earth revolves around its elliptical orbit, the planet is farthest from the sun in July and closest to the sun in January. The elliptical orbit in this illustration has been exaggerated for emphasis.

The Coriolis Effect

Evidence of the rotation of Earth can also be seen in the movement of ocean surface currents and wind belts. Ocean currents and wind belts do not move in a straight path. The rotation of Earth causes ocean currents and wind belts to be deflected to the right in the Northern Hemisphere. In the Southern Hemisphere, ocean currents and wind belts deflect to the left. This curving of the path of wind belts and ocean currents is caused by Earth's rotation underneath the atmosphere and the sea and is called the *Coriolis effect*.

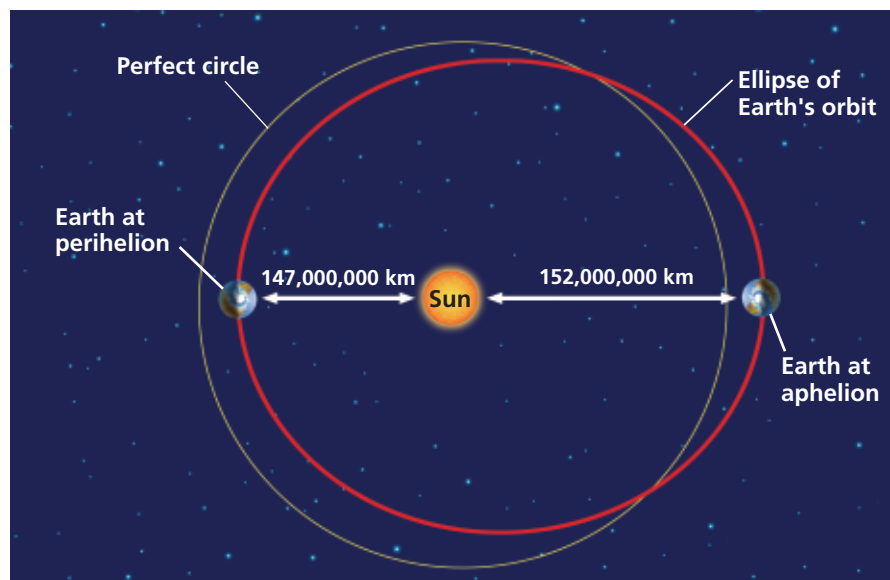
The Revolving Earth

As Earth spins on its axis, Earth also revolves around the sun. Even though you cannot feel Earth moving, it is traveling around the sun at an average speed of 29.8 km/s. The motion of a body that travels around another body in space is called **revolution**. Each complete revolution of Earth around the sun takes one year, or about 365 $\frac{1}{4}$ days.

Earth's Orbit

The path that a body follows as it travels around another body in space is called an *orbit*. Earth's orbit around the sun is not quite a circle. Earth's orbit is an ellipse. An *ellipse* is a closed curve whose shape is determined by two points, or *foci*, within the ellipse. In planetary orbits in our solar system, one focus is located deep within the sun. No object is located at the other focus.

Because its orbit is an ellipse, Earth is not always the same distance from the sun. The point in the orbit of a planet at which the planet is closest to the sun is the **perihelion**. The point in the orbit of a planet at which the planet is farthest from the sun is the **aphelion** (uh FEE lee uhn). As shown in **Figure 2**, Earth's aphelion distance is 152 million km. Its perihelion distance is 147 million km.



Constellations and Earth's Motion

Evidence of Earth's revolution and rotation around the sun can be seen in the motion of constellations. A *constellation* is a group of stars that are organized in a recognizable pattern. In 1930, the International Astronomical Union divided the sky into 88 constellations. Many of the names given to these constellations came from the ancient Greeks more than 2,000 years ago. Taurus, the bull, and Orion, the hunter, are some examples of names from Greek mythology that have been given to constellations.

Evidence of Earth's Rotation

If you gaze at a constellation in the evening sky, you might notice that it appears to be moving in the shape of an arc, as if it were tracing a circle around a fixed point. The apparent change in its position occurs for the same reason that the sun appears to move across the daytime sky. That is, Earth's rotation makes the constellations appear to move in this way.

Evidence of Earth's Revolution

The position of a constellation in the evening sky changes not only because of Earth's rotation but also because of Earth's revolution around the sun. Examine **Figure 3**, which shows the same region of the sky at the same time of night in February and in March. Notice that all the constellations appear lower in the sky in March than they do in February. This change in the position of the constellations is a result of Earth's revolution. As Earth revolves around the sun, the night side of Earth faces in a different direction of the universe. Thus, as Earth moves, different constellations are visible in the night sky from month to month and from season to season.

 **Reading Check** How does the movement of the constellations provide evidence of Earth's rotation and revolution?



Figure 3 In one month's period, the position of the constellations in the sky seen from Denver, Colorado, at 10 PM change because of the revolution of Earth.

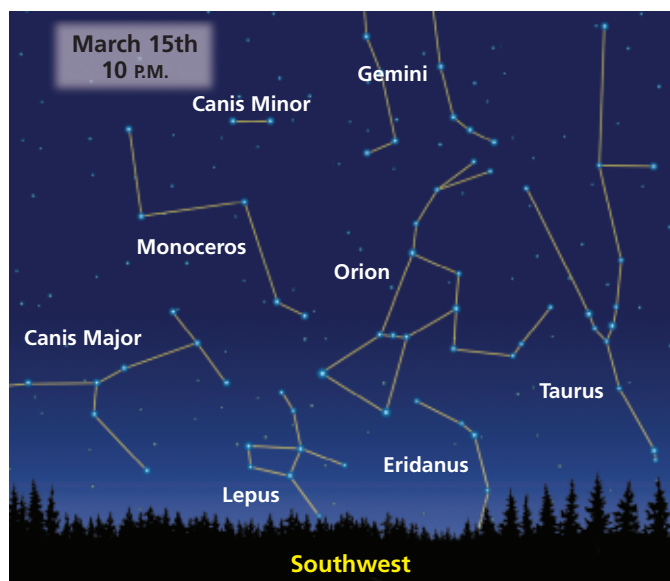
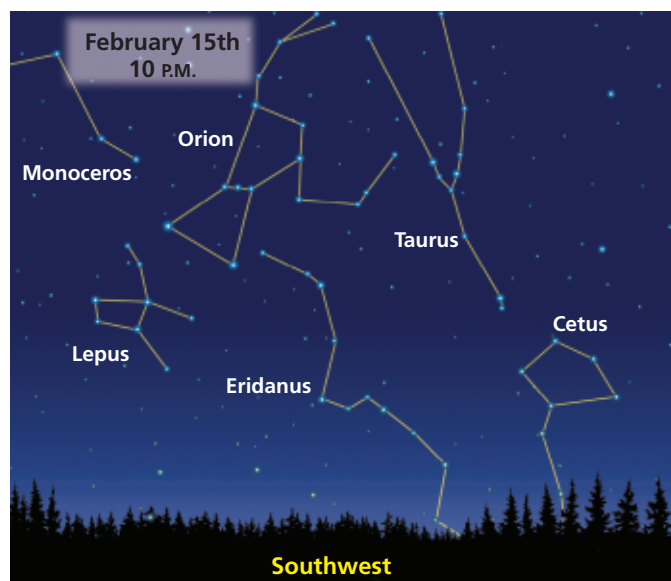




Figure 4 This is a reconstruction of a 3.6 m stone carving that functioned, in part, as a calendar based on solar and lunar cycles.

READING TOOLBOX

Using Spatial Language

How important is spatial language for communicating with people? Choose three sentences in Section 2 that use spatial words or phrases. Try to rewrite each sentence without using the spatial language. Can you do it?

Measuring Time

Earth's motion provides the basis for measuring time. For example, the day and year are based on periods of Earth's motion. The day is determined by Earth's rotation on its axis. Each complete rotation of Earth on its axis is one day, which is then divided into 24 hours.

The year is determined by Earth's revolution around the sun. Each complete revolution of Earth around the sun takes $365 \frac{1}{4}$ days, or one year.

A month is based on the moon's motion around Earth. A month was originally determined by the period between successive full moons, which is 29.5 days. The word *month* actually comes from the word *moon*. However, the number of full moons in a year is not a whole number. Therefore, a month is now determined as roughly one-twelfth of a year.

Formation of the Calendar

A *calendar* is a system created for measuring long intervals of time by dividing time into periods of days, weeks, months, and years. Many ancient civilizations created versions of calendars based on astronomical cycles. The ancient Egyptians used a calendar based on a solar year. The Babylonians used a 12-month lunar year. The Aztecs, who lived in what is now Mexico, also created a calendar, which is shown in **Figure 4**.

Because the year is about $365 \frac{1}{4}$ days long, the extra $\frac{1}{4}$ day is usually ignored to make the number of days on a calendar a whole number. To keep the calendars on the same schedule as Earth's movements, we must account for the extra time. So, every four years, one day is added to the month of February. Any year that contains an extra day is called a *leap year*.

More than 2,000 years ago, Julius Caesar, of the Roman Empire, revised the calendar so that an extra day every four years was added. His successor, Augustus Caesar, made the extra day come at the end of the shortest month, February. He also made July and August long months with 31 days each.

The Modern Calendar

Because the year is not exactly 365 days long, over centuries, the calendar gradually became misaligned with the seasons. In the late 1500s, Pope Gregory XIII formed a committee to create a calendar that would keep the calendar aligned with the seasons. We use this calendar today. In this Gregorian calendar, century years, such as 1800 and 1900, are not leap years unless the century years are exactly divisible by 400. Thus, 2000 was a leap year even though it was a century year. However, 2100, 2200, and 2300 will not be leap years.

Time Zones

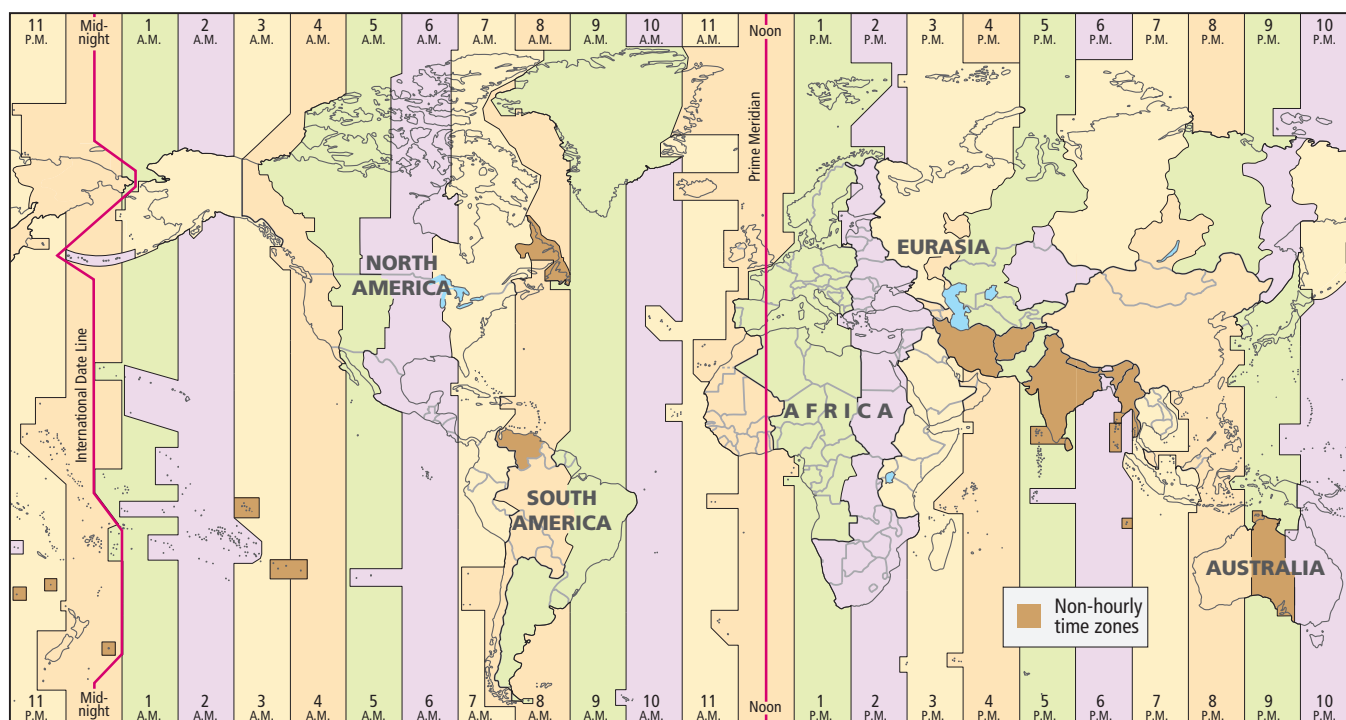
Using the sun as the basis for measuring time, we define noon as the time when the sun is highest in the sky. Because of Earth's rotation, the sun is highest above different locations on Earth at different times of day. Earth's surface has been divided into 24 standard time zones, as shown in **Figure 5**, to avoid problems created by different local times. In each zone, noon is set as the time when the sun is highest over the center of that zone. Earth's circumference equals 360° measured from Earth's center. If you divide 360° by the 24 hours needed for one rotation, you find that Earth rotates at a rate of 15° per hour. Therefore, each of Earth's 24 standard time zones covers about 15° . The time in each zone is one hour earlier than the time in the zone to the east of each zone.

International Date Line

There are 24 standard time zones and 24 h in a day. But there must be some point on Earth's surface where the date changes. The *International Date Line* was established to prevent confusion. The International Date Line is an imaginary line that runs from north to south through the Pacific Ocean. When it is Friday west of the International Date Line, it is Thursday east of the line. The line is drawn so that it does not cut through islands or continents. Thus, everyone living within one country has the same date. Note where the line is drawn between Alaska and Siberia in **Figure 5**.

Reading Check What is the purpose of the International Date Line?

Figure 5 Earth has been divided into 24 standard time zones. A few time zones may differ between 15 and 45 minutes compared to most time zones. If it is 6 P.M. in Florida, what time would it be in California?



Academic Vocabulary

significant (sig NIF uh kahnt)
important

Daylight Savings Time

Because of the tilt of Earth's axis, the duration of daylight is shorter in the winter months than in the summer months. During the summer months, days are longer so that the sun rises earlier in the morning when many people are still sleeping. To take advantage of that daylight time, the United States uses *daylight savings time*. Under this system, clocks are set one hour ahead of standard time in March, which provides an additional hour of daylight during the evening. The additional hour also saves energy because the use of electricity decreases. In November, clocks are set back one hour to return to standard time. Countries that are in the equatorial region do not observe daylight savings time because there are not significant changes in the amount of daylight time in the equatorial region. There, daylight is about 12 h every day of the year.

The Seasons

Earth's axis is tilted at 23.5° . As Earth revolves around the sun, Earth's axis always points toward the North Star. Thus, during each revolution, the North Pole sometimes tilts toward the sun and sometimes tilts away from the sun, as shown in **Figure 6**. When the North Pole tilts toward the sun, the Northern Hemisphere has longer periods of daylight than the Southern Hemisphere does. When the North Pole tilts away from the sun, the Southern Hemisphere has longer periods of daylight.

The angle at which the sun's rays strike each part of Earth's surface changes as Earth moves through its orbit. When the North Pole tilts toward the sun, the sun's rays strike the Northern Hemisphere more directly. When the sun's rays strike Earth directly, that region receives a higher concentration of solar energy and is warmer. When the North Pole tilts away from the sun, the sun's rays strike the Northern Hemisphere less directly. When the sunlight is less direct, the concentration of solar energy is less and that region is cooler.

Reading Check What is daylight savings time?



Figure 6 The direction of tilt of Earth's axis remains the same throughout Earth's orbit around the sun. Thus, the Northern Hemisphere receives more direct sunlight during summer months and less direct sunlight during winter months.



Seasonal Weather

Changes in the angle at which the sun's rays strike Earth's surface cause the seasons. When the North Pole tilts away from the sun, the angle of the sun's rays falling on the Northern Hemisphere is low. As a result, the sun's rays spread solar energy over a large area, which leads to lower temperatures. The tilt of the North Pole away from the sun also causes the Northern Hemisphere to experience fewer daylight hours. Fewer daylight hours also means less energy and lower temperatures. Lower temperatures cause the winter seasons. During winter, the Northern Hemisphere tilts away from the sun, and the Southern Hemisphere tilts toward the sun. The sun's rays strike the Southern Hemisphere at a greater angle than they do in the Northern Hemisphere, and there are more daylight hours in the Southern Hemisphere. Therefore, the Southern Hemisphere experiences summer. So, the seasons are caused by the tilt of Earth's axis and not by Earth's distance from the sun.

Equinoxes

The seasons fall and spring begin on days called equinoxes. An **equinox** is the moment when the sun appears to cross the celestial equator. The *celestial equator* is an imaginary line in the sky directly overhead from the equator on Earth. During an equinox, the sun's rays strike Earth at a 90° angle along the equator. The hours of daylight and darkness are approximately equal everywhere on Earth on that day. The *autumnal equinox* occurs on September 22 or 23 of each year and marks the beginning of fall in the Northern Hemisphere. The *vernal equinox* occurs on March 21 or 22 of each year and marks the beginning of spring in the Northern Hemisphere.

equinox the moment when the sun appears to cross the celestial equator

Quick Lab



10 min

The Angle of the Sun's Rays

Procedure

- 1 Turn the lights down low or off in the classroom.
- 2 Place a **piece of paper** on the floor. Using a **meterstick**, hold a **flashlight** 1 m above the paper, and shine the light of the flashlight straight down on the piece of paper.
- 3 Have a partner outline the perimeter of the circle of light cast by the flashlight on the paper. Label the circle " 90° angle." Place a clean piece of paper on the floor.
- 4 At a height of 0.5 m from the floor, shine the light of the flashlight on the paper at an angle. Make sure the distance between the flashlight and the paper is 1 m.
- 5 Have a partner outline the perimeter of the circle of light cast by the flashlight on the paper. Label the circle "low angle."



Analysis

1. Compare the two circles drawn in steps 3 and 5. Which circle concentrates the light in a smaller area?
2. Which circle would most likely model the sun's rays striking Earth during the summer season?

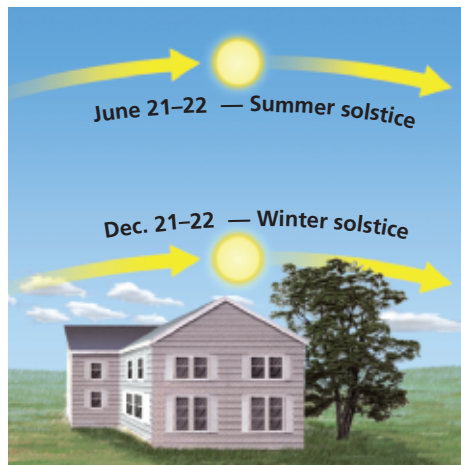


Figure 7 In the Northern Hemisphere, the sun appears to follow its highest path across the sky during the summer solstice and its lowest path across the sky during the winter solstice.

solstice the point at which the sun is as far north or as far south of the equator as possible

Summer Solstices

The seasons of summer and winter begin on days called **solstices**. Each year on June 21 or 22, the North Pole's tilt toward the sun is greatest. On this day, the sun's rays strike Earth at a 90° angle along the Tropic of Cancer, which is located at 23.5° north latitude. This day is called the *summer solstice* and marks the beginning of summer in the Northern Hemisphere. *Solstice* means "sun stop" and refers to the fact that in the Northern Hemisphere, the sun follows its highest path across the sky on this day, as shown in **Figure 7**, and then moves lower every day afterward.

The Northern Hemisphere has its most hours of daylight during the summer solstice. The farther north of the equator you are, the longer the period of daylight you have. North of the Arctic Circle, which is located at 66.5° north latitude, there are 24 h of daylight during the summer solstice. At the other extreme, south of the Antarctic Circle, there are 24 h of darkness at that time.

Winter Solstices

By December, the North Pole is tilted to the farthest point away from the sun. On December 21 or 22, the sun's rays strike Earth at a 90° angle along the Tropic of Capricorn, which is located at 23.5° south latitude. This day is called the *winter solstice*. It marks the beginning of winter in the Northern Hemisphere. During the winter solstice, the Northern Hemisphere has the fewest daylight hours. The sun follows its lowest path across the sky. Places that are north of the Arctic Circle then have 24 h of darkness. However, places that are south of the Antarctic Circle have 24 h of daylight at that time.

Section 2 Review

Key Ideas

- 1. Explain** how the apparent change of position of constellations over time provides evidence of Earth's revolution around the sun.
- 2. Describe** two lines of evidence that indicate that Earth is rotating.
- 3. Summarize** how movements of Earth provide a basis for measuring time.
- 4. Explain** why today's calendars have leap years.
- 5. Identify** two advantages in using daylight savings time.
- 6. Explain** how the tilt of Earth's axis and Earth's movements cause seasons.
- 7. Identify** the position of Earth in relation to the sun that causes winter in the Northern Hemisphere.

- 8. Describe** the position of Earth in relation to the sun during the Northern Hemisphere's summer solstice.

Critical Thinking

- 9. Understanding Relationships** How can it be that Earth is at perihelion during wintertime in the Northern Hemisphere?
- 10. Predicting Consequences** Explain how measurements of time might differ if Earth rotated on its axis only once per year.

Concept Mapping

- 11.** Use the following terms to create a concept map: *revolution, perihelion, aphelion, rotation, ellipse, orbit, rotation, Foucault pendulum, Coriolis effect, Earth, and constellation*.

What Time Is It?

REAL
WORLD

“Synchronizing your watches” is a surprisingly intricate undertaking. Coordinated Universal Time (UTC), also called civil time, is the time we live by. It is based on Earth’s rotation rate. Although the time for a full rotation of Earth is usually expressed as 24 h per day, it is actually 23 h 56 min 4s. As well, Earth’s rotation rate is not constant—the moon’s gravity is slowing it down. Thus, scientists use atomic clocks to establish International Atomic Time (TAI). Atomic clocks are very precise, because they are based on the vibration rate of atoms. To synchronize UTC with TAI, leap seconds may be added to UTC. Since 1972, 23 leap seconds have been added.

International Atomic Time

Data from about 250 atomic clocks, located in about 50 laboratories around the world, are averaged.

International Atomic Time (TAI)

Coordinated
Universal Time
(UTC)

Add leap seconds.

Civil time as reported on radio, TV,
computer networks, and other media

YOUR
TURN

UNDERSTANDING CONCEPTS

What is the role of atomic clocks in determining civil time?

CRITICAL THINKING

Why is accurate time necessary? Name two situations in which accurate time is very important.

What You'll Do

- **Design** an experiment to measure the movement of Earth.
- **Analyze** the effectiveness of your experimental design.
- **Demonstrate** how shadows can be used to measure time.

What You'll Need

board, wooden,
20 cm × 30 cm
clock or watch
compass, magnetic
dowel, 30 cm long,
0.64 cm (¼ inch) diameter
paper, lined
pencil
ruler, metric
tape, masking

Earth-Sun Motion

During the course of a day, the sun moves across the sky. This motion is due to Earth's rotation. In ancient times, one of the earliest devices used by people to study the sun's motion was the shadow stick. The shadow stick is a type of sundial. Before clocks were invented, sundials were one of the only means of telling time.

In this lab, you will use a shadow stick to identify how changes in a shadow are related to Earth's rotation. You will also determine how a shadow stick can be used to measure time.

Ask a Question

- 1 How can I measure the movement of Earth?

Form a Hypothesis

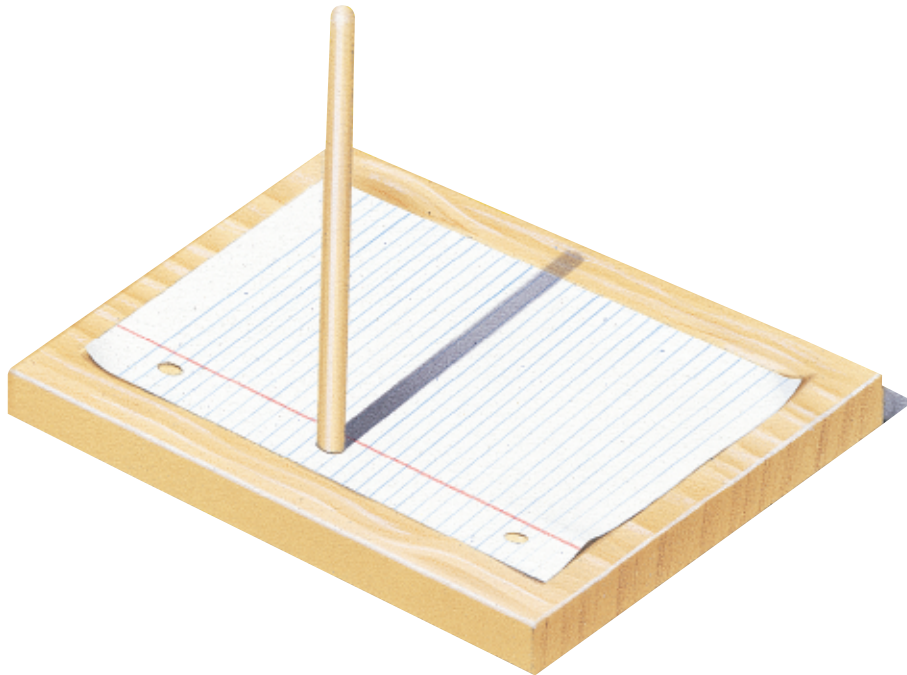
- 2 With a partner, build a shadow stick apparatus that is similar to the one in the illustration on the following page. Brainstorm with your partner a way in which you can use the apparatus in an experiment to measure the movement of Earth for 30 min. Write a few sentences that describe your design and your hypothesis about how this experiment will measure Earth's motion.

Step 2



Test the Hypothesis

- 3 When you complete your experimental design, have your teacher approve your design before you begin. **CAUTION** Never look directly at the sun.
- 4 Follow your design to set up and complete your experiment.
- 5 Take measurements every 5 min, and record this information in a data table.



Analyze the Results

1. **Analyzing Data** In what direction did the sun appear to move in the 30 min period?
2. **Evaluating Methods** If you made your shadow stick half as long, would its shadow move the same distance in 30 min? Explain your answer.
3. **Evaluating Methods** Would you make any changes to your experimental design? Explain your answer.

Draw Conclusions

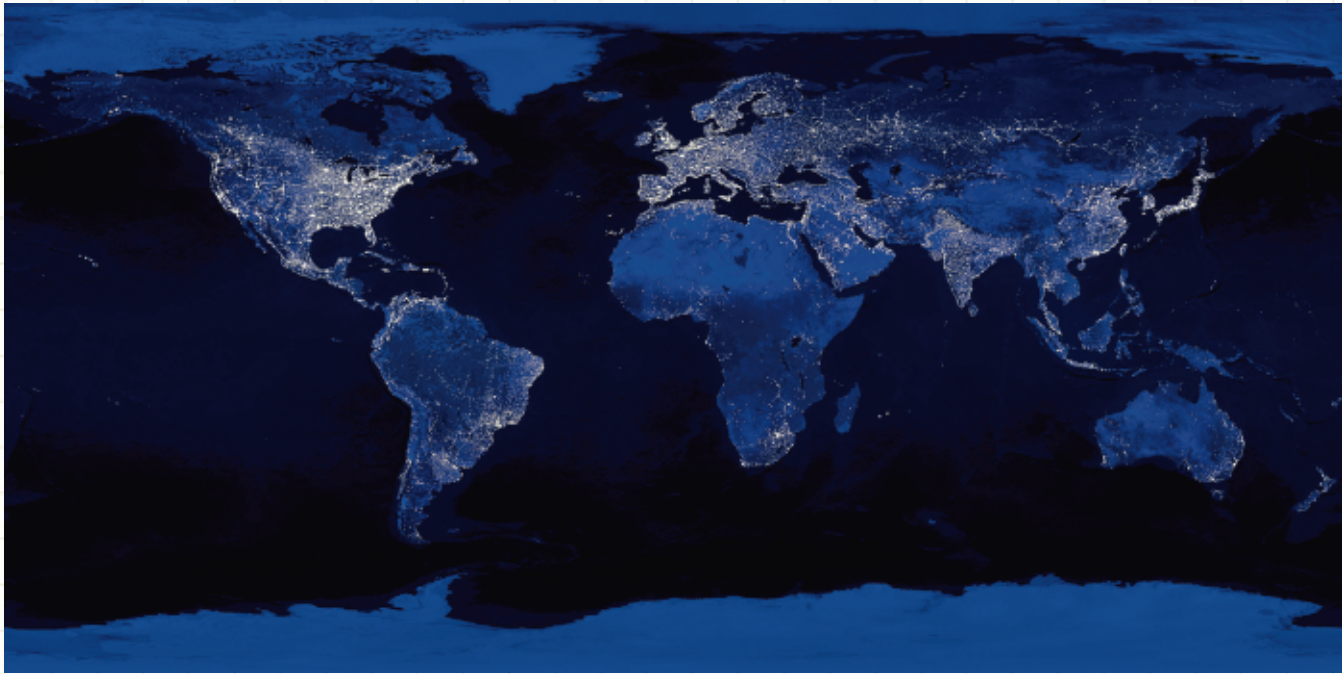
4. **Drawing Conclusions** In what direction does Earth rotate?
5. **Applying Conclusions** How might a shadow stick be used to tell time?

Extension

Evaluating Methods

Repeat this lab at different hours of the day. Perform the lab early in the morning, early in the afternoon, and early in the evening. Record the results and any differences that you observe. Explain how shadow sticks can be used to tell direction.

Light Sources



Map Skills Activity

This image of Earth as seen from space at night shows light sources that are almost all created by humans. The image is a composite made from hundreds of nighttime images taken by orbiting satellites. Use the image to answer the questions below.

- 1. Comparing Areas** Some climatic conditions on Earth, such as extreme cold, heat, wetness, or a thin atmosphere, make parts of our planet less habitable than other parts. Examples of areas on our planet that do not support large populations include deserts, high mountains, polar regions, and tropical rain forests. Using the image, identify regions of Earth where climatic conditions may not be able to support large human populations.
- 2. Inferring Relationships** Using a map of the world and the brightness of the light sources on the image as a key, identify the locations of some of the most densely populated areas on Earth.
- 3. Finding Locations** Many large cities are ports on the coastlines of the world's oceans. By using the image, can you look along coastlines and locate light sources that might indicate the sites of large ports? Using a map of the world, name some of these cities.
- 4. Inferring Relationships** By looking at the differences in the density of the light sources on the image, can you locate any borders between countries? Identify the countries on both sides of these borders.

Section 1**Key Ideas****Viewing the Universe**

- › The universe is about 14 billion years old. It is very large, and objects within it are very far apart. The universe is made up of millions of galaxies, each of which is a large collection of stars, dust, and gases. Some stars, such as our own, include planets and other smaller objects.
- › The visible part of the electromagnetic spectrum is visible light. The nonvisible parts include radio waves, microwaves, infrared waves, ultraviolet rays, X rays, and gamma rays.
- › Refracting telescopes use lenses to gather and focus light, while reflecting telescopes use curved mirrors to gather and focus light.
- › Telescopes for nonvisible electromagnetic radiation are designed to gather and focus nonvisible electromagnetic radiation rather than visible light.

Key Terms

astronomy, p. 721
galaxy, p. 722
astronomical unit, p. 722
electromagnetic spectrum, p. 723
telescope, p. 724
refracting telescope, p. 725
reflecting telescope, p. 725

Section 2**Movements of Earth**

- › The Foucault pendulum and the Coriolis effect provide evidence of Earth's rotation. As the pendulum swings with a constant motion, the floor beneath it changes position. Wind belts and ocean currents follow a curved, not a straight, path because they are deflected by Earth's rotation.
- › The apparent movement of constellations in a circular motion provides evidence of Earth's rotation. The apparent movement from night to night and the change in location in the night sky of constellations from season to season provide evidence of Earth's revolution.
- › Movements of Earth provide a basis for measuring time. One revolution of Earth around the sun is equal to one year. One rotation of Earth on its axis is equal to one day.
- › The angle of the sun's rays changes throughout the year and leads to seasonal change on Earth.

rotation, p. 729
revolution, p. 730
perihelion, p. 730
aphelion, p. 730
equinox, p. 735
solstice, p. 736

- 1. Two-Column Notes** Use the FoldNote that you made at the beginning of this chapter to study the key terms. See if you know all the definitions. When you have reviewed the terms, use each term in a sentence.



USING KEY TERMS

Use each of the following terms in a separate sentence.

2. *electromagnetic spectrum*
3. *galaxy*
4. *perihelion*

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

5. *reflecting telescope* and *refracting telescope*
6. *solstice* and *equinox*
7. *rotation* and *revolution*

UNDERSTANDING KEY IDEAS

8. Stars organized into a pattern are
 - a. perihelions.
 - b. satellites.
 - c. constellations.
 - d. telescopes.
9. Days are caused by Earth's
 - a. perihelion.
 - b. aphelion.
 - c. revolution.
 - d. rotation.
10. The seasons are caused by
 - a. Earth's distance from the sun.
 - b. the tilt of Earth's axis.
 - c. the sun's temperature.
 - d. the calendar.
11. Which of the following is a tool that is used by astronomers to study radiation?
 - a. a computer model
 - b. a ground-based telescope
 - c. a Foucault pendulum
 - d. a calendar

12. Which of the following is evidence of Earth's revolution?
 - a. a Foucault pendulum
 - b. the Coriolis effect
 - c. night and day
 - d. constellation movement
13. Which of the following forms of radiation can be shielded by Earth's atmosphere?
 - a. gamma rays
 - b. radio waves
 - c. visible light
 - d. All of the above
14. Which of the following names is not associated with a space telescope?
 - a. *Hubble*
 - b. *Chandra*
 - c. *Cassini*
 - d. *Spitzer*
15. Which of the following marks the beginning of spring in the Northern Hemisphere?
 - a. vernal equinox
 - b. autumnal equinox
 - c. summer solstice
 - d. winter solstice
16. Which of the following is evidence of Earth's rotation?
 - a. a Foucault pendulum
 - b. day and night
 - c. the Coriolis effect
 - d. All of the above

SHORT ANSWER

17. Which two forms of electromagnetic radiation have the shortest wavelengths?
18. What is an advantage of using orbiting telescopes rather than ground-based telescopes?
19. Why does the rotation of Earth require people to establish time zones?
20. What is a leap year, and what purpose does it serve?
21. What line on Earth's surface marks where the date changes?
22. How does the tilt of Earth's axis cause the seasons?

CRITICAL THINKING

- 23. Evaluating Data** If telescopes had not been developed, how would our knowledge of the universe be different?
- 24. Analyzing Ideas** In each time zone, it gets dark earlier on the eastern side of the zone than on the western side. Explain why.
- 25. Applying Ideas** How would seasons be different if Earth was not tilted on its axis?
- 26. Making Inferences** What limitation of a refracting telescope could be overcome by placing the telescope in space? Explain your answer.

CONCEPT MAPPING

- 27.** Use the following terms to create a concept map: *Galileo, spacecraft, telescope, constellation, rotation, revolution, Foucault pendulum, Coriolis effect, equinox, solstice, and astronomy.*

MATH SKILLS

Math Skills

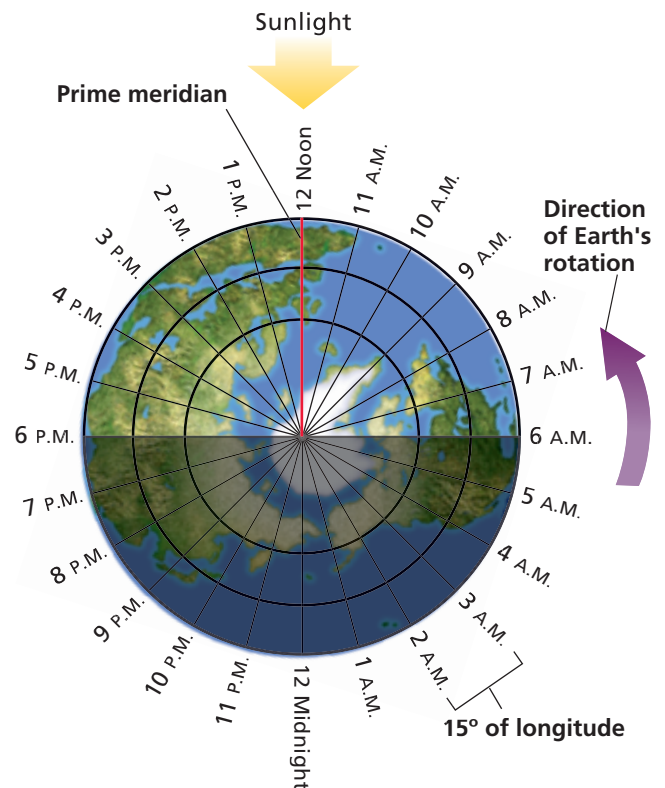
- 28. Making Calculations** A certain star is 1.135×10^{14} km away from Earth. If light travels at 9.4607×10^{12} km per year, how long will it take for light from the star to reach Earth?
- 29. Applying Quantities** At aphelion, Earth is 152,000,000 km from the sun. At perihelion, the two bodies are 147,000,000 km apart. What is the difference in kilometers between Earth's farthest point from the sun and Earth's closest point to the sun?

WRITING SKILLS

- 30. Creative Writing** Imagine that you are the head of a space program that has created the first orbiting telescope. Write a press release that explains to the public why your space agency has spent billions of dollars to build and launch a space telescope.
- 31. Communicating Main Ideas** Explain how a Foucault pendulum and the Coriolis effect provide evidence of Earth's rotation.

INTERPRETING GRAPHICS

The diagram below shows the different time zones of the world by looking down at the North Pole. Use the diagram to answer the questions that follow.



- 32.** If it is 6 P.M. at the prime meridian, what is the time on the opposite side of the world?
- 33.** On the diagram, it is 9 P.M. in Japan and 2 A.M. in Alaska. How many degrees apart are Alaska and Japan?
- 34.** If it is 6 A.M. in Alaska, what time is it in Japan?
- 35.** How many hours are in 120°?

Understanding Concepts

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

- Earth is closest to the sun at which of the following points in its orbit?
 - aphelion
 - perihelion
 - an equinox
 - a solstice
- What object is located at one of the focus points for the orbit of each planet in the solar system?
 - Earth is located at one of the focus points in the orbit of each planet in the solar system.
 - A moon of each planet is located at one of the focus points in that planet's orbit.
 - The sun is located at one of the focus points in the orbit of each planet in the solar system.
 - The orbits of the planets do not share any common focus points.
- Earth revolves around the sun about once every
 - 1 hour.
 - 24 hours.
 - 1 month.
 - 365 days.
- Which of the following statements describes the position of Earth during the equinoxes?
 - The North Pole tilts 23.5° toward the sun.
 - The South Pole tilts 23.5° toward the sun.
 - Rays from the sun strike the equator at a 90° angle.
 - Earth's axis tilts 90° and points directly at the sun.
- Which of the following statements about the electromagnetic spectrum is true?
 - It moves slower than the speed of light.
 - It consists of waves of varying lengths.
 - The shortest wavelengths are orange and red.
 - We can only detect waves of visible light.

Directions (6–8): For each question, write a short response.

- In what year did NASA first land astronauts on the moon?
- What is the term that describes a spacecraft sent from Earth to another planet?
- How does the wavelength of gamma rays compare to the wavelength of visible light?

Reading Skills

Directions (9–10): Read the passage below. Then, answer the questions.

The Chandler Wobble

In 1891, an American astronomer named Seth Carlo Chandler, Jr., discovered that Earth “wobbles” as it spins on its axis. This change in the spin of Earth's axis, known as the Chandler wobble, can be visualized if you imagine that Earth is penetrated by an enormous pen at the South Pole. This pen emerges at the North Pole and draws the pattern of rotation of Earth on its axis on a gigantic paper placed directly at the tip of the pen. If Earth did not have a wobble, you would expect the pen to draw a dot as Earth rotated on its axis. Because of the wobble, however, the pen draws a small circle. Over the course of 14 months, the pen will draw a spiral.

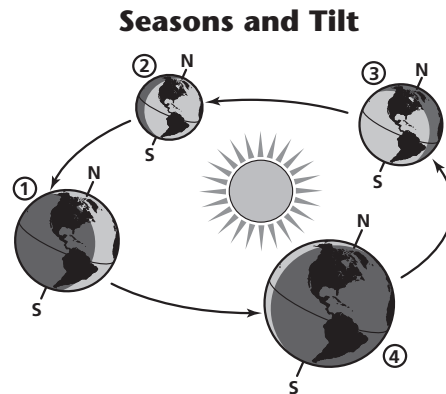
While the exact cause of the Chandler wobble is not known, scientists think that it is related to fluctuating pressure at the bottom of the ocean caused by temperature, salinity, and circulation changes. This wobble affects celestial navigation slightly. Because of the wobble, navigators' star charts occasionally are changed to reflect new reference points for the North Pole and South Pole.

- Because of the Chandler wobble, celestial navigators must occasionally account for new reference points for the poles. Changes in determining the location of the North Pole by using a compass are not required. Why?
 - Compasses point to Earth's magnetic north pole, not Earth's geographic North Pole.
 - Compasses automatically adapt and move with the wobble.
 - The wobble is related to stellar movements.
 - The wobble improves compass accuracy.
- Which of the following statements can be inferred from the information in the passage?
 - Earth's axis moves once every 14 months.
 - The Chandler wobble prevents the liquid center of Earth from solidifying.
 - The Chandler wobble causes the oceans to move and fluctuate in pressure.
 - To accurately calculate a satellite orbit, scientists must account for the Chandler wobble.

Interpreting Graphics

Directions (11–14): For each question below, record the correct answer on a separate sheet of paper.

The diagram below shows the position of Earth during the four seasons. Use this diagram to answer questions 11 and 12.



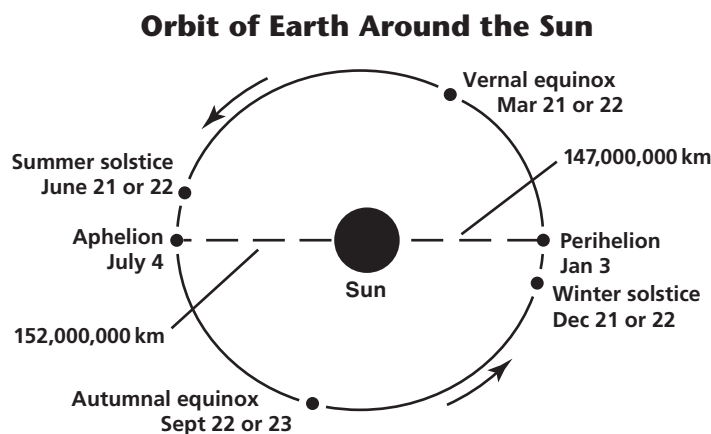
11. The Northern Hemisphere tilts toward the sun during which season?

- | | |
|------------------|------------------|
| F. winter | H. summer |
| G. spring | I. fall |

12. The Northern Hemisphere experiences a vernal equinox when it is at which of the following positions on the diagram?

- | | |
|----------------------|----------------------|
| A. position 1 | C. position 3 |
| B. position 2 | D. position 4 |

The diagram below shows the dates of specific events in Earth's orbit around the sun. Use this diagram to answer questions 13 and 14.



13. Use the diagram to describe the shape of Earth's orbit around the sun, and explain how the solstices differ from the aphelion and perihelion.

14. What is the relationship between Earth and the sun on March 21 or 22? Compare this relationship with the relationship between Earth and the sun on September 22 or 23.

Test Tip

Keep an eye on your time limit. If you begin to run short on time, quickly read the remaining questions to determine which questions might be the easiest for you to answer.