

# Earth's Structure and Motion

Each day, Earth's structure and its motions have profound effects on us.

What materials make up our home planet?

CHAPTER

4



## PREVIEW

► **FOCUS QUESTIONS** In this chapter you will study Earth's structure and motion and learn more about the questions below.

Section 1 How was Earth formed, and what are some characteristics of its structure?

Section 2 What is rotation and what are its effects?

Section 3 What is revolution and what are its effects?

► **REVIEW TOPICS** As you investigate Earth's structure and motion, you will need to use information from earlier chapters.

- characteristics of the geosphere (p. 9)
- models of Earth (p. 44)
- longitude and latitude (p. 46)

► **READING STRATEGY****SET A PURPOSE**

Read the key questions listed above. Before you begin reading Chapter 4, write a sentence or two in your science notebook that identifies a purpose for reading each section.



At our Web site, you will find the following Internet support for this chapter.

**DATA CENTER****EARTH NEWS****VISUALIZATIONS**

- Origin of the Solar System
- Evidence of Earth Rotating about an Axis
- Earth's Daily Rotation
- Night Sky over a Year
- Earth's Revolution around the Sun

**LOCAL RESOURCES****INVESTIGATIONS**

- How Do We Know about Layers Deep within Earth?
- What Time Is It?

# 4.1

## Earth's Formation

### KEY IDEA

Earth formed from a whirling cloud of gas and debris into a multilayered sphere, which has since been losing heat.

### KEY VOCABULARY

- geology
- inner core
- outer core
- mantle
- crust
- lithosphere
- asthenosphere
- magnetic field



Observe an animation showing the origin of the solar system.

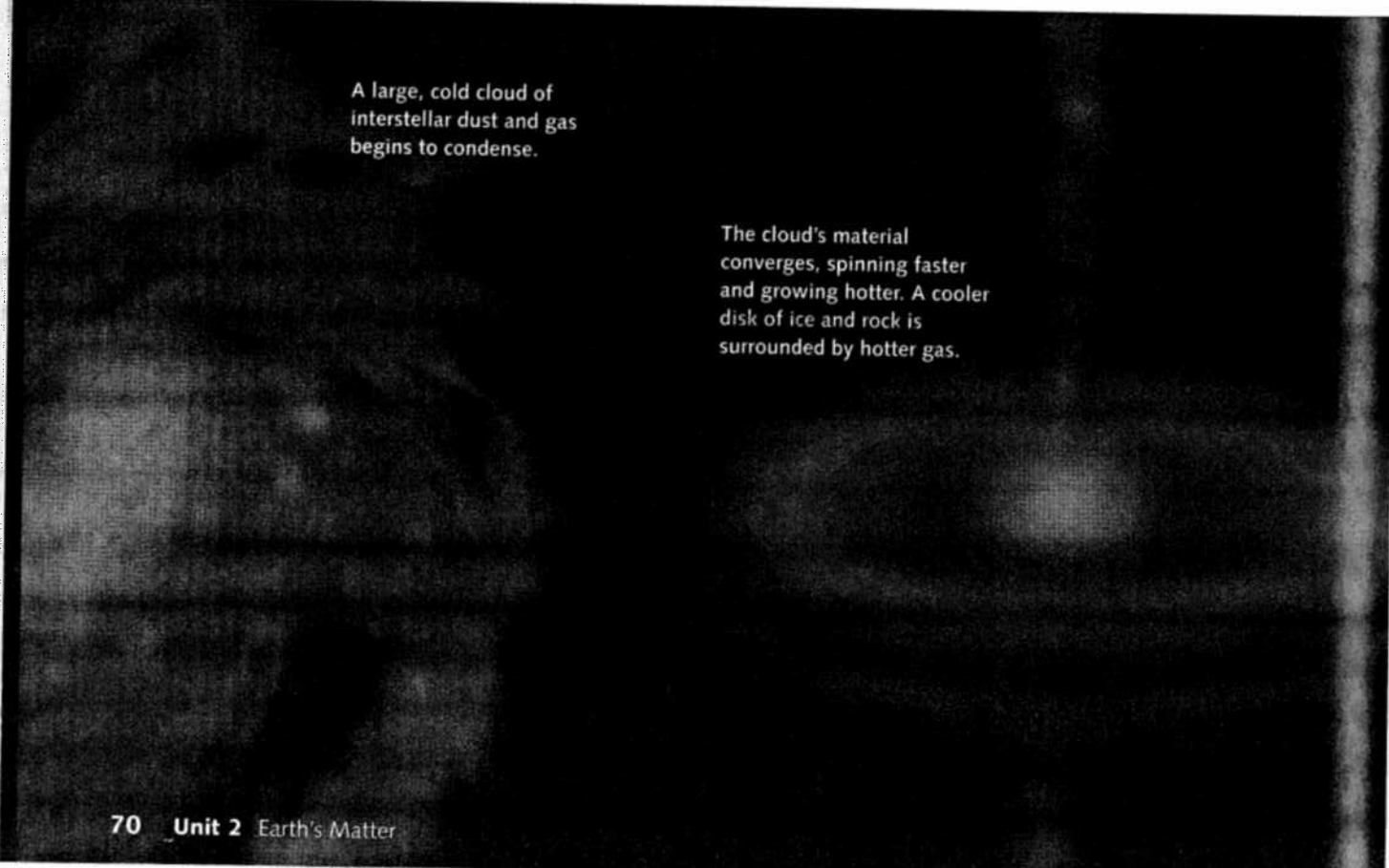
Keycode: ES0401

Physical and chemical processes change our planet every day. **Geology** is the study of the planet Earth, its structure and composition, and how it has changed over time. Earth as you know it today is the result of changes that have occurred over billions of years.

### Origin of the Solar System

The most widely accepted model of the formation of our solar system is called the nebular hypothesis. It suggests that about 4.6 billion years ago a great cloud of gas and dust was rotating slowly in space. The cloud was at least 10 billion kilometers in diameter. As time passed, the cloud shrank under the pull of its own gravity. As it shrank, its rate of rotation increased. Most of the material in the rotating cloud gathered around its center. The compression of this material made its interior so hot that a powerful reaction called hydrogen fusion occurred. At this time, the star we now know as our sun was born.

About 10 percent of the material in the cloud formed a great platelike disk surrounding the sun and extending far into space. Frictional, electromagnetic, and gravitational forces within the disk caused most of its mass to condense, forming solid particles of ice and rock. The condensed particles in the spinning cloud eventually combined into larger bodies called planetesimals, as shown in the illustration below. Keep in mind that this illustration of solar-system formation is not drawn to scale.



A large, cold cloud of interstellar dust and gas begins to condense.

The cloud's material converges, spinning faster and growing hotter. A cooler disk of ice and rock is surrounded by hotter gas.

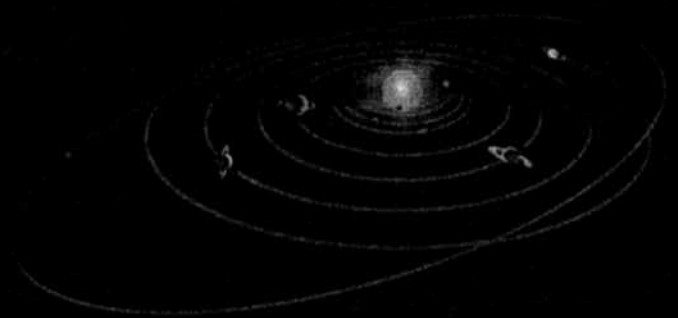
## Earth's Size and Shape

The planetesimals continued to compress and spin, sometimes colliding with each other and other objects in space. Eventually these planetesimals developed into planets and moons. Of these new objects, the third closest to the sun became Earth. The spinning motion of the young Earth caused it to form into a sphere that bulges in the center. Such a shape is called an oblate spheroid (AHB-LAYT SFEER-OYD).

While scientists cannot directly observe the events that led to Earth's formation, they can directly observe Earth's shape. Many photographs of Earth have been taken from space. The photographs show that Earth is spherical. It is not, however, a perfect shape.

One way scientists show that Earth is not a perfect sphere is by measuring the weight of an object at several places on Earth's surface. The weight of an object, in newtons, is the force with which gravity pulls the object toward Earth's center. The farther away an object is from Earth's center, the lighter it is. Conversely, the closer an object is to Earth's center, the heavier it is. Careful measurements show that an object that weighs 195 newtons at the North Pole or the South Pole weighs 194 newtons at the equator. This difference in weight is evidence that the object is nearer to Earth's center at the poles than at the equator. If Earth were a perfect sphere, the distance to its center would be the same at the poles as it is at the equator. In addition, an object's weight in newtons would be the same at any given point on the planet's surface. Of course, you would have to account for elevation, because an object at sea level is heavier than it is at the top of Mount Everest.

As fusion first occurs in the new star,  
planetesimals form and begin to attract  
more and more material as they orbit.



Over time, nearly all of the material  
from the original cloud becomes part  
of the star and its orbiting planets.

The total surface area of Earth is about 510 million square kilometers, equivalent to about 55 continental United States of Americas. Of this area, about 149 million square kilometers lie above sea level as continents and islands. Oceans cover the remaining 361 million square kilometers. In other words, about 29 percent of Earth's surface is dry land, while about 71 percent is covered by water.

## Earth's Interior

According to the nebular hypothesis, the original surface of Earth looked much as the moon's surface does today. Earth was probably composed of the same type of material from its surface all the way to its center.

When objects collide, energy from the collision is converted into heat. In its early history, Earth frequently collided with material left over from the formation of the solar system. These impacts helped cause Earth to grow hot enough that heavy elements such as iron and nickel melted.

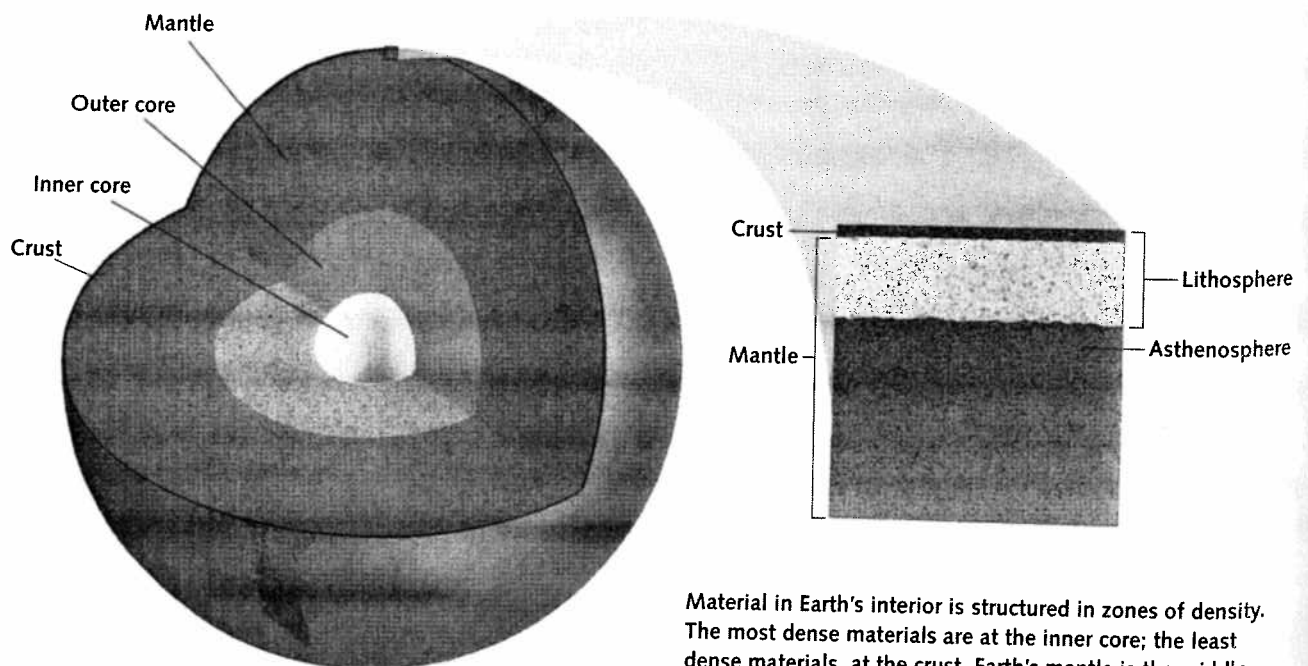
Recall that the density of a substance is the amount of mass of that substance that occupies a particular volume of that substance. If two liquids of different densities are mixed, over time the liquids will separate, with the denser liquid settling on the bottom. In the same way, the material composing Earth gradually separated into several layers, with denser material located toward the center.

At Earth's center is an **inner core** composed of solid iron and nickel. Surrounding the inner core is an **outer core** composed of iron and nickel in a liquid state. Around the core is the thickest of Earth's layers, called the **mantle**. The mantle is composed mostly of compounds rich in iron,

### VOCABULARY STRATEGY

The words *lithosphere* and *asthenosphere* both contain the root *sphere*, referring to the round shape of Earth. In Greek, *lithos* means "stone," while *asthenes* means "weak." So the lithosphere and the asthenosphere are respectively the "stony-sphere" and the "weak-sphere."

### Earth's Interior



Material in Earth's interior is structured in zones of density. The most dense materials are at the inner core; the least dense materials, at the crust. Earth's mantle is the middle zone—what remains after heavier materials sank, and lighter materials rose to the surface.

## SUMMARY Characteristics of Earth's Layers

	State	Depth from surface (km)	Temperature (K)
Inner core	solid	6371	approximately 6000
Outer core	liquid	5150	3700–5500 (increases with depth)
Mantle	solid with liquid properties	2890	1500–3200 (increases with depth)
Crust	solid	0–65	<1000 (increases 10–30K/km of depth)

silicon, and magnesium. Although the mantle is solid, high pressures and temperatures cause it to behave as a liquid in some ways. Surrounding the mantle is the **crust**, a thin, rigid layer of lighter rocks that includes Earth's surface.

Earth's near-surface layers are further classified by their material properties. The crust and the uppermost portion of the mantle together make up the **lithosphere**. The more rigid material of the lithosphere floats upon a thin, slushlike layer of the mantle called the **asthenosphere**.

Compared to Earth's major layers, the crust has the smallest mass and volume. However, the crust is that part of the geosphere with which humans have direct contact, and it is the only place where life has been found. As you know from Chapter 1, we rely on the geosphere to provide the materials we need to build cities and grow crops. Although we do not have direct contact with the asthenosphere, it also affects our environment. As you will learn in Chapter 8, this part of the mantle is thought to be responsible for the movements of Earth's crust known as plate tectonics.

## Earth's Heat

Events that gave rise to the formation of Earth generated heat. Some of the heat that caused Earth's layers to form came from meteorite impacts, and some arose as the weight of overlying materials caused compression in Earth's interior. Heat was also generated by the decay of radioactive isotopes, elements that release heat as they disintegrate into more stable forms.

Since its original heating, Earth has been slowly losing heat. The amount of heat loss varies from place to place, for the following reasons:

1. Some rocks lose heat more quickly than others.
2. The thickness of the crustal rock varies from place to place.
3. The percentage of radioactive materials in rocks varies.

You may have noticed that on a warm summer day, an underground cave remains cool. Deep caves stay about the same temperature all year because neither the sun's warmth nor the winter's cold can penetrate there.



## INVESTIGATIONS

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### How Do We Know about Layers

**Deep within Earth?** View animations of earthquake waves moving through model planets. Use the information to predict what Earth's interior is like.

Keycode: ES0402

## Scientific Thinking

### DESIGN AN EXPERIMENT

It is difficult and expensive to gather information about Earth's crust, let alone its inner layers. For example, the deepest underground gold mines reach depths of only about 4 kilometers, whereas Earth's crust is, on average, about 65 kilometers deep. In such situations, scientists often design experiments to help them test their hypotheses.

How would you go about building a working model of Earth's interior? What equipment and materials would you need? Think about ways a computer might help you test a hypothesis about Earth's structure.



10-Minute

## Mini LAB

### Modeling Earth's Magnetic Field

#### Materials

- bar magnet
- card stock
- iron filings
- tape

#### Procedure

- 1 Tape the magnet beneath the center of a piece of white card stock.
- 2 Sprinkle the iron filings onto the card stock above the magnet.
- 3 Tap the card stock to allow the filings to align.
- 4 Draw what you see.

#### Analysis

Describe the alignment of the iron filings. Earth's magnetic field is similar to that of a bar magnet. Sketch Earth's outline over your drawing of the filing pattern, and mark the location of the poles.

Below a depth of 70 meters, however, ground temperatures begin to increase. Underground temperatures have been measured at tunnels, mines, oil wells, and water wells. While the rate of temperature increase varies from one location to another, the average rate of increase in the outer crust is about  $1^{\circ}\text{C}$  for every 40 meters of depth. Evidence suggests that the temperature increase becomes more gradual beneath the first 1000 meters of Earth's crust.

## Earth's Magnetic Field

You may have noticed that a compass needle always points north. In fact the compass needle aligns itself along the lines of force that make up Earth's magnetic field. The magnetic north pole is the equivalent of the attracting, or positive, end of a bar magnet, so it attracts your compass needle. On the other hand, the magnetic south pole is like the negative end of a bar magnet, so it repels the compass needle.

To visualize Earth's **magnetic field**, imagine a bar magnet lying inside Earth with each end pointing toward one of Earth's poles. Now imagine that the ends of the magnet are tilted about  $11^{\circ}$  away from the poles. Earth's magnetic field is the resulting lines of force that loop from one end of the bar magnet to the other. The  $11^{\circ}$  tilt explains why the magnetic north pole and the geographic north pole are not in exactly the same place.

Although scientists do not fully understand the origin of Earth's magnetic field, many support a hypothesis first developed in the 1900s. The hypothesis credits Earth's magnetic field to the movement of fluid in the outer core. An electric current is generated when liquid iron moves across an already existing, but weak, magnetic field. The electric current produces a magnetic field that, with the fluid motion, produces yet another magnetic field. Together, these fields create Earth's strong magnetic field.

### 4.1 Section Review

- 1 What evidence is there for Earth's spheroidal shape?
- 2 Describe the arrangement of Earth's layers, starting with the crust and moving inward.
- 3 Describe three sources of Earth's internal heat. Which internal process is still producing heat?
- 4 **CRITICAL THINKING** Describe how Earth would be different today if it contained no radioactive material. What would the consequences be for the Earth's interior layers?
- 5 **MATHEMATICS** Assume that the crust temperature increases by 30K for each kilometer below Earth's surface, where the temperature is 300K. Calculate what the temperature would be at Earth's center if the rate of increase were the same below the crust as in it. Compare your result with the actual inner-core temperature.

# Earth's Rotation

The spinning motion that helped form primitive Earth still influences our planet and our lives today. Earth completes one whole turn around its axis about every 24 hours. This spinning of Earth around its axis is called **rotation**.

## Evidence for Rotation

One remarkable piece of evidence for Earth's rotation was built by physicist Jean Foucault in 1851. By attaching an iron sphere to a very long wire, Foucault constructed a pendulum that was 20 stories high. Physicists of the time knew that once a pendulum is set in motion, its direction of swing would not change. Foucault, however, observed that the direction of swing of his pendulum seemed to change. Each hour it shifted about 11° in a clockwise direction. After eight hours the pendulum was swinging at a right angle to its starting direction. Because the pendulum itself could not have changed its direction of swing, Foucault concluded that the shift he saw was caused by Earth's turning beneath his pendulum. The Foucault pendulum is now a famous demonstration of Earth's rotation.

More evidence of Earth's rotation can be seen by observing wind. If Earth did not rotate, winds would blow along straight paths from areas of high pressure to areas of low pressure. Because of Earth's rotation, winds appear to be turned, or deflected. In the Northern Hemisphere, winds are deflected to their right relative to Earth's surface. In the Southern Hemisphere, winds are deflected to their left. This apparent deflection is called the Coriolis effect. Any substance or object moving freely above Earth's surface is subject to the Coriolis effect. You will study the Coriolis effect in Chapter 19.

# 4.2

### KEY IDEA

Earth rotates on its axis once approximately every 24 hours, resulting in day and night and providing the basis for time zones.

### KEY VOCABULARY

- rotation
- standard time zones
- time meridian
- prime meridian
- International Date Line



Observe evidence of Earth turning about an axis.

Keycode: ES0403

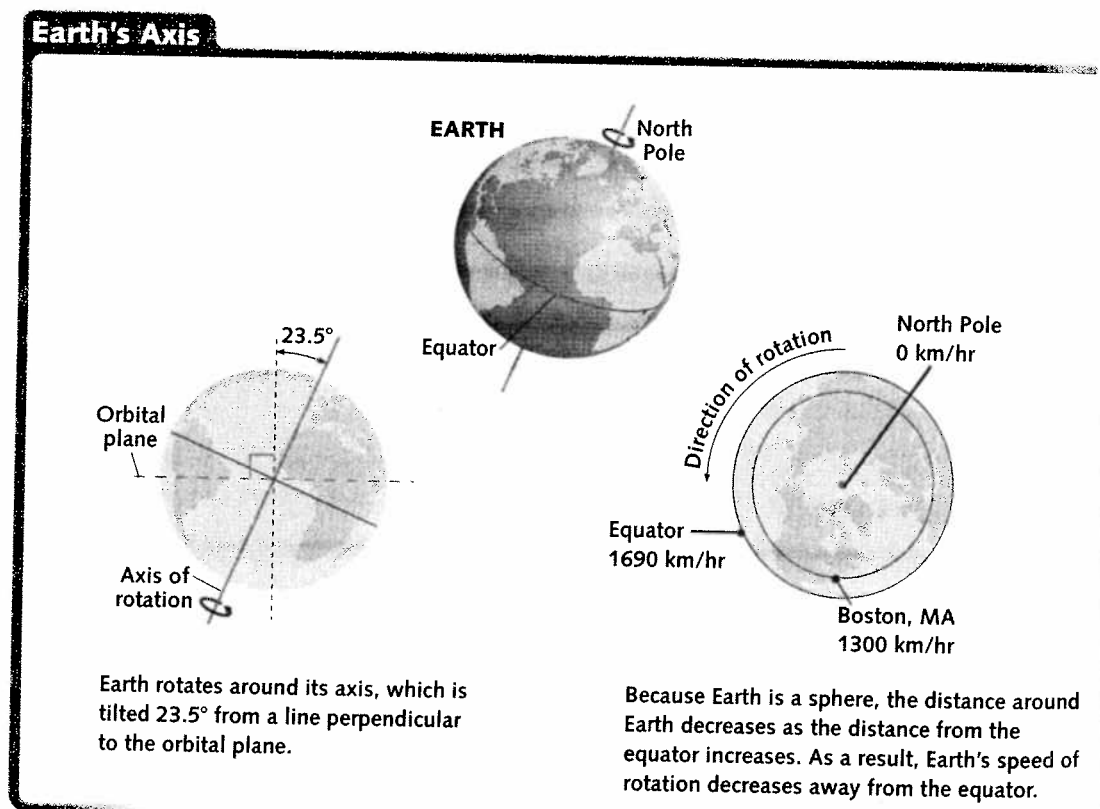


This pendulum in the Cumberland Museum, Nashville, Tennessee, is suspended from a wire far above the heads of the observers.

## Axis and Rate of Rotation

Like the other planets in our solar system, Earth rotates as it travels around the sun. Recall that Earth's axis of rotation is an imaginary straight line through Earth between the North Pole and the South Pole. When Earth rotates, it turns around this axis. Earth's orbit, or path around the sun, lies within an imaginary flat surface called an orbital plane. As shown below, the axis of rotation is not perpendicular to Earth's orbital plane; that is, the two do not make a right angle. The axis is slightly tilted, making an angle of  $23.5^\circ$  with the perpendicular.

At present, Earth's axis points toward Polaris, the North Star. The tilt of Earth's axis stays the same throughout the year. This consistency in Earth's tilt is called parallelism. Because of parallelism, the North Star always appears at the same angle above the horizon in the Northern Hemisphere.



### VISUALIZATIONS CLASSZONE.COM

Explore a model of Earth's daily rotation.

Keycode: ES0404

Earth makes one complete turn equal to a rotation of  $360^\circ$  approximately every 24 hours. That means that every location on Earth's surface rotates at a rate of  $15^\circ$  per hour. However, because of Earth's spheroidal shape, the speed of rotation varies from point to point. While rate of rotation is measured in degrees per unit of time, speed of rotation is measured in distance per unit of time. The distance traveled in one rotation varies by latitude. At the equator, one rotation equals the Earth's circumference, or 40,074 kilometers. Therefore, points on the equator rotate at a speed of about 1690 kilometers per hour. At the latitude of Boston, Massachusetts, the speed of rotation is only about 1300 kilometers per hour. Near the poles, the speed of rotation is almost 0 kilometers per hour, because the poles are on the axis of rotation.

## Effects of Rotation

The behavior of a Foucault pendulum and the Coriolis effect are both a result of Earth's rotation. Another effect of Earth's rotation is the daily change from day to night. From the standpoint of the North Pole, Earth rotates counterclockwise. Thus, the sun appears to rise in the east and set in the west. Only half of Earth receives sunlight at any given time. If Earth did not rotate, the half facing the sun would have constant light, while the other half would have perpetual dark.

## Measuring Time

One day, 24 hours, is the approximate time it takes Earth to rotate once on its axis. For centuries, people figured the time of day by the sun's position in the sky. Each day, the sun rises on the eastern horizon, seems to move in an arc across the sky, and sets below the western horizon. Solar noon occurs when the sun is at the highest position on this arc.

Because of Earth's rotation, of course, solar noon does not occur at the same time everywhere. Instead, it moves westward at a rate of about  $15^\circ$  each hour, or  $1^\circ$  every four minutes. Consider New York City, located at longitude  $74^\circ$  W, and Philadelphia, near longitude  $75^\circ$  W. Because of the  $1^\circ$  difference in longitude, solar noon occurs in New York City about four minutes before it occurs in Philadelphia.

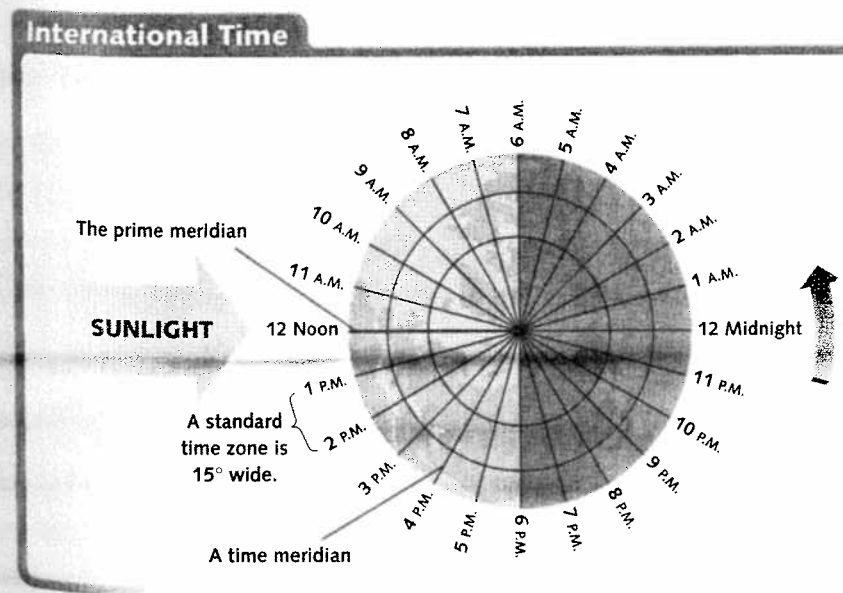
## Standard Time Zones

The problem of having different solar times in nearby communities was solved through the development of time zones. As shown, 24 worldwide **standard time zones** were developed, each  $15^\circ$  of longitude wide.

The basis for time zones is the rate at which the sun appears to move across the sky. Each standard time zone is roughly centered on a line of longitude exactly divisible by  $15^\circ$ , called a **time meridian**. All areas within a time zone keep the same clock time. Clock time is the average solar time at that zone's time meridian.



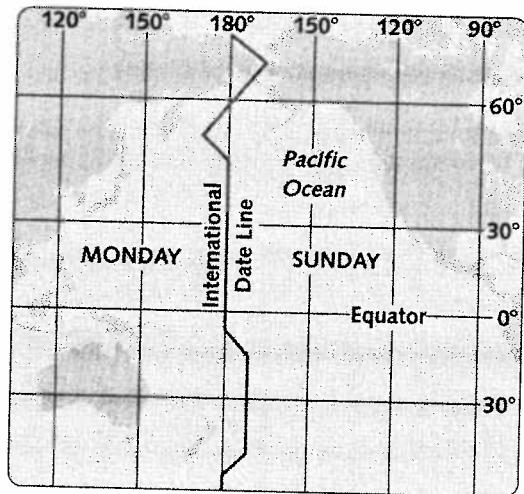
**What Time Is It?** View maps of Earth showing where it is light and dark. Interpret them to tell what time it is in different parts of the world.  
Keycode: ES0405



The starting point for the standard time zones is an arbitrary longitude line called the **prime meridian**, which passes through Greenwich, England. Travelers moving westward from Greenwich move their clocks back to earlier times, while those moving eastward change to later times. When it is 10 A.M. in Greenwich (longitude  $0^\circ$ ), it is 11 A.M. in Rome (longitude  $15^\circ$  E), 5 A.M. in Philadelphia (longitude  $75^\circ$  W), and 3 A.M. in Denver (longitude  $105^\circ$  W). People working for international businesses regularly place telephone calls across several time zones. They must keep these time differences in mind when scheduling their calls.

In theory, each standard time zone should be exactly  $15^\circ$  wide. On land, however, such exactness is not always convenient. For example, having a time-zone boundary cut right through a city could be confusing. Because of this, time-zone boundaries on land are seldom straight lines. Instead, they shift east or west to meet the needs of the people living in the area.

### The International Date Line



**THE INTERNATIONAL DATE LINE** follows the 180th meridian, varying from it only where necessary to avoid land.

Travelers going completely around the world gain or lose time at each time zone until they have gained or lost an entire day. How can travelers know where to change from one date to another? An imaginary line called the **International Date Line** represents the longitude at which the date changes. Upon crossing the date line, which goes through the Pacific Ocean, travelers change not their watches but their calendars. For travelers moving westward, the date is one day later; for eastward travelers, it is one day earlier. When travel agents don't keep these changes in mind, a traveler may miss a connecting flight or lose a hotel reservation.

The International Date Line lies within a time zone. Locations on either side of the date line within the same time zone keep the same time, but the western half is one day ahead of the eastern half. For much of each day, the continental United States is one day behind eastern Asia.

### 4.2 Section Review

- ❶ Describe two pieces of evidence for Earth's rotation.
- ❷ Why is the speed of Earth's rotation different at the equator than it is at the poles?
- ❸ Explain how time zones are determined.
- ❹ **CRITICAL THINKING** In any given time zone, it gets dark a little earlier on the eastern side than on the western side. Why?
- ❺ **WRITING** Imagine that you are on a flight leaving New York City at 6 A.M. on Sunday, December 14, and passing through Seattle, Tokyo, Riyadh, and London. Supposing it takes 10 hours to fly between cities, write a travel diary that includes the time and date you reach each city.

# SCIENCE & Technology

## Measuring Time

*The way we tell time has changed significantly over the years. As technology improves, measuring time becomes increasingly precise.*

How do you know time is passing? Is there more than one way to measure time?

In ancient times, when most activities were limited to daylight, people used shadow-casting instruments—such as gnomons, obelisks, and sundials—or water clocks to measure the passage of time. For over 5000 years there wasn't much change in how people marked time. It wasn't until improvements were made in machinery and gear making that telling time changed significantly.

By the mid-1300s, Europeans were building large mechanical, weight-driven clocks housed in towers for public reference. In 1656, Dutch astronomer Christiaan Huygens invented the pendulum clock, the first to accurately count seconds. Although driven by weights, the clock was regulated by the naturally periodic swinging motion of a pendulum. Before this invention, even

the most efficient clocks could be off by 20 minutes per day!

The quartz clock, invented in 1927, was so precise that it helped scientists find irregularities in the rate of Earth's rotation. When placed in alternating electric fields, quartz crystals vibrate at a very regular frequency. These vibrations are used to regulate the clock precisely. Most wristwatches and clocks today are quartz clocks.

In nature, an atom of any chemical element emits electromagnetic radiation at a unique frequency. In 1957, the first atomic clock was made. Scientists based the design of the clock on the exposure of the element cesium to radiation. Radiation causes the cesium atom to release energy at a constant frequency, thus creating the basis for increments of time. By 1967, cesium's



**ON A SUNDIAL**, as the sun moves across the sky, the shadow cast by the center of the sundial moves along the perimeter scale, indicating the time of day.

frequency became the new international unit of time.

One second is now defined as 9,192,631,770 cycles of the cesium atom's frequency, equal to an average second of Earth's rotation time. ■

### Extension

#### SCIENCE NOTEBOOK

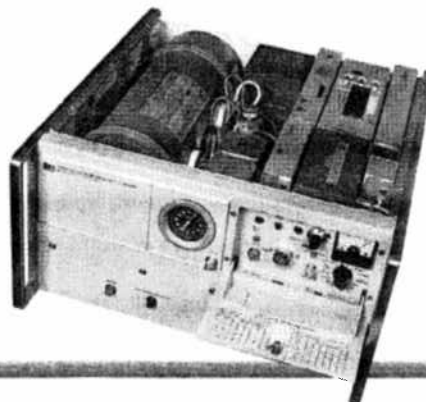
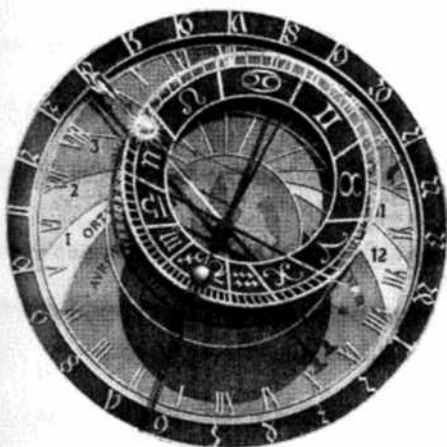
In addition to relying on clocks, people through the ages have used calendars to mark the passage of time. Research and report on the types of yearly calendars in use today or on a calendar used by an ancient culture.



Learn more about how time is measured.

Keycode: ES0406

**ASTRONOMICAL CLOCKS** like this one in Prague, the Czech Republic, are beautiful but are less efficient timekeepers than atomic clocks.



**ATOMIC CLOCKS** like this one use the vibrations of cesium atoms to mark time.

# 4.3

## KEY IDEA

Earth revolves around the sun in an elliptical orbit, causing seasonal variations.

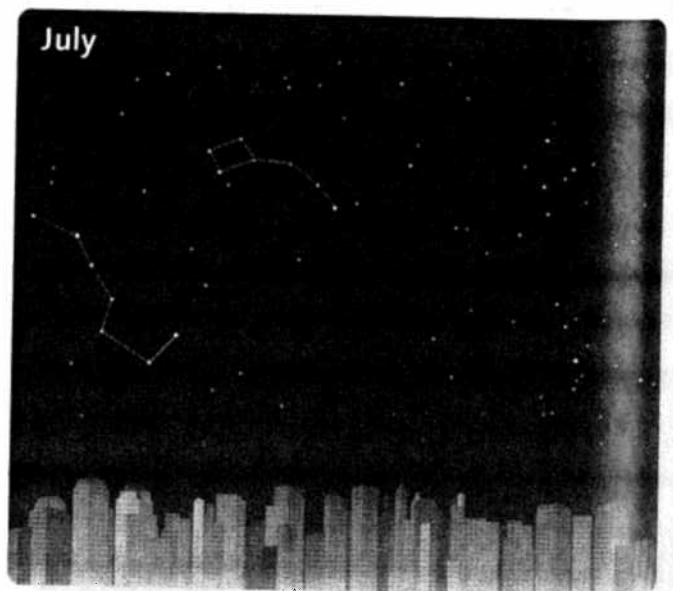
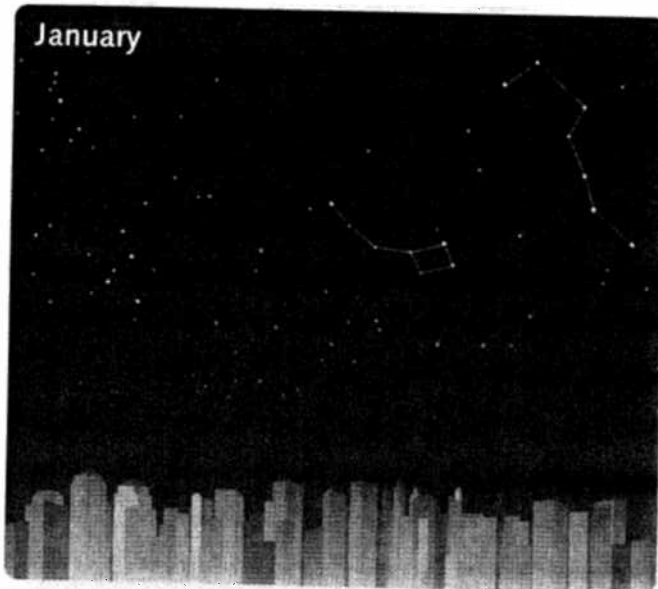
## KEY VOCABULARY

- revolution
- parallax
- summer solstice
- winter solstice
- vernal equinox
- autumnal equinox



Observe the view of the night sky from the same location over a year.  
Keycode: ES0407

Looking north, from New York City after 11 P.M. in January, the Big Dipper appears on the opposite side of the sky than when viewed at the same time of night six months later.



## Earth's Revolution

Rotation is one type of motion characteristic of Earth. Another motion is **revolution**, the movement of Earth in its orbit around the sun.

## Evidence for Revolution

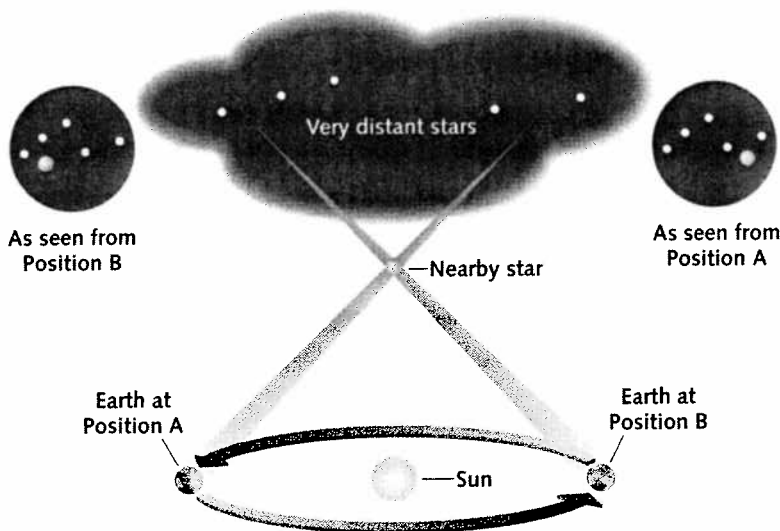
For centuries, people gazing at the stars have observed evidence of Earth's revolution. Although groups of stars called constellations are visible every clear night, their positions in the sky appear to change as Earth rotates and revolves. Constellations that are visible on a winter evening are either in a different place in the summer night sky, or they are not visible at all. The shifting position of Earth in its orbit around the sun causes such changes in our view of the constellations.

As Earth moves in its orbit, nearby stars appear to shift position when compared to distant stars. This apparent shift in position is called **parallax**. Among stars, parallax cannot be detected by eye, but it can be measured with precise instruments. You can see the effect of parallax for yourself. Hold a pencil upright at arm's length and notice what happens when you look at the pencil with first one eye alone and then the other eye alone. Viewing the pencil from the two different positions produces the same apparent shift as seen in nearby stars when Earth is in two different positions. If Earth did not orbit the sun, no shift would occur. Therefore, the parallax of nearby stars is evidence of Earth's revolution.

## Path and Rate of Revolution

The direction of Earth's revolution is the same as its direction of rotation, that is, counterclockwise when viewed from above the North Pole. Like the orbits of the other planets, Earth's orbit is an ellipse, with the sun located at one focus. Because the orbit is elliptical, the distance between Earth and the sun changes throughout the year. The average distance is about

## Parallax

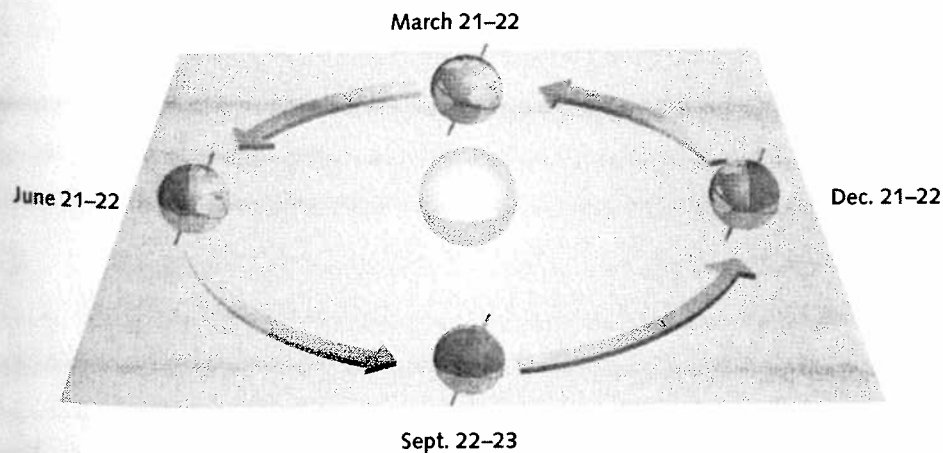


As Earth revolves around the sun, nearby stars appear to shift position. This shift, called parallax, is evidence of Earth's revolution. The diagram above shows two views of stars seen from Earth six months apart. Notice that the nearby star in the center seems to shift position relative to the very distant stars beyond it.

150 million kilometers. The sun is about 2.4 million kilometers from the center of the orbit. At perihelion, its point nearest the sun, Earth is about 147.6 million kilometers from the sun. Perihelion occurs on or about January 2. At aphelion, its point farthest from the sun, Earth is about 152.4 million kilometers from the sun. Aphelion occurs on or about July 4.

Earth makes one revolution around the sun every 365.24 days, defining the length of one year. Because one orbit represents a journey of 360°, Earth's rate of revolution around the sun is very close to 1° per day.

While Earth's rotation makes the sun appear to move across the sky once every day, Earth's revolution around the sun causes the sun's apparent path across the sky to change throughout the year.



## VISUALIZATIONS

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Explore a model of Earth's yearly revolution around the sun.

Keycode: ES0408

**ORBITAL PLANE** Earth's orbit around the sun defines the orbital plane. Earth remains tilted 23.5° from the vertical at all times during its orbit.

In describing the sun's position in the sky, astronomers refer to the point directly above the observer as the zenith. The angular distance between the horizon and the sun's position at any given time is called its altitude. When the sun is at the zenith, its altitude is  $90^\circ$ . When it is on the horizon, its altitude is  $0^\circ$ . For locations in the United States (except Hawaii), the sun is always below the zenith.

## Effects of Revolution and Tilt

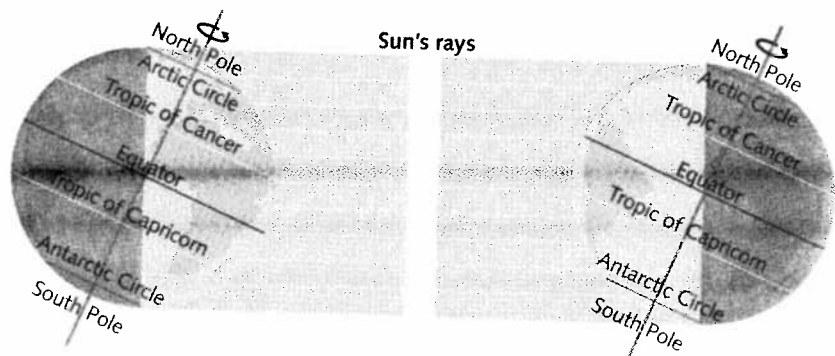
Effects of Earth's revolution include the seasons and variation in the length of days and nights. In addition to revolution, the tilt of Earth's axis relative to its plane of orbit has a profound effect on Earth. At almost any given time, one hemisphere is tilted toward the sun, as the other is tilted away. The hemisphere tilted toward the sun receives more direct sunlight and thus has warmer temperatures and longer days. The hemisphere tilted away from the sun receives indirect sunlight. That hemisphere has cooler temperatures and shorter days.

The changes in hours of daylight and in temperature caused by revolution and tilt lead to the yearly change of seasons at middle latitudes. If Earth's axis were perpendicular to its plane of orbit, seasons would not occur. In addition, every place on Earth's surface would experience 12 hours of daylight and 12 hours of darkness every day. On the other hand, if Earth's axis were tilted more than  $23.5^\circ$ , each hemisphere would experience hotter summers and colder winters.

The first day of summer in the Northern Hemisphere occurs on or about June 21 each year. This day has the longest daylight period, because the sun's path in the sky is longer and higher than at any other time of the year. The point at which this daily increase stops is the **summer solstice** (SOHL-stihs). At the summer solstice the Northern Hemisphere is at its maximum tilt toward the sun. Because this tilt is equal to  $23.5^\circ$ , the sun is straight overhead at locations along the latitude line of  $23.5^\circ$  N. This latitude line is called the Tropic of Cancer.

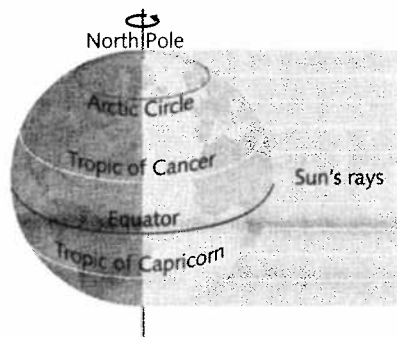
On the first day of summer, every point on Earth within  $23.5^\circ$  of the North Pole experiences 24 hours of daylight. The boundary of this region, at latitude  $66.5^\circ$  N, is the Arctic Circle. On June 21 in the Southern Hemisphere, every point south of the Antarctic Circle (latitude  $66.5^\circ$  S) experiences 24 hours of darkness.

**EFFECT OF TILT** Earth's Northern Hemisphere receives the most sunlight at the summer solstice (left) and the least sunlight at the winter solstice (right). Direct sunlight falls on the Tropic of Cancer at the summer solstice and on the Tropic of Capricorn at the winter solstice.



Winter begins in the Northern Hemisphere on or about December 21. This is the **winter solstice**, the shortest day of the year, when the sun follows its lowest and shortest path across the sky. On this day, the Northern Hemisphere is at its maximum tilt away from the sun, while the Southern Hemisphere is at its maximum tilt toward the sun. The sun is straight overhead at the Tropic of Capricorn, which is at latitude 23.5° S. Daytime and nighttime conditions on December 21 are the opposite of those on June 21. On December 21, every point north of the Arctic Circle experiences 24 hours of darkness while every point south of the Antarctic Circle has 24 hours of daylight.

There are two days each year, midway between the solstices, when neither hemisphere tilts toward the sun. On these days, daytime and nighttime are equal in length all over the world. Each of these days, therefore, is known as an equinox (EE-kwuh-NAHKS). The **vernal equinox** occurs on or around March 21. The **autumnal equinox** is on or near September 22. The sun is overhead at the equator at noon on these dates.



**EQUINOX** At an equinox, each of Earth's hemispheres receives equal amounts of sunlight. Direct sunlight falls on the equator.

The equinoxes also mark the beginning of periods of long twilight at the poles. On March 21, the sun rises above the horizon at the North Pole for the first time in six months. The sun then remains visible at the North Pole for the next six months, while at the South Pole there are six months of darkness. On September 22, a six-month period of darkness begins at the North Pole, while that at the South Pole ends.

#### VOCABULARY STRATEGY

*Solstice* comes from the Latin words *sol* (meaning "sun") and *stitium* (meaning "stoppage"). *Equinox* comes from the Latin words *aequalis* (meaning "equal") and *nox* (meaning "night"). So a solstice is a "sun stop," while an equinox is a time when night and day are of equal length.

### 4.3 Section Review

- 1 What evidence is there for Earth's revolution around the sun?
- 2 Describe the shape of Earth's orbit and explain how Earth's position relative to the sun changes as Earth revolves.
- 3 Name the solstices and equinoxes and the dates on which they occur.
- 4 **CRITICAL THINKING** How would the solstices and equinoxes change if the Earth's orbit were circular instead of elliptical? Explain how a circular orbit would affect seasonal changes.

# CHAPTER 4

## REVIEW

### Summary of Key Ideas

**4.1** Earth formed about 4.6 billion years ago from a whirling cloud of dust and gas. It developed layers as it cooled and dense material sank to its center. Meteorite impacts, the weight of overlying material, and the decay of radioactive isotopes caused Earth to heat up soon after its formation. Since then, Earth has been losing heat. Earth has a magnetic field.

**4.2** Earth makes one complete turn on its axis about every 24 hours. Its axis of rotation is tilted with respect to Earth's orbital plane. Effects of this rotation include the Coriolis effect, Foucault pendulum behavior, day and night, and sunrise and sunset. Earth is divided into 24 worldwide standard time zones that begin at the prime meridian.

**4.3** Earth revolves around the sun in an elliptical orbit with the sun as one focus. Earth's revolution along with its tilt cause seasonal changes. The summer and winter solstices are the longest and shortest days of the year, respectively. On the vernal and autumnal equinoxes, day and night are of equal lengths.

### KEY VOCABULARY

asthenosphere (p. 73)	parallax (p. 80)
autumnal equinox (p. 83)	prime meridian (p. 78)
crust (p. 73)	revolution (p. 80)
geology (p. 70)	rotation (p. 75)
inner core (p. 72)	standard time zones (p. 77)
International Date Line (p. 78)	summer solstice (p. 82)
lithosphere (p. 73)	time meridian (p. 77)
magnetic field (p. 74)	vernal equinox (p. 83)
mantle (p. 72)	winter solstice (p. 83)
outer core (p. 72)	

### Vocabulary Review

Explain the difference between the terms in each pair.

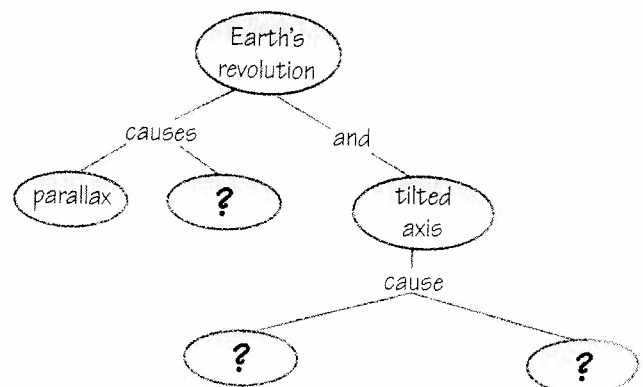
- inner core, outer core
- mantle, crust
- time meridian, prime meridian
- rotation, revolution
- summer solstice, winter solstice
- vernal equinox, autumnal equinox

Write the term from the key vocabulary list that best completes the sentence.

- A compass needle points northward due to Earth's \_\_\_\_?
- Earth is divided into 24 worldwide \_\_\_\_ , each 15° wide.
- A traveler crossing the \_\_\_\_? will either gain or lose a day.
- The apparent shift in the position of nearby stars when compared to distant stars is \_\_\_\_?

### Concept Review

- In five or more steps, summarize the major events described by the nebular hypothesis.
- Describe Earth's shape and surface area. Include any available numerical data.
- List evidence for the rotation of Earth. What is one effect of rotation?
- Graphic Organizer** Copy and complete the concept map below.



## Critical Thinking

15. **Infer** What has happened to Earth's temperature over time? If this trend continues, what might eventually happen to the temperatures of Earth's inner and outer cores, its mantle, and its crust?
16. **Draw Conclusions** During a total eclipse of the sun, the moon's shadow falls on Earth as a dark circle. What does the shape of the shadow suggest about the shape of the moon?
17. **Predict** Earth experiences an apparent force away from its center of rotation. This force is greatest at the equator. Jupiter rotates more rapidly than Earth. Predict the shape of Jupiter. Explain your reasoning.
18. **Infer** How would increasing the tilt of Earth's axis affect the amount of daylight throughout the year? If Earth's axis were tilted at  $33.5^\circ$  instead of  $23.5^\circ$ , where would the tropics of Cancer and Capricorn and the Arctic and Antarctic circles be located?

## Interpreting Graphs

The apparent size or diameter of an object in the sky depends on your distance from the object. Apparent diameters are measured in degrees. The width of your fist viewed at arm's length has an apparent diameter of about  $10^\circ$ . The apparent diameter of the sun, a much larger object, is less than  $1^\circ$ . The graph records the apparent diameter of the sun when viewed from Earth over the course of a year.

19. In which season is the sun's apparent diameter largest? Is Earth closer to or farther from the sun at that time?
20. In which season is the sun's apparent diameter smallest? Is Earth closer to or farther from the sun at that time?
21. Based on your previous answers, explain how you know that distance from the sun is not a cause of seasons.
22. Use the graph to determine the months during which Earth is at aphelion and at perihelion.

## Internet Extension



Learn more about methods of keeping time.

Keycode: ES0409

## Writing About the Earth System

**SCIENCE NOTEBOOK** Over the course of the school year, record observations in your notebook about local seasonal changes, including observations about the changing amount of daylight. Using information about your local weather, describe the impact of seasons on the atmosphere and the biosphere.

Apparent Diameter of the Sun

