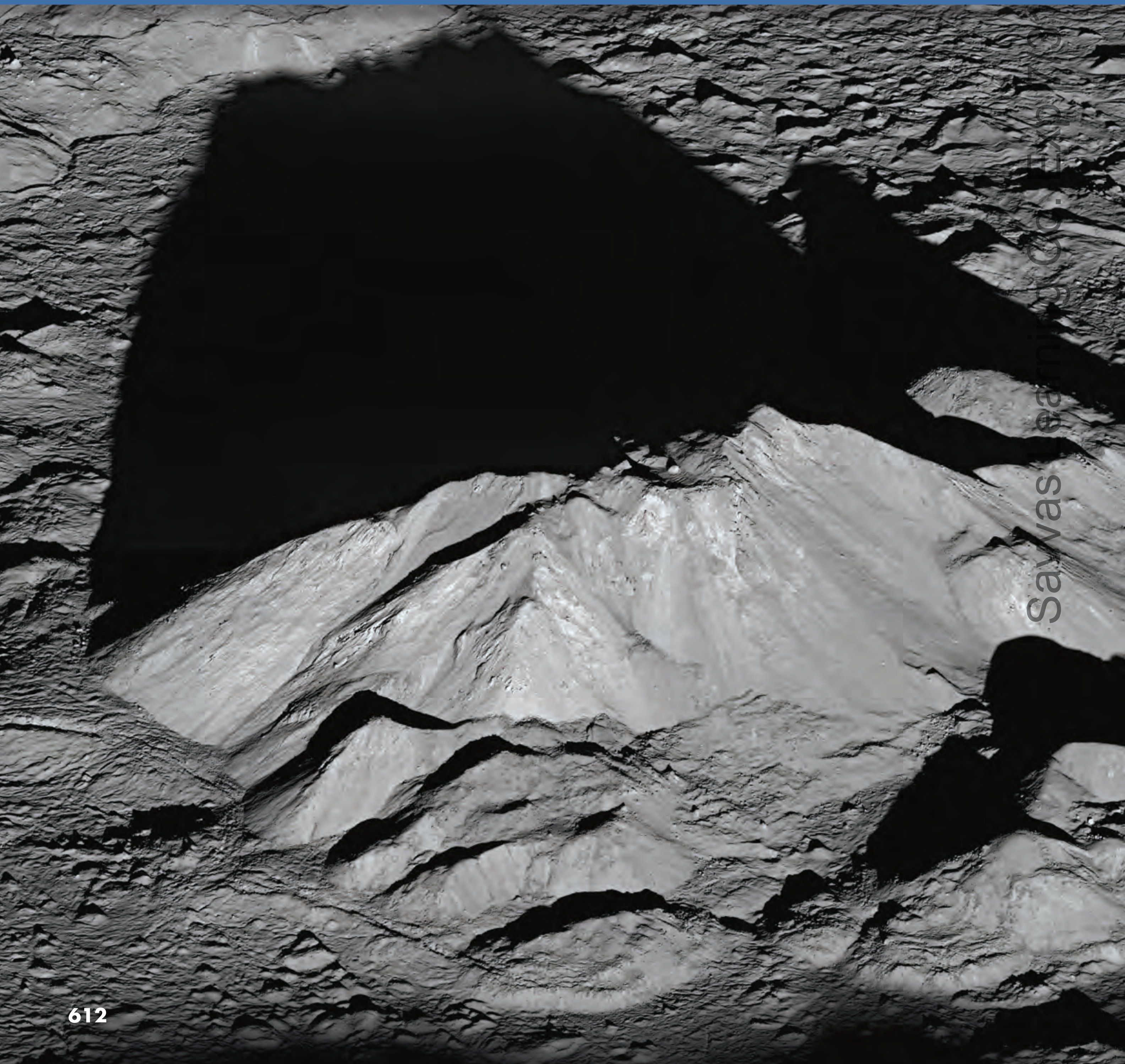
22 Origin of Modern Astronomy

Big idea **Earth and the Universe**

Q: What is the origin of the Moon?

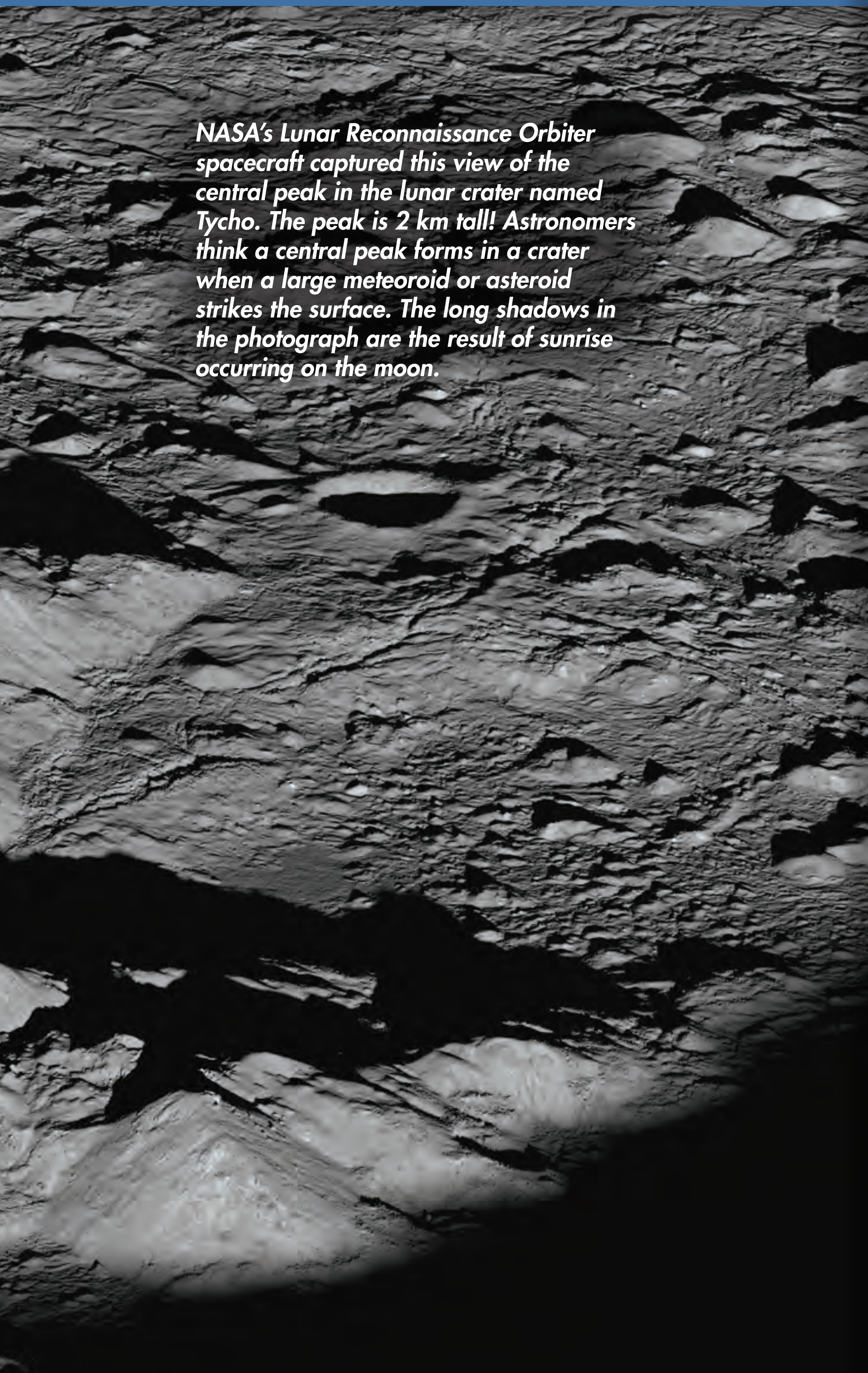


INQUIRY

TRY IT!

VIRGINIA SCIENCE STANDARDS OF LEARNING

ES.1.c, ES.2.c, ES.3.a, ES.3.b, ES.3.c, ES.3.d.
See lessons for details.



NASA's Lunar Reconnaissance Orbiter spacecraft captured this view of the central peak in the lunar crater named Tycho. The peak is 2 km tall! Astronomers think a central peak forms in a crater when a large meteoroid or asteroid strikes the surface. The long shadows in the photograph are the result of sunrise occurring on the moon.

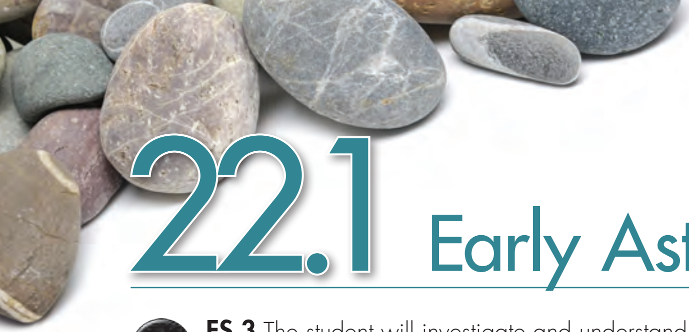
HOW DO IMPACT CRATERS FORM?

Procedure

1. Fill a large, plastic container with sand to a depth of about 3 cm. Flatten the surface of the sand with a wooden ruler.
2. Design a data table to record your measurements.
3. One at a time, drop each of the different-sized balls from heights of 0.5 m, 1 m, and 2 m into the container. Make sure to smooth the surface of the sand between each drop.
4. Measure the diameter and height of the crater produced each time. Record your measurements in your data table.

Think About It

1. **Make Graphs** Identify your dependent and independent variables. Then plot your data on a line graph.
2. **Control Variables** Which of the variables is directly related to the velocity of the falling objects?
3. **Draw Conclusions** Examine your data closely. What can you conclude about the general relationships between crater size and the size, mass, and velocity of the object that produced the crater?



22.1 Early Astronomy

ES.3 The student will investigate and understand the characteristics of Earth and the solar system. Key concepts include **d.** the history and contributions of space exploration.

Key Questions

How does the geocentric model of the solar system differ from the heliocentric model?

What were the accomplishments of early astronomers?

Vocabulary

- astronomy • geocentric
- orbit • heliocentric
- retrograde motion • ellipse
- astronomical unit (AU)

Reading Strategy

Compare and Contrast
Copy the table below. As you read about the geocentric and heliocentric models of the solar system, fill in the table.

	Location of Earth	Location of Sun	Supporters of Model
Geocentric Model	center of universe	a. ___?___	b. ___?___
Heliocentric Model	c. ___?___	d. ___?___	e. ___?___

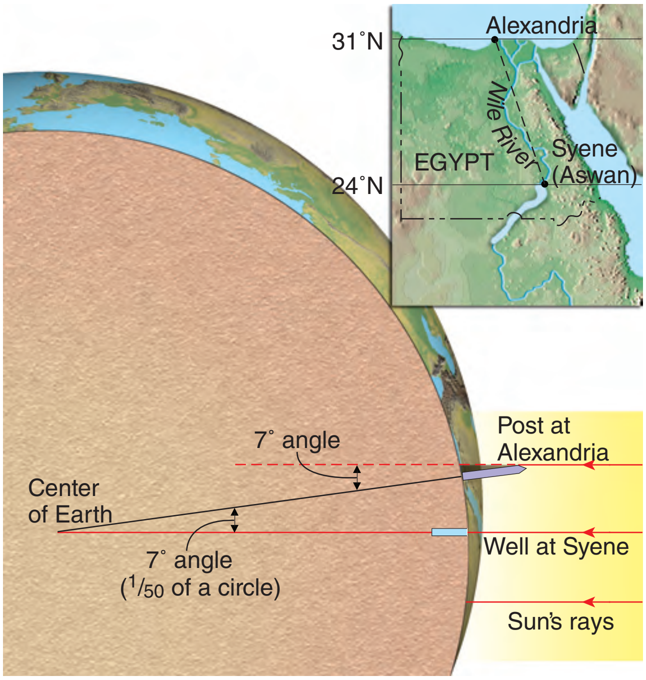
EARTH IS ONE of the planets and many smaller bodies that orbit the sun. The sun is part of a much larger family of perhaps 400 billion stars that make up our galaxy, the Milky Way. There are billions of galaxies in the universe. A few hundred years ago scientists thought that Earth was the center of the universe. In this chapter, you will explore some events that changed the view of Earth's place in space. You will also examine Earth's moon.

Ancient Greeks

Astronomy is the science that studies the universe. It deals with the properties of objects in space and the laws under which the universe operates. The "Golden Age" of early astronomy (600 b.c.–a.d. 150) was centered in Greece. The early Greeks used philosophical arguments to explain natural events. However, they also relied on observations. These early astronomers used instruments such as the astrolabe in **Figure 1** to find the positions of the sun and stars. The Greeks developed the basics of geometry and trigonometry, which was used to measure the sizes and distances of the sun and the moon.

The famous Greek philosopher Aristotle (384–322 b.c.) concluded that Earth is round because it always casts a curved shadow on the moon when it passes between the sun and the moon. Aristotle's belief that Earth is round was abandoned during the Middle Ages.

FIGURE 1 Astrolabe
Early astronomers often used instruments called astrolabes to locate and predict the positions of the sun and stars.



VISUAL SUMMARY

CALCULATING EARTH'S CIRCUMFERENCE

FIGURE 2 The Geometry of Astronomy This diagram shows the angle of the sun's rays at Syene (Aswan) and Alexandria in Egypt on June 21. Eratosthenes used these measurements to calculate the circumference of Earth.

The fi st successful attempt to establish the size of Earth is credited to Eratosthenes (276–194 b.c.). A s shown in **Figure 2,** he observed the angles of the noonday sun on the same day of the year in two Egyptian cities—Syene (now Aswan) and Alexandria. The angles differed by 7 degrees, or 1/50 of a circle, so he concluded that the circumference of Earth must be 50 times the distance between these two cities. The cities were 5000 stadia apart, giving him a calculation of 250,000 stadia. Many historians think that one *stadion* (plural, stadia) was equivalent to 157.6 meters. This would make Eratosthenes's calculation of Earth's circumference—about 39,400 kilometers—a measurement very close to the modern value of 40,075 kilometers.

Geocentric Model Ancient Greeks believed in a **geocentric** universe, in which Earth was a sphere that stayed motionless at the center of the universe. **In the geocentric model, the moon, sun, and the known planets—Mercury, Venus, Mars, Jupiter and Saturn—go around Earth.** The path of an object as it goes around another object in space is called an **orbit.** Beyond the planets was a transparent, hollow sphere on which the stars traveled daily around Earth. This was called the celestial sphere. To the Greeks, all of the heavenly bodies, except seven, appeared to remain in the same relative position to one another. These seven wanderers included the sun, the moon, Mercury, Venus, Mars, Jupiter, and Saturn. Each was thought to have a circular orbit around Earth. The Greeks were able to explain the apparent movements of all celestial bodies in space by using this model. Although the geocentric model of the universe was not correct, astronomers still use the concept of the celestial sphere to describe the motion of objects in the sky as seen from Earth. **Figure 3A** on the next page illustrates the geocentric model.

A

B

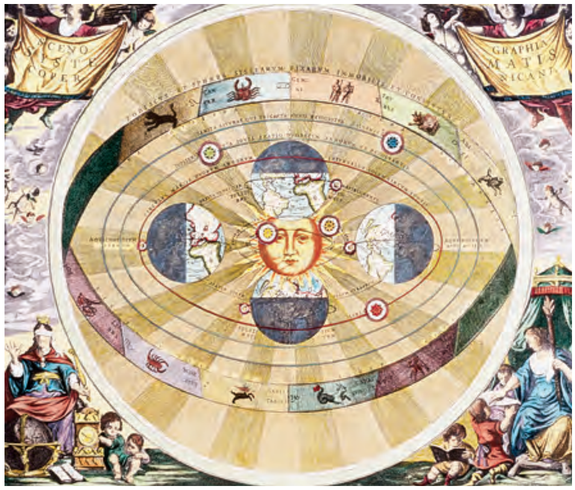


FIGURE 3 A Geocentric Model of the Universe In a geocentric system, the planets and sun orbit Earth. **B Heliocentric Model of the Universe** In a heliocentric system, Earth and the other planets orbit the sun.

PLANET DIARY

For Links on **Astronomy**, visit PlanetDiary.com/HSES.

Heliocentric Model Aristarchus (312–230 b.c.) was the first Greek to propose a sun-centered, or **heliocentric,** universe. **In the heliocentric model, Earth and the other planets orbit the sun.** Aristarchus used geometry to calculate the relative distances from Earth to the sun and from Earth to the moon. He later used these distances to calculate the size of the sun and the moon. But Aristarchus came up with numbers that were much too small. However, he did determine that the sun was many times more distant than the moon and many times larger than Earth. Though there was evidence to support the heliocentric model, shown in **Figure 3B,** the Earth-centered view dominated Western thought for nearly 2000 years.

Ptolemaic System Much of our knowledge of Greek astronomy comes from Claudius Ptolemy. In a.d. 141, Ptolemy presented a model of the universe that was later called the Ptolemaic system. The precision with which his theory was able to predict the motion of the planets allowed it to go unchallenged for nearly 13 centuries.

Just like the Greek model, Ptolemy's model had the planets moving in circular orbits around a motionless Earth. However, the motion of the planets against the background of stars seemed odd. Each planet, if watched night after night, moves slightly eastward among the stars. But periodically, each planet appears to stop, reverse direction for a time, and then resume an eastward motion. The apparent westward drift is called **retrograde motion** and is illustrated in **Figure 4.** This rather odd apparent motion actually results from the combination of the motion of Earth and the planet's own motion around the sun. However, Ptolemy explained retrograde motion by saying that planets moved along smaller circles, called *epicycles*, which in turn moved along their orbits around Earth. Ptolemy's theory was wrong—the planets do not orbit Earth. Yet his theory accounted for the planets' apparent motions.

Reading Checkpoint *What is retrograde motion?*

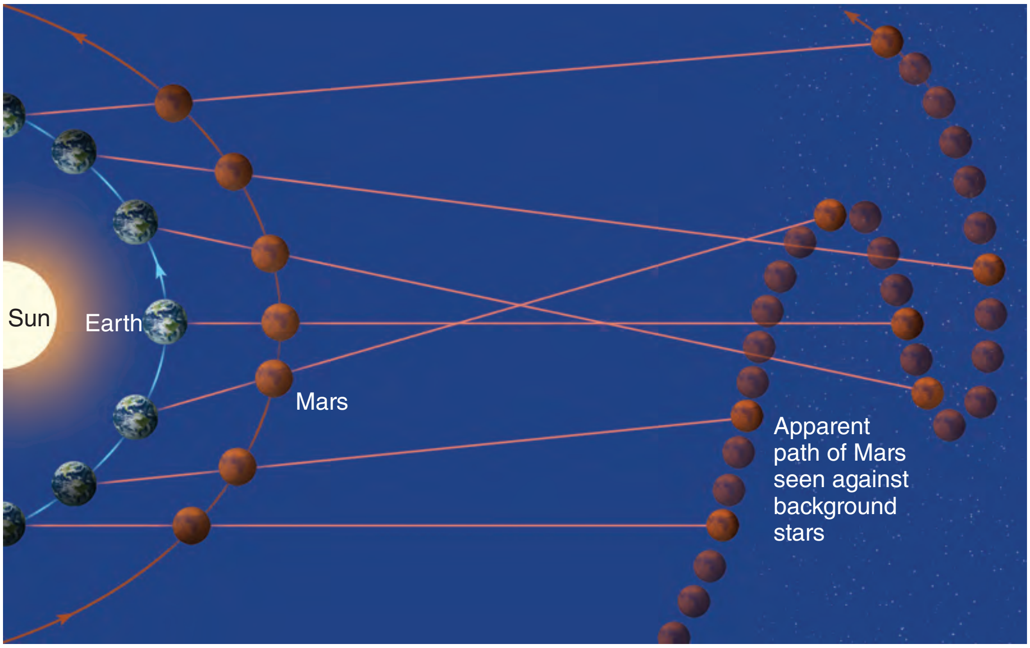


FIGURE 4 Retrograde Motion When viewed from Earth, Mars moves eastward among the stars each day. Then periodically it appears to stop and reverse direction. This apparent movement, called retrograde motion, occurs because Earth has a faster orbital speed than Mars and overtakes it.

The Birth of Modern Astronomy

The development of modern astronomy involved a break from previous philosophical and religious views. Scientists began to discover a universe governed by natural laws. We will examine the work of five noted scientists: Nicolaus Copernicus, Tycho Brahe, Johannes Kepler, Galileo Galilei, and Sir Isaac Newton.

Nicolaus Copernicus For almost 13 centuries after the time of Ptolemy, very few astronomical advances were made in Europe. The fi st great astronomer to emerge after the Middle Ages was Nicolaus Copernicus (1473–1543) from Poland. **Copernicus concluded that Earth is a planet. He proposed a model of the solar system with the sun at the center.** This was a major break from the ancient idea that a motionless Earth lies at the center. Copernicus used circles, which were considered to be the perfect geometric shape, to represent the orbits of the planets. However, the actual path of the planets seemed to stray from the paths predicted by Copernicus.

Tycho Brahe Tycho Brahe (1546–1601) was born of Danish nobility three years after the death of Copernicus. Brahe became interested in astronomy while viewing a solar eclipse that had been predicted by astronomers. He persuaded King Frederick II to build an observatory near Copenhagen. The telescope had not yet been invented. At the observatory, Brahe designed and built other instruments, such as the angle-measuring device shown in **Figure 5.** He used these instruments for 20 years to measure the positions of the the moon, planets, and stars. **Brahe's observations, especially of Mars, were far more precise than any made previously.** In the last year of his life, Brahe found an able assistant, Johannes Kepler. Kepler kept most of Brahe's observations and put them to exceptional use.

FIGURE 5 Tycho Brahe in His Observatory Brahe (seated) is painted on the wall within the arc of a sighting instrument called a quadrant.

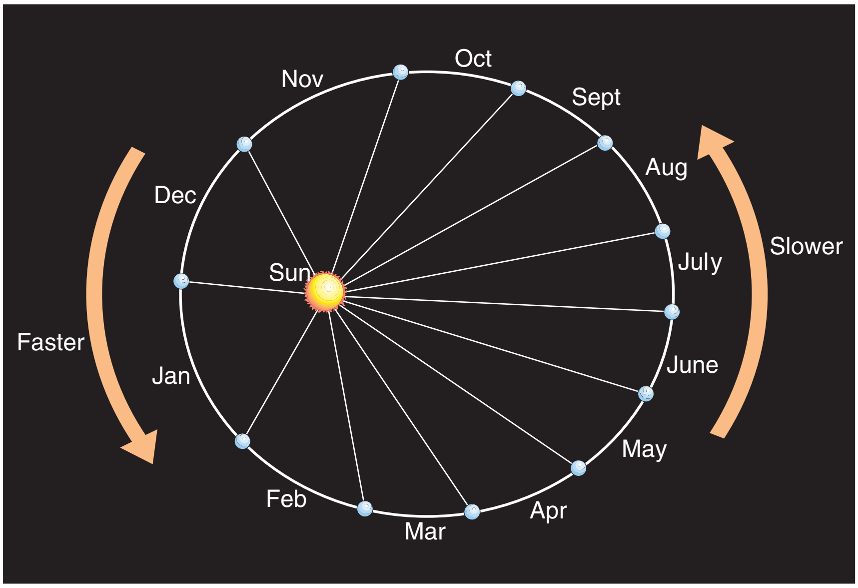


FIGURE 6 Planet Revolution
A line connecting a planet to the sun moves in such a manner that equal areas are swept out in equal times. Thus, planets revolve slower when they are farther from the sun and faster when they are closer.

Johannes Kepler Johannes Kepler (1571–1630) was an astronomer with a strong belief in the accuracy of Brahe's work. **Kepler discovered three laws of planetary motion.** The fi st two laws resulted from his inability to fit Brahe's observations of Mars to a circular orbit. Kepler concluded that the orbit of Mars around the sun is not a perfect circle. Instead, it is an oval-shaped path, called an **ellipse.** Two points inside the ellipse, each called a *focus* (plural, foci), help to determine the shape of the ellipse. The further apart the foci, the more stretched out the ellipse. About the same time, Kepler realized that the speed of Mars in its orbit changes in a predictable way. As Mars approaches the sun, it speeds up. As it moves away from the sun, it slows down.

Kepler summarized three laws of planetary motion:

1. The path of each planet around the sun is an ellipse, with the sun at one focus. The other focus is located at the symmetrically opposite end of the ellipse.
2. Each planet revolves so that an imaginary line connecting it to the sun sweeps over equal areas in equal time intervals, as shown in **Figure 6.** If a planet is to sweep equal areas in the same amount of time, it must travel more rapidly when it is nearer the sun and more slowly when it is farther from the sun.
3. The square of the length of time it takes a planet to orbit the sun (*orbital period*) is proportional to the cube of its mean distance to the sun.

In its simplest form, the orbital period of revolution is measured in Earth years. A planet's distance to the sun is expressed in **astronomical units (AU),** which is the average distance between Earth and the sun. One AU is about 150 million kilometers.

Using these units, Kepler's third law states that a planet's orbital period squared is equal to its mean solar distance cubed ($T^2 = d^3$). Therefore, the solar distances of the planets can be calculated when their periods of revolution are known. For example, Mars has a period of 1.88 Earth years, which squared equals 3.54. The cube root of 3.54 is 1.52, and that is the distance from the sun to Mars in astronomical units. The solar distance and orbital period of all the planets and Pluto—a dwarf planet—are shown in **Table 1.** The farther from the sun, the greater a planet's orbital period.

Table 1 Period of Revolution and Solar Distances of Planets

Planet	Solar Distance (*d*) (AU)*	Period (*T*) (Earth years)
Mercury	0.39	0.24
Venus	0.72	0.62
Earth	1.00	1.00
Mars	1.52	1.88
Jupiter	5.20	11.86
Saturn	9.54	29.46
Uranus	19.18	84.01
Neptune	30.06	164.80
Pluto**	39.44	247.70

*AU = astronomical unit. **As of 2007, Pluto is a dwarf planet.

Galileo Galilei Galileo Galilei (1564–1642) was thought by many to be the greatest Italian scientist of the Renaissance. **Galileo's most important contributions were his descriptions of the behavior of moving objects.** All astronomical discoveries before his time were made without the aid of a telescope. But in the early 1600s, Dutch lensmakers invented a device for "seeing faraway things as though nearby." The device consisted of two lenses in a tube that magnified objects about three times the size seen by the unaided eye. By 1609, these devices were available in Italy. Galileo built his own versions of these early three-power telescopes. In a short time, however, Galileo built improved versions of these early telescopes. His improved telescopes had twenty- and thirty-power magnifications.

Using these telescopes, Galileo was able to view the universe in a new way. He made many important discoveries that supported Copernicus's heliocentric view of the universe, such as the following:

1. *The discovery of four satellites, or moons, orbiting Jupiter*. This proved that the old idea of Earth being the only center of motion in the universe was wrong. Here, plainly visible, was another center of motion—Jupiter. People who opposed the sun-centered system said that the moon would be left ehind if Earth really revolved around the sun. Galileo's discovery disproved this argument.
2. *The discovery that the planets are circular disks, not just points of light, as was previously thought.* This showed that the planets were not stars.
3. *The discovery that Venus has phases just like the moon.* So Venus orbits its source of light—the sun. Galileo saw that Venus appears smallest when it is in full phase and therefore farthest from Earth, as shown in **Figure 7.**
4. *The discovery that the moon's surface was not smooth.* Galileo saw mountains, craters, and plains. Before Galileo, people thought that the objects in the sky were smooth and perfect.
5. *The discovery that the sun had sunspots, or dark regions.* These blemishes on the sun showed that the sun was not perfect. Galileo tracked the movement of these spots and estimated the rotational period of the sun as just under a month.

Many influential people during the time of Galileo strongly believed in the geocentric model of the universe. Galileo's new discoveries directly contradicted these fi mly held beliefs. As a result, Galileo lived the last years of his life under house arrest.

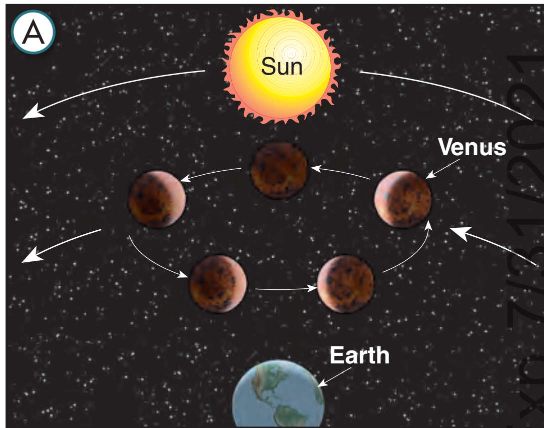
Reading Checkpoint *What is a telescope?*

VISUAL SUMMARY

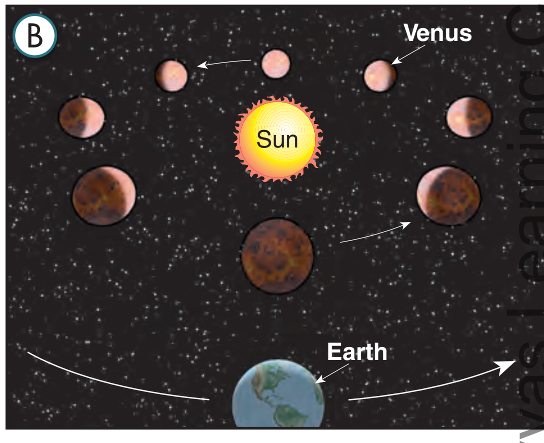
THE SOLAR SYSTEM MODEL EVOLVES

FIGURE 7

Relate Cause and Effect *In the geocentric model, which phase of Venus would be visible from Earth?*



In the Ptolemaic system, the orbit of Venus lies between the sun and Earth.



In the Copernican system, Venus orbits the sun and more of its phases are visible from Earth.

As Galileo observed, Venus goes through phases similar to the moon.

FIGURE 8 Newton and Gravity Sir Isaac Newton explained that the force of gravity kept the planets in their orbits.

Sir Isaac Newton Sir Isaac Newton (1642–1727), shown in **Figure 8,** was born in the year of Galileo's death. Many scientists had attempted to explain the forces involved in planetary motion. Kepler believed that some force pushed the planets along in their orbits. Galileo correctly reasoned that no force is required to keep an object in motion. And he proposed that a moving object will continue to move at a constant speed and in a straight line. This concept is called *inertia*.

The problem, then, was not to explain the force that keeps the planets moving but rather to determine the force that prevents them from going in a straight line out into space. Newton described a force that holds the moon in orbit around Earth. **Although others had theorized the existence of such a force, Newton was the fi st to formulate and test the law of universal gravitation.**

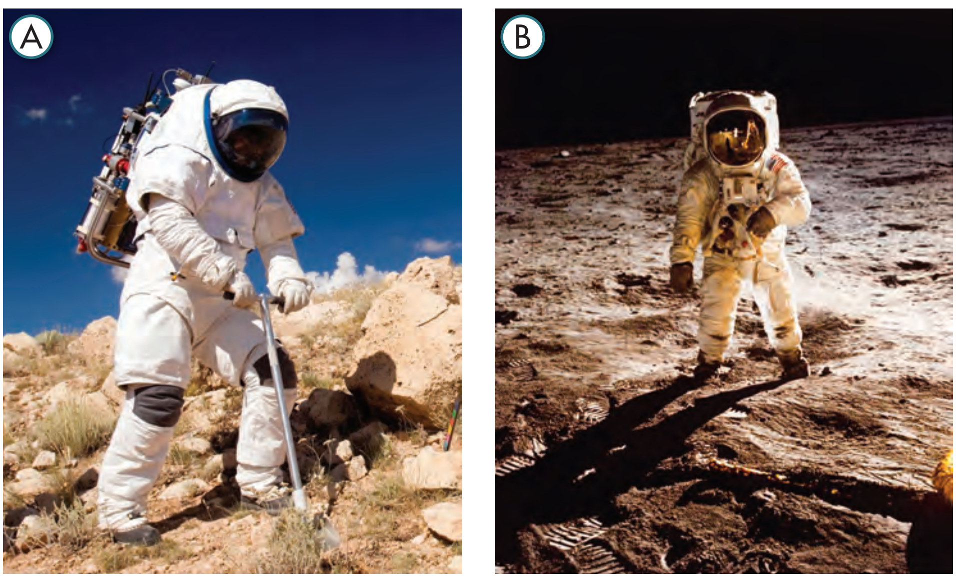
Universal Gravitation According to Newton, every body in the universe attracts every other body with a force that is directly proportional to their masses and inversely proportional to the square of the distance between their centers of mass. The mass of an object is a measure of the total amount of matter it contains.

Gravitational force decreases with distance. Two objects 3 kilometers apart have 3^2, or 9, times less gravitational attraction than if the same objects were 1 kilometer apart.

The law of universal gravitation also states that the greater the mass of the object, the greater is its gravitational force. For example, the mass of the moon creates a gravitational force strong enough to cause ocean tides on Earth. But the tiny mass of an artificial satellite has no measurable effect on Earth.

Weight is not the same as mass. *Weight* is the force of gravity acting upon an object. Therefore, weight varies when gravitational forces change, even if mass is constant. Weight is properly expressed in newtons (N). See **Figure 9.**

FIGURE 9 Gravity Affects Weight Weight is the force of gravity acting on an object. **A** An astronaut with a mass of 88 kg weighs 863 N on Earth. **B** An astronaut with a mass of 88 kg weighs 141 N on the moon.



Astronaut on Earth
Mass = 88.0 kg; Weight = 863 N

Astronaut on Moon
Mass = 88.0 kg; Weight = 141 N

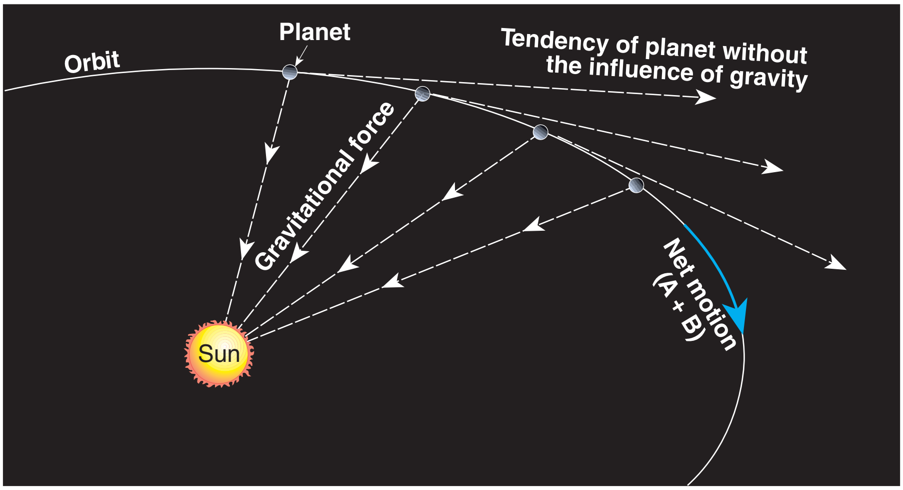


FIGURE 10 Earth's Path Without Gravity Without the influence of gravity, planets would move in a straight line out into space.

Newton proved that the force of gravity, combined with the concept of inertia, results in the elliptical orbits that Kepler discovered. Earth, for example, moves forward in its orbit about 30 kilometers each second. During the same second, the force of gravity pulls it toward the sun about 0.5 centimeter. Newton concluded that it is the combination of Earth's forward motion and its "falling" motion that defines its orbit. As **Figure 10** shows, if gravity were somehow eliminated, Earth would move in a straight line out into space. If Earth's forward motion suddenly stopped, gravity would pull it directly toward the sun.

Newton used the law of universal gravitation to redefine Kepler's third law. When restated, Kepler's third law takes into account the masses of the bodies involved in addition to the distance between the bodies when calculating the orbital period of an object.

22.1 Assessment

Review Key Concepts

1. Compare and contrast the geocentric and heliocentric models of the universe.
2. What produces the retrograde motion of Mars?
3. What geometric arrangements did Ptolemy use to explain retrograde motion?
4. What major change did Copernicus make in the Ptolemaic system? Why was this change significant?

Think Critically

5. **Apply Concepts** What role did the telescope play in Galileo's contributions to science?
6. **Summarize** In your own words, summarize Kepler's three laws of planetary motion.

MATH PRACTICE

7. **Calculate** Use Kepler's third law to show that the distance of a hypothetical planet whose period is 5 years is 2.9 AU from the sun. Do the same for hypothetical planets with a period of 10 years at 4.6 AU from the sun and a period of 10 days at 0.09 AU from the sun.

22.2 The Earth-Moon-Sun System

ES.3 The student will investigate and understand the characteristics of Earth and the solar system. Key concepts include **a.** position of Earth in the solar system; **b.** sun-Earth-moon relationships; (seasons, tides, and eclipses); **c.** characteristics of the sun, planets and their moons, comets, meteors, and asteroids.

Key Questions

In what ways does Earth move?

What causes the phases of the moon?

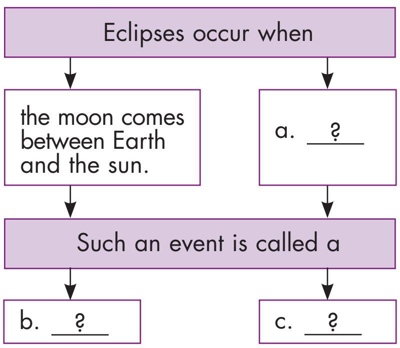
Why are eclipses relatively rare events?

Vocabulary

- rotation
- revolution
- precession
- perihelion
- aphelion
- perigee
- apogee
- phases of the moon
- solar eclipse
- lunar eclipse

Reading Strategy

Monitor Your Understanding Copy and complete the flowchart below.



IF YOU FIND a spot for star gazing away from city lights, it will seem that the stars are fi ed to a giant dome that covers Earth. This impression seems so real that it is easy to understand why many early Greek astronomers regarded the stars as being fi ed to a solid, celestial sphere. The sun and moon, on the other hand, constantly change their positions against the stars. Prehistoric people built observatories to chart their motions. The structure known as Stonehenge, shown in **Figure 11,** was probably an attempt at better solar predictions. At the beginning of summer in the Northern Hemisphere (on June 21), the rising sun comes up directly above the heel stone (small stone in the center of Figure 11) of Stonehenge. Besides keeping this calendar, Stonehenge may also have provided a method of predicting eclipses. In this lesson, you'll learn more about the movements of bodies in space that cause events such as eclipses.

FIGURE 11 Early Astronomical Instrument? On the summer solstice, the sun can be observed rising above the heel stone (small stone in the center) of Stonehenge, an ancient observatory in England.

Motions of Earth

The two main motions of Earth are rotation and revolution. **Rotation** is the turning, or spinning, of a body on its axis. **Revolution** is the motion of a body, such as a planet or moon, along its orbit around some point in space. For example, Earth revolves around the sun, and the moon revolves around Earth. Earth also has another very slow motion known as **precession,** which is the slight cone-shaped movement of where, in the sky, Earth's axis points. The period of Earth's rotation is one day and one revolution takes one year. However, the period of Earth's precession is 26,000 years.

Rotation The main results of Earth's rotation are day and night. Earth's rotation has become a standard method of measuring time because it is so dependable and easy to use. Each rotation of Earth around its axis equals about 24 hours. The result of Earth's rotation is an apparent circular motion by most of the stars in the sky, as shown in **Figure 12.** We can measure Earth's day in two ways. Most familiar is the apparent solar day, the time interval from one noon to the next, which is about 24 hours. Noon is when the sun has reached its highest point in the sky for that day.

The *sidereal day* is the time it takes for Earth to make one complete rotation with respect to a star other than our sun. The sidereal day is measured by the time required for a star to reappear at the identical position in the sky where it was observed the day before. The sidereal day has a period of 23 hours, 56 minutes, and 4 seconds, which is almost 4 minutes shorter than the average solar day. This difference comes from the fact that the direction to distant stars barely changes from day to day as a result of Earth's revolution around the sun. The direction to the sun from one day to the next, on the other hand, changes by almost 1 degree. This difference is shown in **Figure 13.**

Why do we use the mean solar day instead of the sidereal day as a measurement of our day? In sidereal time, "noon" occurs four minutes earlier each day. Therefore, after six months, "noon" occurs at "midnight." Sidereal time is more useful to astronomers because the stars appear in the same position every 24 sidereal hours.

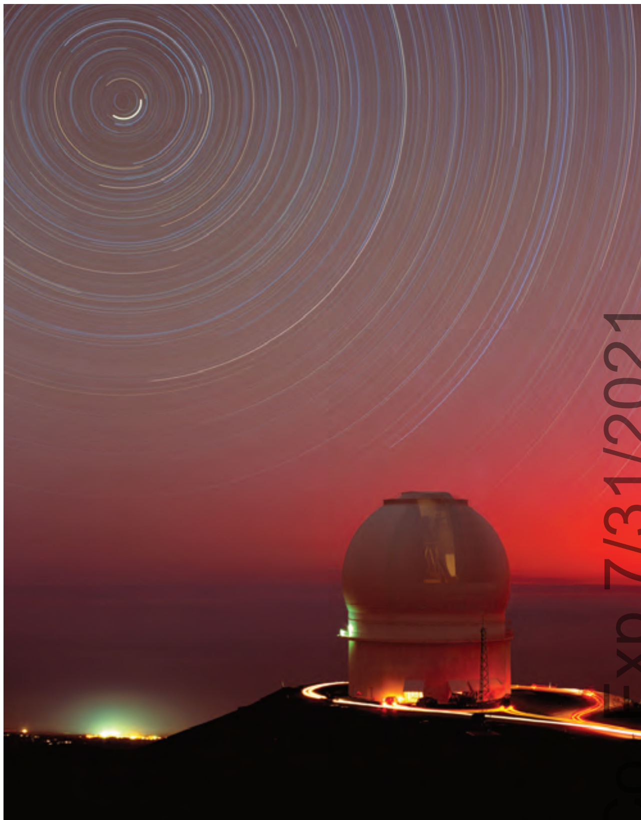


FIGURE 12 Evidence of Earth's Rotation A long exposure pointed at the star Polaris shows the apparent paths of the stars. In fact, this apparent motion is caused by Earth's rotation.

Reading Checkpoint *How is the solar day measured?*

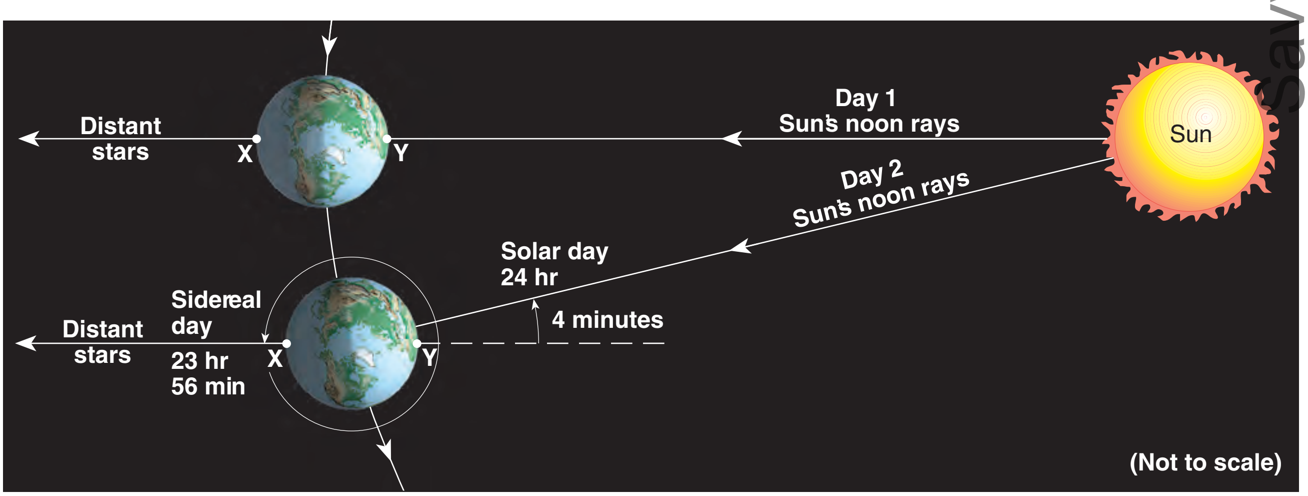
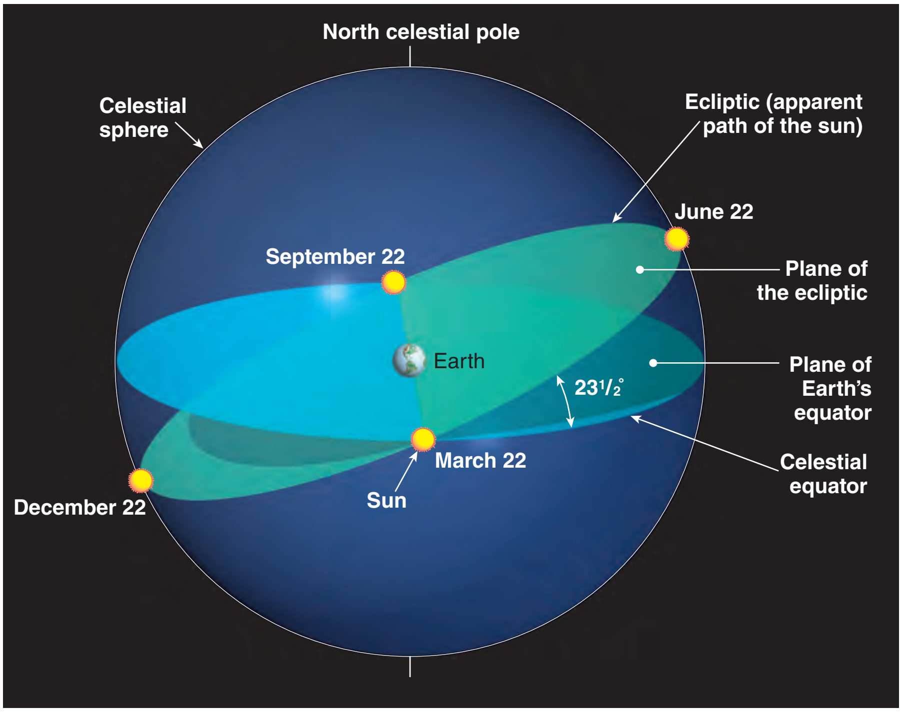


FIGURE 13 Sidereal Day It takes Earth 23 hours and 56 minutes to make one rotation with respect to the stars (sidereal day). However, after Earth has completed one sidereal day, point Y has not yet returned to the "noon position" with respect to the sun. Earth has to rotate another 4 minutes to complete the solar day.

FIGURE 14 The Celestial Sphere Earth's revolution around the sun causes the apparent position of the sun to shift about one degree each day on the celestial sphere.



Revolution Earth revolves around the sun in an elliptical orbit at an average speed of 107,000 kilometers per hour. Its average distance from the sun is 150 million kilometers. But because its orbit is an ellipse, Earth's distance from the sun varies. At **perihelion,** Earth is closest to the sun—about 147 million kilometers. Perihelion occurs around January 3. At **aphelion,** Earth is farthest from the sun—about 152 million kilometers. Aphelion occurs about July 4. So Earth is farthest from the sun in July and closest to the sun in January.

Because of Earth's annual movement around the sun, each day the sun appears to move among the constellations. The apparent annual path of the sun against the backdrop of the celestial sphere is called the *ecliptic*, as shown in **Figure 14.**

Earth's Axis and Seasons The imaginary plane that connects Earth's orbit with the celestial sphere is called the *plane of the ecliptic*. The projection of Earth's equator onto the sky is the *celestial equator*. Earth's axis of rotation is tilted about 23.5 degrees toward the plane of the ecliptic. This angle is very important to Earth's inhabitants. Because of the inclination of Earth's axis to the plane of the ecliptic, Earth has a yearly cycle of seasons.

When the apparent position of the sun is plotted on the celestial sphere over a period of a year's time, its path intersects the celestial equator at two points. From a Northern Hemisphere point of view, these intersections are called the spring equinox (March 19 or 20) and autumnal equinox (September 22 or 23). On June 20 or 21, the date of the summer solstice, the sun appears 23.5 degrees north of the celestial equator. Six months later, on December 21 or 22, the date of the winter solstice, the sun appears 23.5 degrees south of the celestial equator.

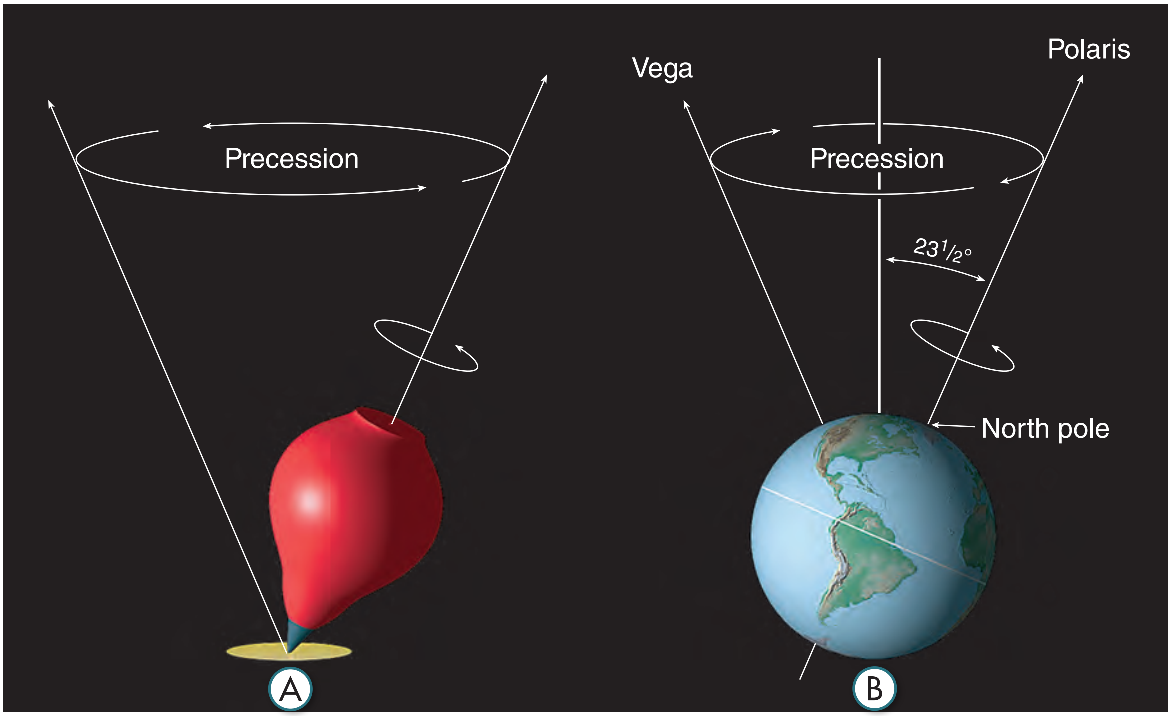


FIGURE 15 Precession

A Precession is similar to a spinning top. It causes the North Pole to point at different parts of the sky during a 26,000-year cycle.

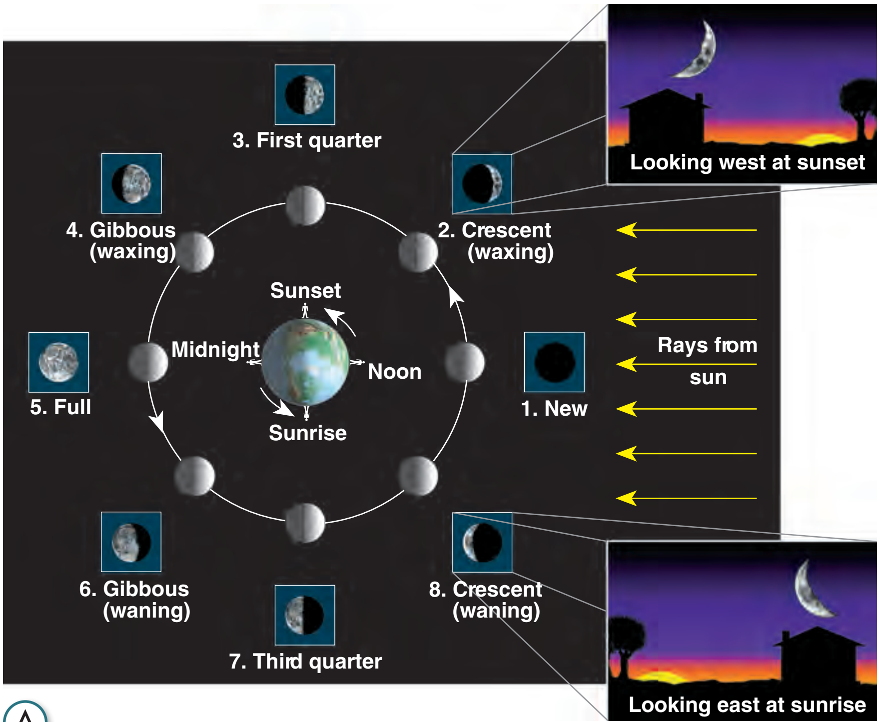
B Today, the North Pole points to Polaris.

Interpret Visuals *What star will the North Pole point to in about 13,000 years?*

Precession A slow movement of Earth, called *precession,* is the motion of Earth's axis as it traces out a circle on the sky. Earth's axis varies in tilt between 21.5° and 24.5° with a repeating period of 41,000 years. This shifting axis is important in affecting climate change. In addition, the direction in which the axis points continually changes. This movement is very similar to the wobble of a spinning top, as shown in **Figure 15A.** At the present time, the axis points toward the bright star Polaris. In about 13,000 years, it will point toward the bright star Vega, which will then become the North Star, as shown in **Figure 15B.** The period of precession, or the amount of time for the axis to complete one circle, is 26,000 years. So, by the year 28,000, Polaris will once again be the North Star.

Earth-Sun Motion In addition to its own movements, Earth accompanies the sun as the entire solar system speeds in the direction of the bright star Vega at 20 kilometers per second. Also, the sun, like other nearby stars, revolves with the Milky Way Galaxy. This trip takes 230 million years to traverse at speeds approaching 250 kilometers per second. The galaxies themselves are also in motion. The Milky Way Galaxy is presently approaching one of its nearest galactic neighbors, the Andromeda Galaxy.

☑ **Reading Checkpoint** *What is precession?*



A

Motions of the Earth-Moon System

Earth has one natural satellite, the moon. It takes about one month for our moon to orbit Earth. When viewed from above the North Pole, the direction of the moon's motion is counterclockwise. Because the moon's orbit is elliptical, its distance to Earth varies but averages 384,401 kilometers. At a point known as **perigee,** the moon is closest to Earth. At **apogee,** the moon is farthest from Earth. The terms *perigee* and *apogee* are also used to describe the closest and farthest orbital points of artificial satellites orbiting Earth.

B

FIGURE 16 Phases of the Moon
A The outer figures show the phases as seen from Earth's Northern Hemisphere.
B Compare these photographs with the diagram. Clockwise from the top left, they show four phases: waning crescent, third quarter, waning gibbous, and full.

Phases of the Moon On a monthly basis, we observe the **phases of the moon** as a change in the amount of the moon that appears lit. Look at the new moon shown in **Figure 16A.** About two days after the new moon, a thin sliver (crescent phase) appears low in the western sky just after sunset. During the following week, the lighted portion of the moon visible from Earth increases (waxing) to a half circle (fi st-quarter phase) and is visible from noon to midnight. A week later, the full disk (full-moon phase) can be seen rising in the east as the sun is sinking in the west. During the next two weeks, the percentage of the moon that can be seen decreases (waning), until the moon disappears altogether (new-moon phase). The cycle begins again with the reappearance of the crescent moon.

Lunar phases are caused by the changes in how much of the sunlit side of the moon faces Earth. This is illustrated in **Figure 16B.** Half of the moon is illuminated at all times. But to an observer on Earth, the percentage of the bright side that is visible depends on the location of the moon with respect to the sun and Earth. When the moon lies between the sun and Earth, none of its bright side faces Earth.

When the moon lies on the side of Earth opposite the sun, all of its lighted side faces Earth. So we see the full moon. At all positions between the new moon and the full moon, a part of the moon's lit side is visible from Earth.

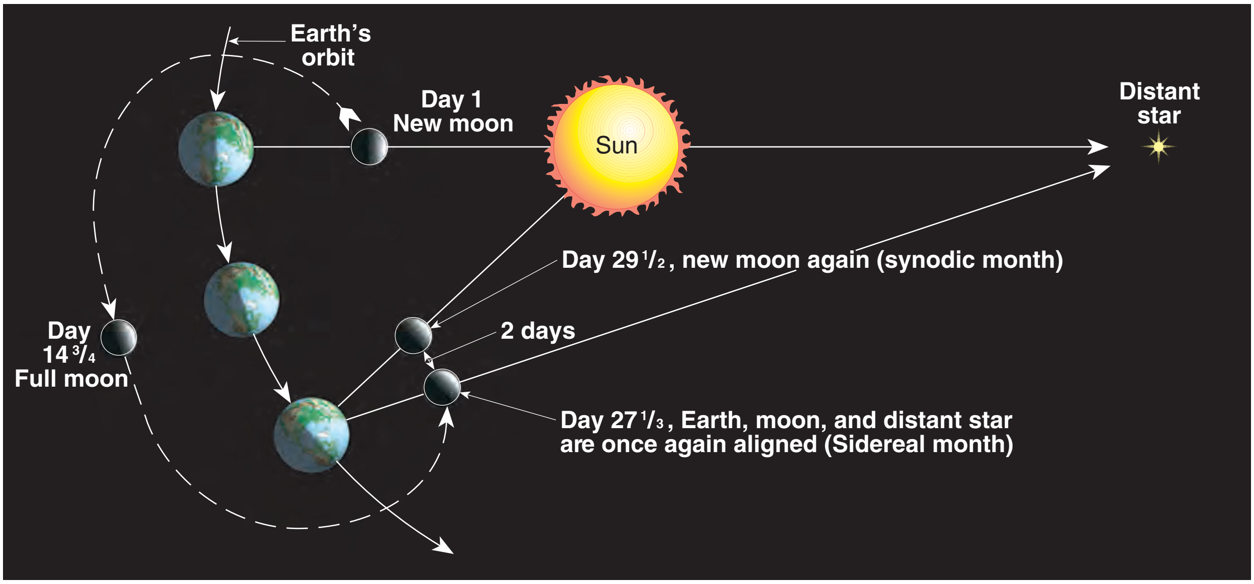


FIGURE 17 Lunar Motion As the moon orbits Earth, the Earth-moon system also revolves around the sun. Thus, even after the moon makes one revolution around Earth, it has not yet reached its starting point in relation to the sun.

Lunar Motions The cycle from new moon to full moon and back to new moon takes about $29\frac{1}{2}$ days, or one *synodic month*. This cycle was the basis for the fi st Roman calendar, which included twelve synodic periods per year. However, a synodic month is the apparent period of the moon's revolution around Earth. The true period, which takes only $27\frac{1}{3}$ days, is known as the *sidereal month*.

The reason for the difference of nearly two days between synodic and sidereal months is illustrated in **Figure 17.** Note that as the moon orbits Earth, the Earth-moon system also revolves in an orbit around the sun. Assume that the starting position of one period occurs when the moon is directly between Earth and the sun. Even after the moon has made a complete revolution around Earth, it is not yet directly between Earth and the sun. It takes another two days for the moon to reach its starting position (relative to the sun).

An interesting fact about the moon is that the same side of the moon constantly faces Earth. It takes the moon the same amount of time to rotate (spin) on its axis as it does to revolve around Earth. Both motions take $27\frac{1}{3}$ days. So, as the moon revolves around Earth, the same side of the moon is always facing Earth. Humans had their fi st views of the far (or back) side of the moon only when artificial satellites with cameras orbited the moon and took the fi st pictures of the far side. The far side of the moon appears to have many more craters than the side we see. One reason for this is that the far side is constantly pointed toward space.

Another interesting fact is that the length of one daylight period on the moon is two Earth weeks. Since the moon rotates on its axis only once every $27\frac{1}{3}$ days, any spot on the moon's surface has two weeks of daylight followed by two weeks of night. This partially accounts for the high temperature of 127°C on the day side of the moon and the low temperature of −173°C on its night side.

☑ **Reading Checkpoint** *Why does the same side of the moon always face Earth?*

ACTIVE ART

For: Phases of the Moon Activity
Visit: PearsonSchool.com
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INQUIRY
APPLY IT!

Q: *Why do we sometimes see the moon in daytime?*

A: During phases of the lunar cycle other than the full moon, the moon and sun are not directly opposite each other. This makes it possible to see the moon during daylight hours.

Eclipses

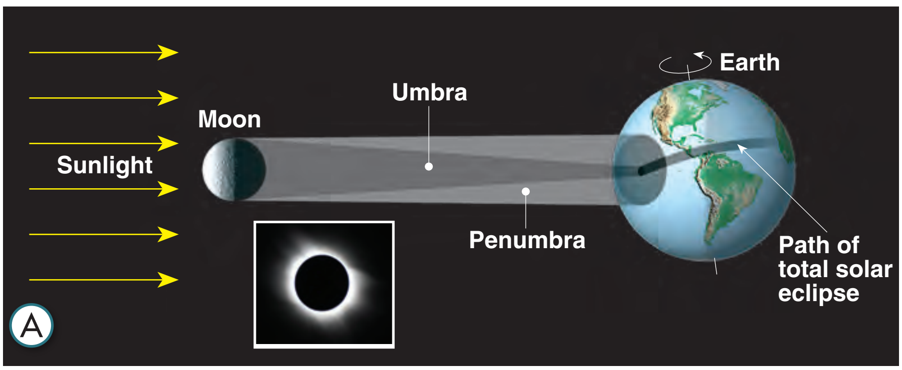
Along with understanding the moon's phases, early Greek astronomers also realized that eclipses are the result of the shadows that Earth and the moon project into space. When the moon moves in a line directly between Earth and the sun, it casts a dark shadow on Earth. This produces a **solar eclipse.** This situation occurs during new-moon phases. When the moon's orbit takes it into Earth's shadow, this produces a **lunar eclipse.** This situation occurs during full-moon phases. **Figure 18** illustrates solar and lunar eclipses.

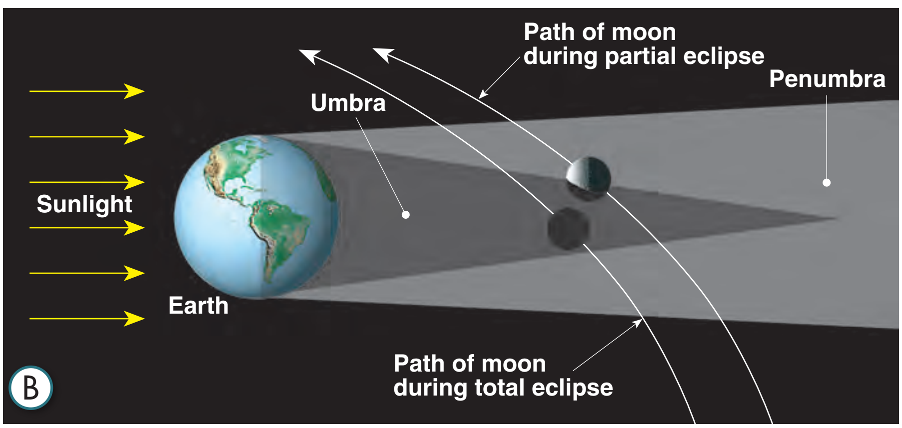
Why doesn't a solar eclipse occur with every new moon and a lunar eclipse with every full moon? If the orbit of the moon lay exactly along the plane of Earth's orbit around the sun, then we would have one solar and lunar eclipse each month. However, the moon's orbit is inclined about 5 degrees to the plane that contains Earth and the sun. During most new-moon phases, the shadow of the moon misses Earth (passes above or below). Similarly, during most full-moon phases, the shadow of Earth misses the moon. **During a new-moon or full-moon phase, the moon's orbit must cross the plane of the ecliptic for an eclipse to take place.** Because these conditions are normally met only twice a year, the usual number of eclipses is four. These occur as a set of one solar and one lunar eclipse, followed six months later with another set. Occasionally, the alignment can result in additional eclipses. However, the total number of eclipses in one year isn't more than seven. The exact day, time, and path of eclipses is very predictable. The NASA Web site lists timetables for upcoming eclipses.

VISUAL SUMMARY

SOLAR AND LUNAR ECLIPSE

FIGURE 18 Moving In and Out of Shadow A Observers in the umbra see a total solar eclipse. Those in the penumbra see a partial eclipse. The path of the solar eclipse moves eastward across the globe. The figure shows a total solar eclipse.
B During a total lunar eclipse, the moon's orbit carries it into Earth's umbra. During a partial eclipse, only a portion of the moon enters the umbra.





During a total lunar eclipse, Earth's circular shadow can be seen moving slowly across the disk of the full moon. When totally eclipsed, the moon is completely within Earth's shadow, but it is still visible as a coppery disk. This happens because Earth's atmosphere bends and transmits some light into its shadow. A total eclipse of the moon can last up to four hours and is visible to anyone on the side of Earth facing the moon.

During a total solar eclipse, the moon casts a circular shadow that is never wider than 275 kilometers, about the length of South Carolina. Anyone observing within this region will see the moon slowly and completely block the sun from view and the sky darken. When the eclipse is almost complete, the temperature sharply drops a few degrees. The solar disk is completely blocked for seven minutes at the most. The reason for the short duration of a solar eclipse is that the diameter of the moon's shadow is so small. Then one edge of the solar disk reappears and the moon continues moving until it no longer covers any part of the sun.

When the eclipse is complete, the dark moon is seen covering the complete solar disk. Only the sun's brilliant white outer atmosphere is visible. Total solar eclipses are visible only to people in the dark part of the moon's shadow known as the *umbra*. A partial eclipse is seen by those in the light portion of the shadow, known as the *penumbra*.

A total solar eclipse is a rare event at any location. The next one that will be visible from parts of the United States will take place on August 21, 2017. It will sweep southeast across the country from Oregon to South Carolina.

22.2 Assessment

Review Concepts

1. In what ways does Earth move?

2. What phenomena result from Earth's rotation and revolution?

3. What causes the phases of the moon?

4. How does the crescent phase that precedes the new moon differ from the crescent phase that follows the new moon?

5. Why don't eclipses occur during every full-moon or new-moon phase?

6. Describe the locations of the sun, moon, and Earth during a solar eclipse and during a lunar eclipse.

Think Critically

7. Predict Currently, Earth is closest to the sun in January (perihelion) and farthest from the sun in July (aphelion). However, 13,000 years from now, perihelion and aphelion will be reversed. How might this affect average summer and winter temperatures?

BIG IDEA EARTH AND THE UNIVERSE

8. Communicate Even when you are standing still you are moving rapidly through space. Write a paragraph that summarizes the many different motions you undergo during one Earth day as a result of Earth's movement through the universe.

22.3 Earth's Moon

ES.3 The student will investigate and understand the characteristics of Earth and the solar system. Key concepts include **c.** characteristics of the sun, planets and their moons, comets, meteors, and asteroids.

Key Questions

What processes created surface features on the moon?

How did the moon form?

Vocabulary

- crater
- ray
- mare
- rille
- lunar regolith

Reading Strategy

Sequence Copy Copy the flowchart below. As you read, fill in the stages leading to the formation of the moon.

Mars-size body impacted Earth.
↓
a. ?
↓
b. ?
↓
c. ?

EARTH HAS ONE natural satellite, the moon. Earth's moon, shown in **Figure 19,** is thought to be about the same age as Earth. The moon is at least 4.5 billion years old, based on the analysis of moon rocks brought back by astronauts and on other factors. The moon's average diameter is 3475 kilometers, about the same as the distance from Maine to Colorado. Its size makes the moon unique in our solar system. While other planets have moons, those moons are much smaller compared to the size of their parent planets. Earth's moon is large compared to the size of Earth.

Since Galileo first aimed a telescope at the moon, astronomers have been gathering new information. Using human and nonhuman space missions, scientists are constantly learning more about Earth's moon. For example, the moon's density is 3.3 grams per cubic centimeter (g/cm^3). That density is much less than Earth's density ($5.5\ g/cm^3$). Comparing lunar density with the density of Earth helps scientists understand the internal structure of the moon.

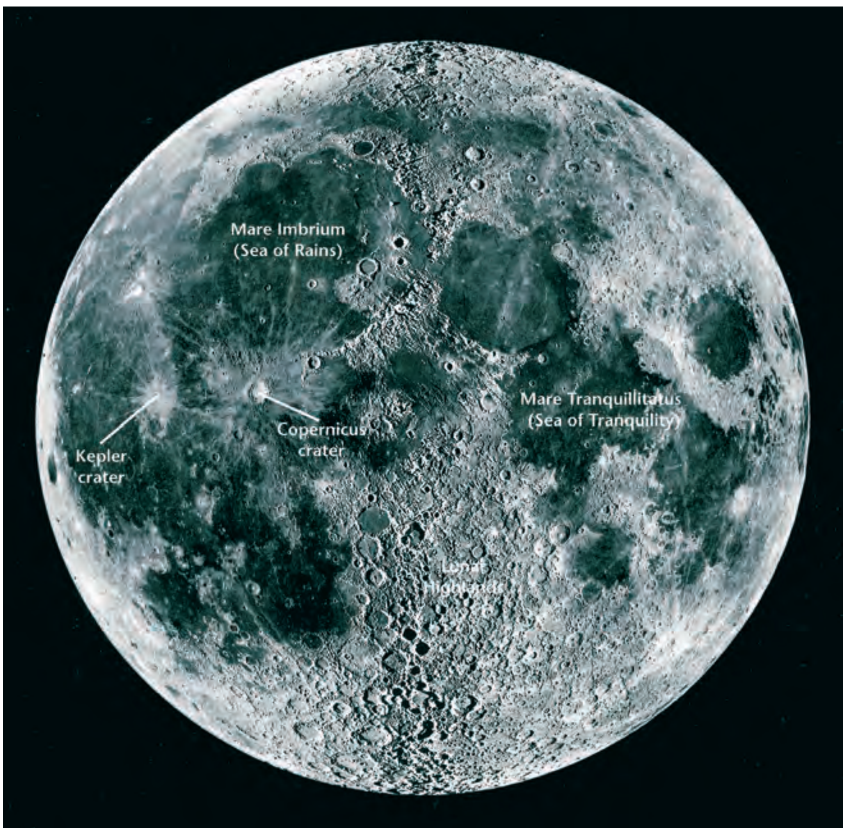


FIGURE 19 The Moon Through a Telescope This is what the moon's surface looks like from Earth when viewed through a telescope.

The Lunar Surface

Through his telescopes, Galileo saw two different types of lunar landscape—dark lowlands and bright highlands. Because the dark regions resembled seas on Earth, they were later named *maria*, which comes from the Latin word for *sea*. We know now that there is no water on the surface of the moon and virtually no atmosphere. So the lunar surface is not eroded in the same way that Earth's surface is. Instead, the moon's surface is eroded from impact by *meteoroids*, solid particles that travel through space. These particles can range in size from microscopic to a kilometer or more in diameter. Continual bombardment over billions of years has given the moon a surface that is much different from Earth's surface.

Craters

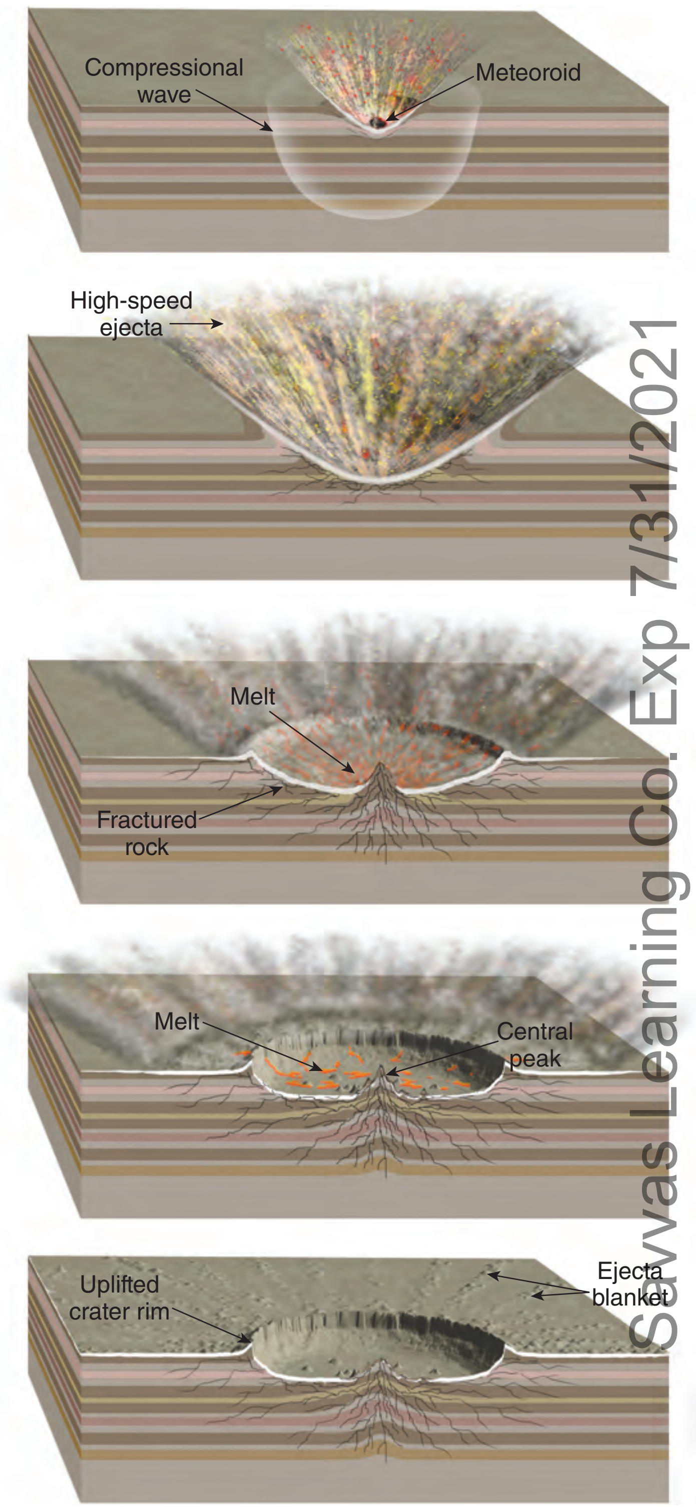
The most obvious features of the lunar surface are **craters,** which are round depressions in the surface of the moon. **Most craters were produced by the impact of rapidly moving debris or meteoroids.** Some astronomers think it is impossible to count the number of craters on the moon because the closer you look, the more small craters you fi d. The moon's surface probably has many billions of craters, from microscopic to very large. The largest craters are about 250 kilometers in diameter, about the width of Indiana.

By contrast, Earth has fewer easily recognized impact craters. Friction with Earth's atmosphere burns up small debris before it reaches the ground. Evidence for craters that formed early in Earth's history has been destroyed by erosion and other forces that change Earth's surface.

The formation of an impact crater is modeled in **Figure 20.** Upon impact, the colliding object compresses the material it strikes. This process is similar to the splash that occurs when a rock is dropped into water. In larger craters, a central peak forms as a result of the impact.

Most of the ejected material lands near the crater, building a rim around it. Heat generated by the impact is enough to melt rock. Astronauts brought back to Earth samples of lunar glass and rock formed by such impact.

A meteoroid only 3 meters in diameter can blast out a 150-meter-wide crater. A few of the large craters, such as those named *Kepler* and *Copernicus*, formed from the impact of bodies one kilometer or more in diameter. These two large craters are thought to be relatively young because the bright **rays,** or elongated streaks that radiate outward for hundreds of kilometers, are still visible.

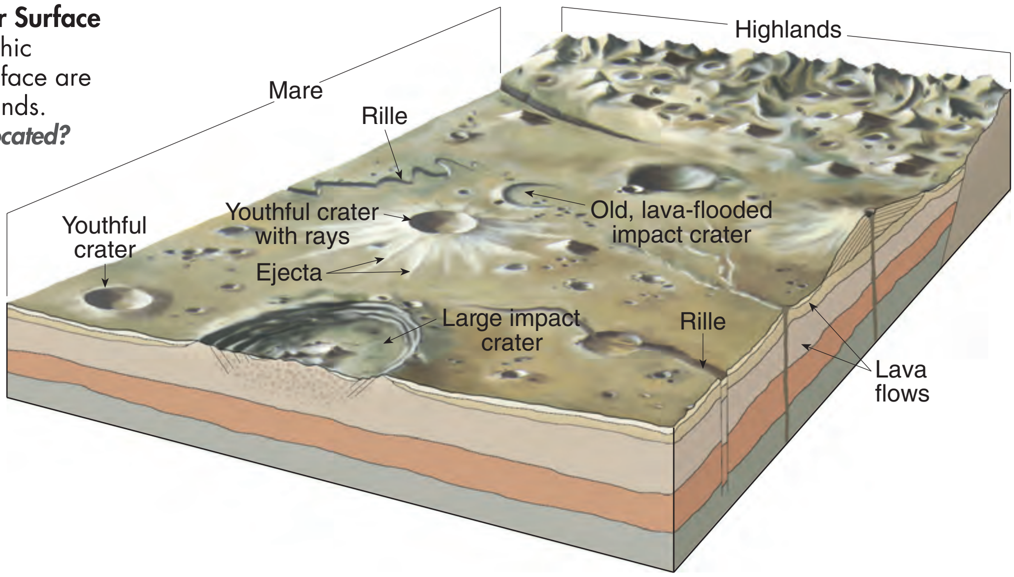


VISUAL SUMMARY

FORMATION OF A CRATER

FIGURE 20 Impact Craters
The energy of the rapidly moving meteoroid is transformed into heat energy. Rock compresses and then quickly rebounds. The rebounding rock causes debris to be ejected from the crater.

FIGURE 21 Typical Lunar Surface Features Major topographic features on the moon's surface are craters, maria, and highlands. **Identify** *Where are rilles located?*



Highlands Most of the lunar surface is made up of light-colored, mountainous areas known as highlands. **Figure 21** shows highlands and other features of the moon. In fact, highlands cover most of the surface of the far side of the moon. Within the highland regions are mountain ranges and large concentrations of impact craters. The highest lunar peaks reach elevations of almost 8 kilometers. This height is only one kilometer lower than Mount Everest, the highest mountain on Earth. The origin of lunar mountains is thought to be a different process than the origin of mountains on Earth. Many astronomers think that the mountains in lunar highlands were formed when very large space debris, called *asteroids*, struck the moon's surface.

Maria The dark, relatively smooth areas on the moon's surface are called maria (singular: **mare**). **Maria, ancient beds of basaltic lava, originated when asteroids punctured the lunar surface, letting magma "bleed" out.** Apparently, the craters were flooded with layer upon layer of very fluid basaltic lava somewhat resembling the Columbia Plateau in the northwestern United States. The lava flows are often over 30 meters thick. The total thickness of the material that fills the maria could reach thousands of meters.

Long channels called **rilles** are associated with maria. Rilles look somewhat similar to river valleys. Rilles may be the remnants of ancient rivers of lava.

Regolith All lunar terrains are covered with a layer of gray debris that came from billions of years of bombardment from space debris. This uppermost layer, called **lunar regolith,** is composed of igneous rocks, beads, and fi e lunar dust. In the maria explored by astronauts, the lunar regolith is just over 3 meters thick. It is thought that in other areas, the regolith could be more than 20 meters thick.

Reading Checkpoint *What is lunar regolith?*

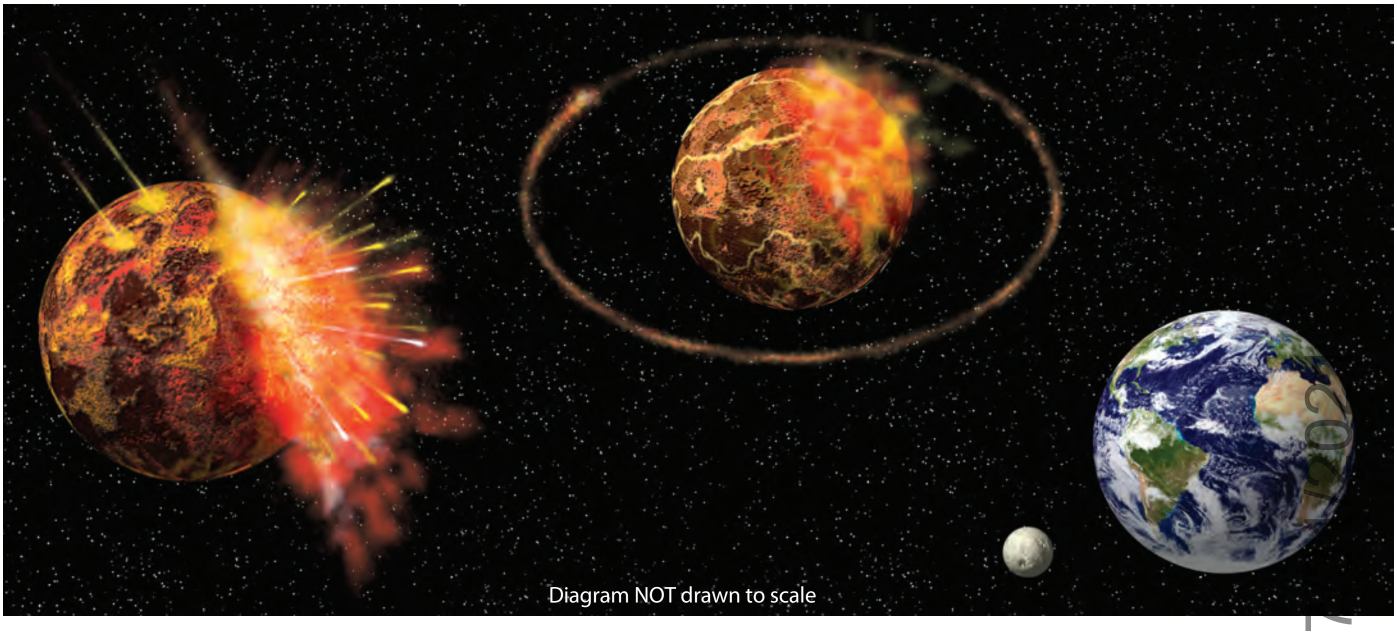


FIGURE 22 Formation of the Moon The moon may have formed when a large object collided with Earth. The resulting debris was ejected into space. The debris began orbiting around Earth and eventually united to form the moon.

Lunar History

The moon is our nearest planetary neighbor. Although astronauts have walked on its surface, much is still unknown about its origin. **The most widely accepted model for the origin of the moon is that when the solar system was forming, a body the size of Mars impacted Earth.** The impact, shown in **Figure 22,** would have liquefied Earth's surface and ejected huge quantities of crustal and mantle rock from an infant Earth. A portion of this ejected debris would have entered an orbit around Earth where it combined to form the moon.

The giant-impact hypothesis is consistent with other facts known about the moon. The ejected material would have been mostly iron-poor mantle and crustal rocks. These would account for the lack of a sizable iron core on the moon. The ejected material would have remained in orbit long enough to have lost the water that the moon lacks. Despite this supporting evidence, many more questions need to be answered about how and when the moon formed.

Space geologists have worked out the basic details of the moon's more recent history. One of their methods is to observe variations in crater density (the number of craters per unit area). The greater the crater density, the older the surface must be. From such evidence, scientists concluded that the moon evolved in three phases—the original crust (highlands), followed by maria basins, and fi ally rayed craters.

During its early history, the moon was continually impacted as it swept up debris. This continuous bombardment, combined with radioactive decay, generated enough heat to melt the moon's outer shell and possibly some of the interior as well. Remnants of this original crust occupy the densely cratered highlands. These highlands have been estimated to be as much as 4.5 billion years old, about the same age as Earth.

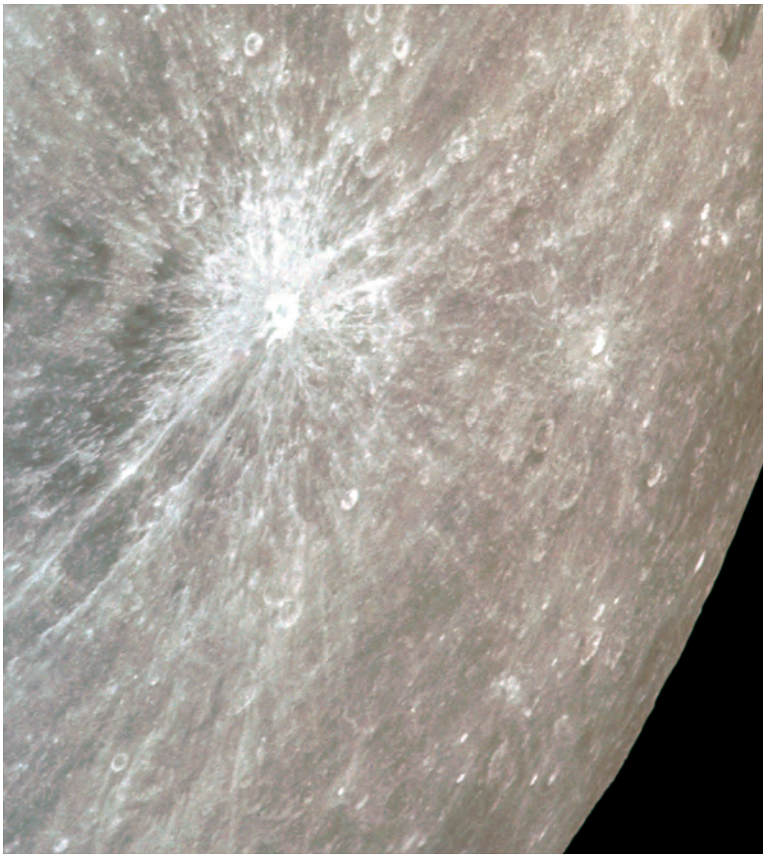


FIGURE 23 Most Recent Lunar Features Bright-rayed craters such as this one, located on the far side of the moon, are the most recent major features that formed on the lunar surface. Notice how the rays can be seen on top of other surface features. This is evidence that the rays are younger than those other features.

The next phase of the moon's history was the formation of maria basins. Analysis of rock samples from lunar maria has shown the maria to be between 3.2 billion and 3.8 billion years old. This is about a billion years younger than the moon's original crust. In other words, the maria formed about a billion years after the moon formed. In places, these lava flows overlap the highlands, which is further evidence that the maria are younger than the highlands.

The most recent prominent features that formed are the rayed craters. Material ejected from these relatively young depressions can be clearly seen covering the lunar surface and many older craters. Even a young crater like the one shown in **Figure 23** is probably millions of years old. If this crater had formed on Earth, erosional forces would have erased it long ago. Compared with Earth, the lunar surface changes very slowly. For example, footprints left by astronauts on the moon will likely remain, little changed, for millions of years. However, a million years from now if you could view a lunar footprint through a microscope, you would probably see many, many craters formed by the impact of microscopic meteoroids.

22.3 Assessment

Review Concepts

1. How did most lunar craters form?

2. How did maria originate?

3. What is one hypothesis that explains how the moon formed?

Think Critically

4. Apply Concepts On Earth, the four major spheres (atmosphere, hydrosphere, geosphere, and biosphere) interact as a system. Which of these spheres are absent, or nearly absent, on the moon? Based on your answer, identify at least five processes that operate on Earth but not on the moon.

5. Infer Why are craters more common on the moon than on Earth, even though the moon is a smaller target?

CONNECTING CONCEPTS

6. Explain Write a paragraph explaining what evidence scientists use to reconstruct the history of the moon.

EARTH & HISTORY

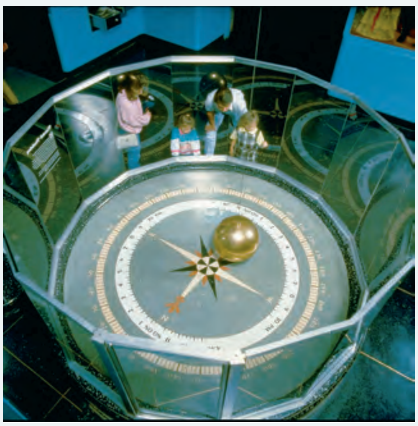
Foucault's Experiment

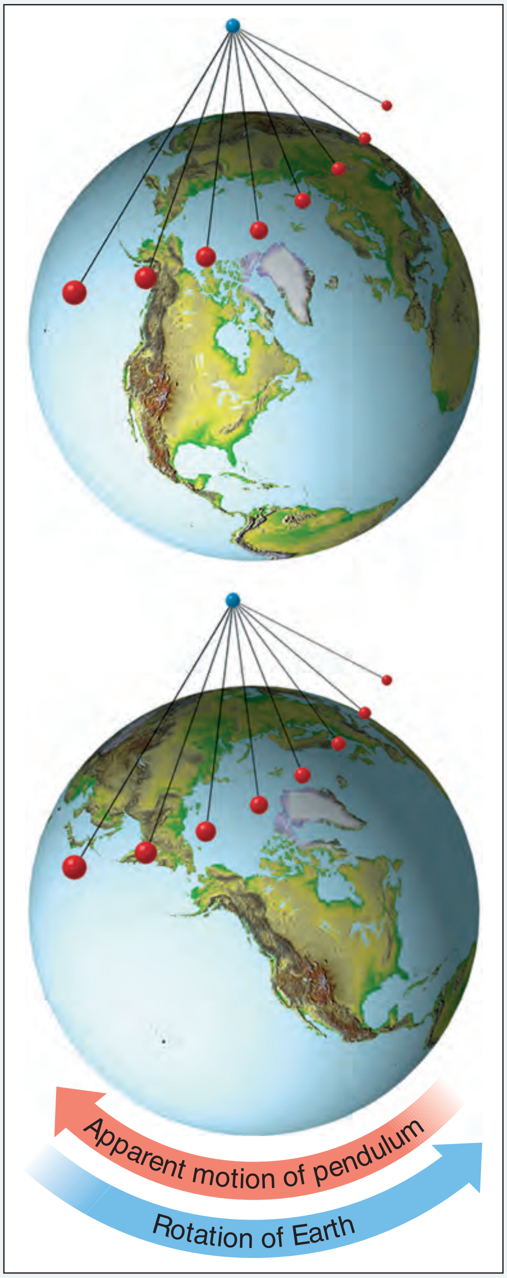
Today, scientists understand that Earth rotates on its axis once each day, which produces periods of daylight and darkness. However, day and night can be accounted for equally well by a sun and a celestial sphere that revolve around a stationary Earth. How to prove that Earth rotates?

In the 1500s, Copernicus realized that a rotating Earth that also revolves around the sun greatly simplified the model of the universe. But he was unable to prove his theory. The first proof was presented 300 years after the death of Copernicus by French physicist Jean Foucault.

The Swinging Pendulum

In 1851, Foucault used a free-swinging pendulum to demonstrate that Earth does, in fact, turn on its axis. To picture Foucault's experiment, imagine a large pendulum swinging over the North Pole, as shown in the illustration on this page. Keep in mind that once a pendulum is put into motion, it continues swinging in the same plane unless acted upon by some outside force. Assume that a sharp point is attached to the bottom of this pendulum, marking the snow as it swings. If we were to observe the marks made by the point, we would see that the pendulum is slowly but continually changing position. At the end of 24 hours, the pendulum would have returned to its starting position.





Evidence of Earth's Rotation

No outside force acted on the pendulum to change its position. So what we observed must have been Earth rotating beneath the pendulum. Foucault conducted a similar experiment when he suspended a long pendulum from the dome of the Pantheon in Paris. Today, Foucault pendulums can be found in some museums to recreate this famous science experiment.

INQUIRY

EXPLORATION LAB

Modeling Synodic and Sidereal Months

Problem How do synodic and sidereal months differ?

Materials pencil, paper, lamp, basketball, softball

Skills Observe, Use Models, Analyze Data, Draw Conclusions

Connect to the Big idea The time interval required for the moon to complete a full cycle of phases is 29.5 Earth days, or one synodic month. The true period of the moon's revolution around Earth, however, is only 27.3 Earth days and is known as the sidereal month. In this lab, you will model the differences between synodic and sidereal months.

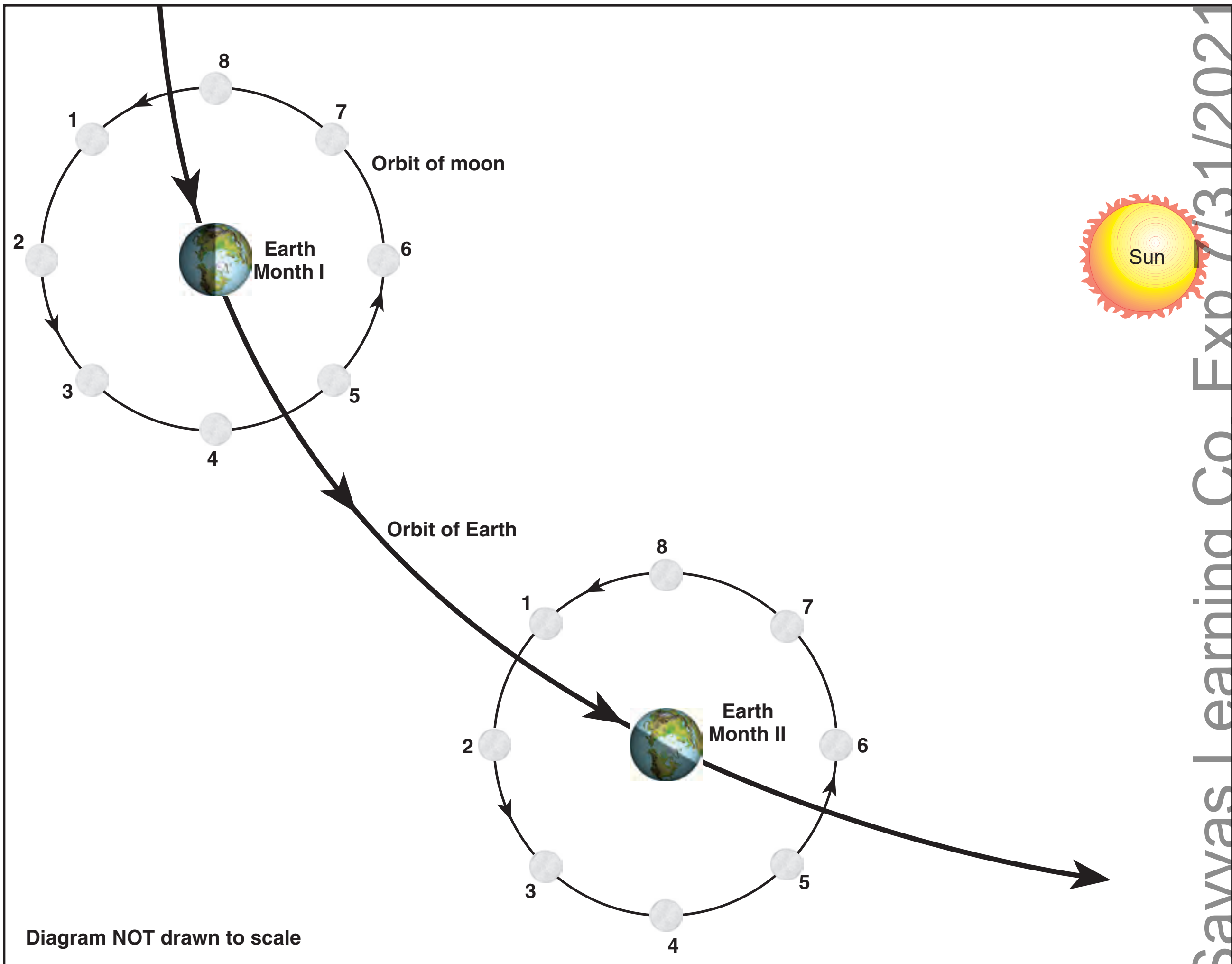
Procedure

1. Copy the diagram on the next page onto a sheet of paper. In Month 1, indicate the dark half of the moon on each of the eight lunar positions by shading the appropriate area with a pencil.
2. On the diagram of Month 1, label the position of the new moon. Do the same for the other lunar phases.
3. Repeat Steps 1 and 2 for the diagram of Month 2.
4. Place the lamp on a desk or table. The lamp represents the sun. Hold the softball, which represents the moon. Have a partner hold the basketball, which represents Earth. Turn on the lamp and turn off ll other lights in the room.
5. Stand so that the "moon" is in the position of the new-moon phase in Month 1, relative to "Earth" and the "sun." Revolve the moon around Earth while at the same time moving both Earth and the moon to Month 2. Stop at the same numbered position at which you began. Use the diagrams to guide your movements.

Analyze and Conclude

1. **Use Models** After one complete revolution beginning at the new-moon phase in Month 1, in what position is the moon located in Month 2?
2. **Interpret Data** Based on your answer to the previous question, does this position occur before or after the moon has completed one full cycle of phases?
3. **Identify** In Month 2, what position represents the new-moon phase? When the moon reaches this position, will it have completed a synodic or sidereal month?
4. **Explain** In your own words, explain the difference between a sidereal and synodic month.

GO FURTHER With your partner's help, use the lamp, softball, and basketball to model the positions of the sun, Earth, and moon during a lunar eclipse and a solar eclipse. On your diagram, label the position of the moon during each eclipse.



ES.1 The student will plan and conduct investigations in which **c.** scales, diagrams, charts, graphs, tables, imagery, models, and profiles are constructed and interpreted. **ES.2** The student will demonstrate an understanding of the nature of science and scientific reasoning and logic. Key concepts include **c.** observation and logic are essential for reaching a conclusion. **ES.3** The student will investigate and understand the characteristics of Earth and the solar system. Key concepts include **a.** position of Earth in the solar system; **b.** sun-Earth-moon relationships; (seasons, tides, and eclipses).

22 Study Guide

Big idea Earth and the Universe

22.1 Early Astronomy

In the geocentric model, the moon, sun, and the known planets—Mercury, Venus, Mars, Jupiter, and Saturn—orbit Earth.

In the heliocentric model, Earth and the other planets orbit the sun.

Copernicus placed the sun at the center of the solar system, with the planets orbiting around it.

Brahe's observations, especially of Mars, were far more precise than any made previously.

Using Brahe's precise observations, Kepler discovered three laws of planetary motion.

Galileo described the behavior of moving objects.

Newton was the first to formulate and test the law of universal gravitation.

astronomy (614)
geocentric (615)
orbit (615)
heliocentric (616)
retrograde motion (616)
ellipse (618)
astronomical unit (AU) (618)

22.2 The Earth-Moon-Sun System

The two main motions of Earth are rotation and revolution.

Lunar phases are caused by the changes in how much of the sunlit side of the moon faces Earth.

An eclipse can only occur during a new moon or full moon when the moon's orbit crosses the plane of the ecliptic.

rotation (622)
revolution (622)
precession (622)
perihelion (624)
aphelion (624)
perigee (626)
apogee (626)
phases of the moon (626)
solar eclipse (628)
lunar eclipse (628)

22.3 Earth's Moon

Most craters were produced by the impact of rapidly moving debris or meteoroids.

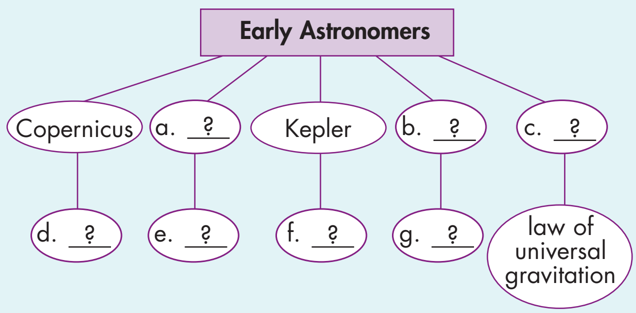
Maria, ancient beds of basaltic lava, originated when asteroids punctured the lunar surface, letting magma "bleed" out.

The most widely accepted model for the origin of the moon is that when the solar system was forming, a body the size of Mars impacted Earth.

crater (631)
ray (631)
mare (632)
rille (632)
lunar regolith (632)

Think Visually

Use the information from the chapter to complete the concept map below.



22 Assessment

Reviewing Content

Choose the letter that best answers the question or completes the statement.

1. Who fi st proposed that the sun was the center of the universe?
a. Aristotle
b. Aristarchus
c. Anaxogoras
d. Ptolemy

2. One astronomical unit averages about
a. 93 million kilometers.
b. 150 million kilometers.
c. 210 million kilometers.
d. 300 million kilometers.

3. During which month is Earth farthest from the sun?
a. January
b. April
c. July
d. October

4. In 13,000 years, Earth's axis will point toward
a. Polaris.
b. Vega.
c. the sun.
d. the moon.

5. At what point is the moon nearest to Earth during its orbit?
a. at apogee
b. at perihelion
c. during an eclipse
d. at perigee

6. What type of eclipse occurs when the moon casts its shadow on Earth?
a. lunar
b. sidereal
c. solar
d. synodic

7. During the period that the moon's phases are changing from new to full, the moon is always
a. waning.
b. approaching Earth.
c. waxing.
d. receding from Earth.

8. The large, dark regions on the moon are called
a. highlands.
b. craters.
c. mountains.
d. maria.

9. Rilles are associated with which of the following lunar features?
a. craters
b. maria
c. rays
d. highlands

10. The oldest lunar features are
a. highlands.
b. rayed craters.
c. rilles.
d. maria.

Understanding Concepts

11. How did Ptolemy explain what is now known as retrograde motion? How was his explanation flawed?

12. Describe how Eratosthenes measured the size of Earth.

13. What was Tycho Brahe's contribution to science?

14. Use Kepler's third law ($T^2 = d^3$) to determine the period of a hypothetical planet whose solar distance is 10 AU.

15. What is an astronomical unit?

16. Newton learned that the orbits of planets are the results of what two forces?

17. Explain the difference between the mean solar day and the sidereal day.

18. What is the approximate length of the cycle of the phases of the moon?

19. What phase of the moon occurs approximately one week after the new moon?

20. How many eclipses normally occur each year?

21. How long can a total eclipse of the moon last? A total eclipse of the sun?

22. Describe three features found on the moon's surface.

23. Briefly outline the history of the moon.

Think Critically

24. **Draw Conclusions** Does Earth move faster in its orbit near perihelion (January) or near aphelion (July)? Based on your answer, is the solar day longest in January or July?

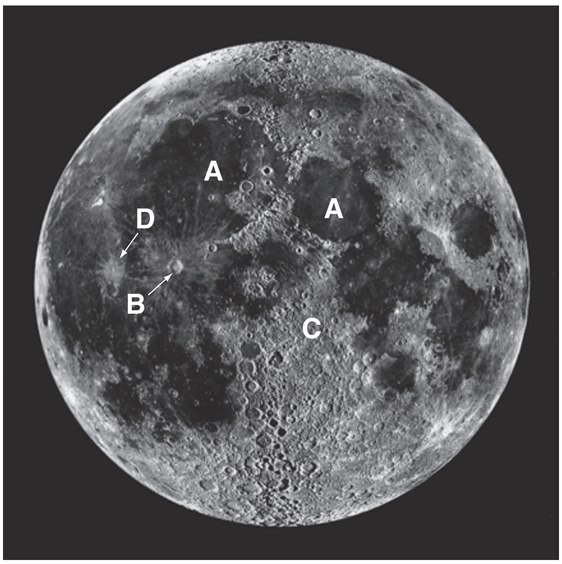
25. **Predict** The moon rotates very slowly on its axis. Predict how this affects the lunar surface temperature.

26. **Apply Concepts** Solar eclipses are slightly more common than lunar eclipses. Why then is it more likely that your region of the country will experience a lunar eclipse?

27. **Draw Conclusions** In what ways do the interactions between Earth and its moon influence the Earth-moon system? If Earth did not have a moon, would the atmosphere, hydrosphere, geosphere, and biosphere be any different? Explain.

Analyze Data

Use the photograph below to answer Questions 28–30.



28. **Interpret Visuals** What feature exists at point A? How did this feature likely form?

29. **Interpret Visuals** Which point represents a ray? Which point represents highlands?

30. **Infer** What is the oldest feature in the photograph? How do you know?

Concepts in Action

31. **Relate Cause and Effect** How does the fact that Venus appears full when it is smallest support Copernicus's view rather than the Ptolemaic system?

32. **Explain** How did Galileo's discovery of Jupiter's moons support the heliocentric model?

33. **Identify** What is the result of the moon having the same period of rotation and revolution?

34. **Apply Concepts** How is crater density used in the relative dating of features on the moon?

Performance-Based Assessment

Observe Record at least four observations of the moon over the next two weeks. Sketch the moon at each observation. Use shading to show the phase you see. Note the date and time of each observation. Afterward, write a paragraph describing how the size and shape of the lit portion of the moon changed over the length of your observations.

Virginia SOL Test Prep

Tips for Success

Eliminating Unreasonable Answers When you answer a multiple-choice question, you can often eliminate at least one answer because it is clearly incorrect. If you eliminate one or more choices, you increase your odds of choosing the correct answer. In the question below, you can immediately eliminate choice A because the moon does not have rivers on its surface. Clearly, choices B and D cannot both be true because they relate to the same phenomenon. You can eliminate both of these choices because volcanic activity is not currently occurring on the moon. The remaining choice, C, must be the correct answer.

The most important factors currently modifying the moon's surface are–

A rivers
B lava flows
C tiny particles from space
D volcanoes

(Answer: C)

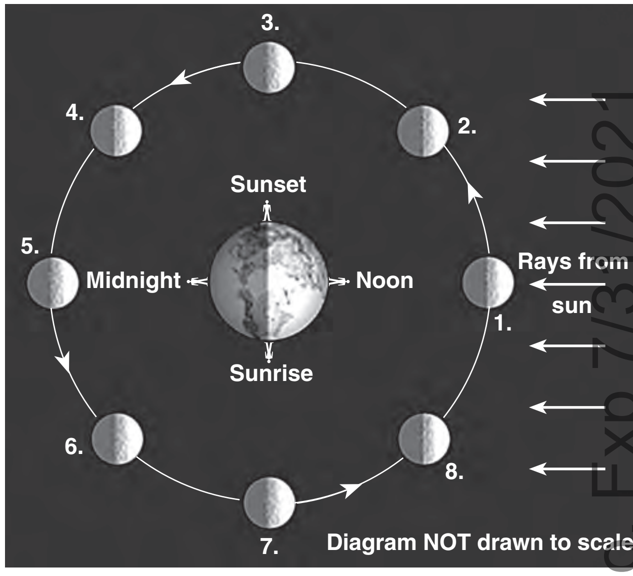
1 The Ptolemaic system assumed that–

A Earth revolved around the sun
B the sun was the center of the universe
C Earth was a wanderer
D Earth was the center of the universe ES.3.a

2 What is the shape of a planet's orbit?

F circular
G irregular
H elliptical
J constantly changing ES.3.a

Use the diagram below to answer Questions 3 and 4.



3 Which number illustrates the moon's position in its orbit during a full moon? A new moon?

A full: 1; new: 5
B full: 3; new: 7
C full: 5; new: 1
D full: 7; new: 3 ES.3.b

4 What number represents the position of the moon during a lunar eclipse? A solar eclipse?

F lunar: 1; solar: 5
G lunar: 3; solar: 7
H lunar: 5; solar: 1
J lunar: 7; solar: 3 ES.3.b

If You Have Trouble With . . .

Question	1	2	3	4
See Lesson	22.1	22.2	22.3	22.3