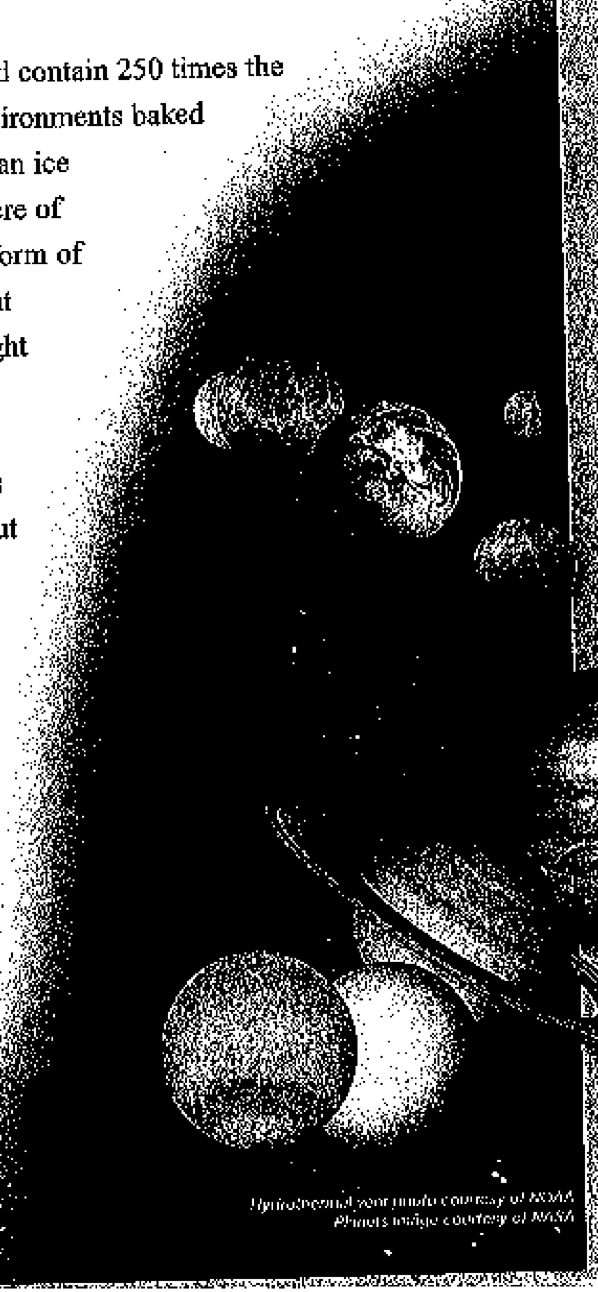
Chapter 26

The Solar System

The eight major planets of our solar system combined contain 250 times the surface area of Earth. This vast territory includes environments baked by heat and radiation (Mercury) and frozen colder than ice (Neptune). Venus, the most Earth-like planet in size, has an atmosphere of carbon dioxide and sulfuric acid that would be instantly fatal to any form of life on Earth. Our own crystal blue world is unique in having the right balance of temperature and environment to sustain life—or is it? Might there be unusual forms of life, unknown to us, on the other planets? Scientists have recently discovered living organisms that feed off hot sulfur emissions from volcanoes on the ocean floor. These organisms might be able to survive on Venus. In this chapter, you will read about the planets, the Sun, and other objects in our solar system.

Key Questions

- ✓ How did scientists develop the model for our solar system?
- ✓ Why do we observe various astronomical cycles on Earth?
- ✓ What makes a planet a planet?



Hydrothermal vent photo courtesy of NOAA
Planets image courtesy of NASA

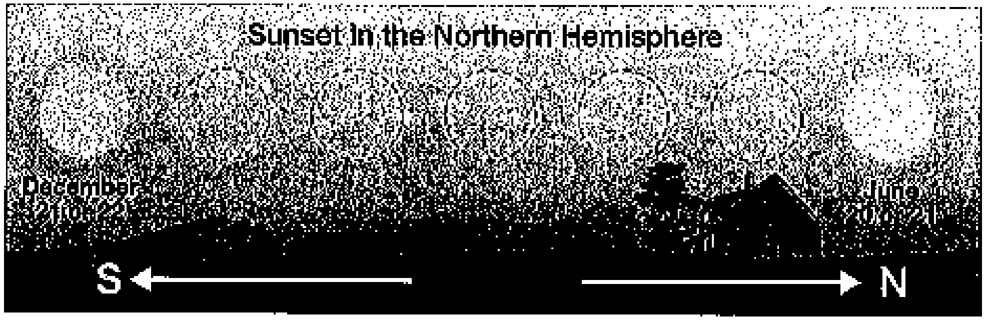
26.1 Motion and the Solar System

Many objects in the sky appear to change position, and sometimes their shape, over time. For example, the Moon appears to change its shape each night along with the time and position that it rises and sets on the horizon (Figure 26.1). Ancient astronomers kept track of those changes and developed calendars based on their observations. Eventually, a conceptual model of our solar system and its motion began to develop. In this section, you will learn how that model developed and changed over time.

Observing patterns in the sky

The position of the sunset and sunrise changes over time

Have you ever noticed that the position of the sunrise and sunset appears to shift along the horizon throughout the year? Ancient astronomers used a landmark, such as a building or tree, to mark the point where the Sun rose or set each day. By marking the extreme positions of the Sun at sunrise or sunset, they could determine the passage of one year.



The rising and setting positions of the stars do not change over time

In contrast to the Sun and the Moon, the rising and setting positions of the stars do not appear to change along the horizon over short periods of time. However, the *time* that stars rise or set each night gradually changes during a year. A result of this gradual change in rising and setting times is that different constellations are visible in the night sky at different times of the year. A **constellation** is a group of stars that, when seen from Earth, form a pattern. Perhaps the most familiar of the 88 recognized constellations is the Big Dipper, which is part of a larger constellation called Ursa Major—the Great Bear (Figure 26.2).

VOCABULARY

constellation - a group of stars that, when seen from Earth, form a pattern.

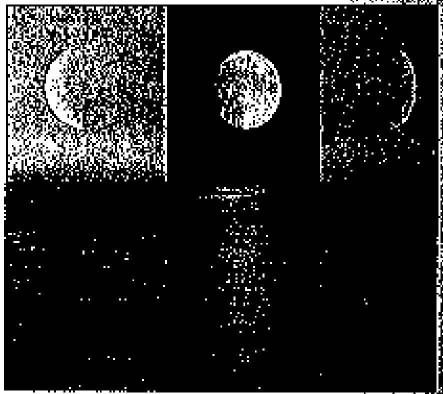


Figure 26.1: *The Moon appears to change its shape and the time and position at which it rises and sets.*

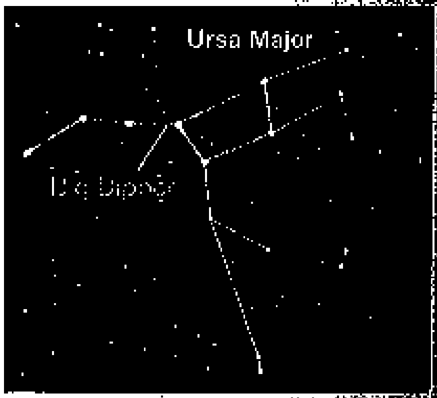


Figure 26.2: *The Big Dipper is part of a larger constellation, Ursa Major.*

Earth-centered model

Wandering stars Through their observations of the night sky, ancient astronomers noticed that five bright objects seemed to wander among the constellations. They called these five objects *planets*, from the Greek word meaning "wandering star," and named them Mercury, Venus, Mars, Jupiter, and Saturn. It took hundreds of years, and many scientists, to figure out an explanation for the motion of the planets. Even though they did not have telescopes, ancient astronomers found ways to predict the motion of the planets and began to develop early models of our solar system.

The apparent paths of the planets Early astronomers had difficulty explaining the apparent paths of the planets. If you observe the position of a planet among the constellations each night over many months, you will notice that it appears to travel in a certain path. On a daily basis, a planet appears to travel from West to East against the background of constellations. Occasionally a planet appears to reverse direction, and travels from east to west. Then, the planet goes back to its west to east path. Figure 26.3 shows the apparent path of a planet over the course of many months.

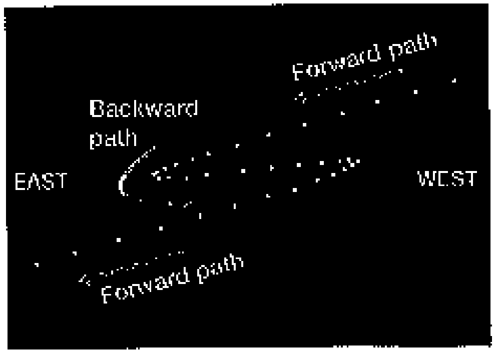
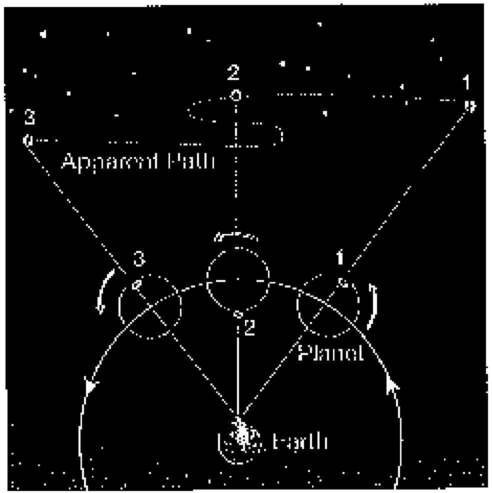


Figure 26.3: *The apparent path of a planet over many months.*



Ptolemy's model of the solar system In 140 AD, the Greek astronomer Ptolemy developed a model that explained the apparent path of the planets (Figure 26.4). He hypothesized that each planet moved on a circle, which, in turn, moved on a larger circle around Earth. Ptolemy reasoned that the smaller circles caused the apparent "backward" path of the planets (see the diagram at the left). In his model, the stars moved on a "celestial sphere" beyond the planets. Ptolemy's model assumed that Earth was at the center of the solar system. However, his model allowed others to only approximately predict the motions of the planets.

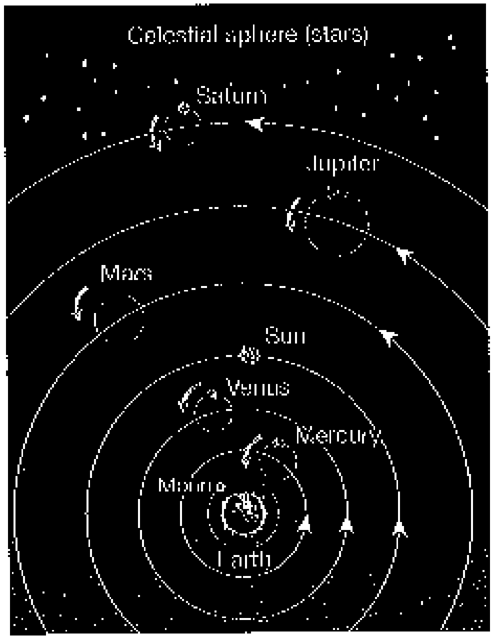


Figure 26.4: *Ptolemy's model explained the apparent path of the planets.*

The Sun-centered model

The Sun is at the center of the solar system

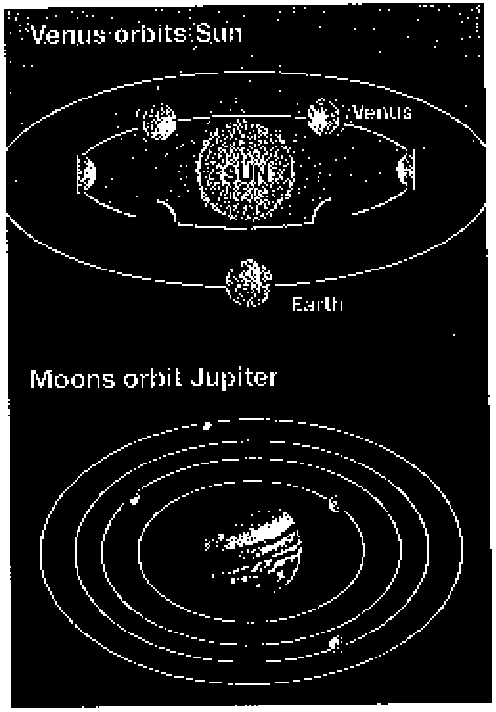
In 1543, the Earth-centered model of the solar system was challenged by a Polish astronomer named Nicolas Copernicus. While the Ptolemaic model could predict the positions of the planets, Copernicus found that its predictions became less and less accurate over the centuries. In Copernicus' model, the *Sun* was at the center of the solar system and the planets, including Earth, orbited in circles around the Sun. Copernicus reasoned that the apparent backward paths of the planets were the result of Earth's motion, combined with the motion of the other planets (Figure 26.5).

Planets reflect light from the Sun

The invention of the telescope supported the Sun-centered model of the solar system. Before telescopes, it appeared that the planets gave off their own light. Today, we know that we see the planets *because they reflect light from the Sun*. For example, Venus appears as a crescent like the Moon, becoming dark at times. This is because Venus does not give off its own light. When Earth is on the same side of the Sun as Venus, we see Venus's shadowed side.

Galileo and the telescope

The phases of Venus, discovered by Galileo in the 1600s, were part of the evidence that eventually overturned Ptolemy's model. Using a telescope he built himself, Galileo made two discoveries that strongly supported Copernicus' ideas. First, he argued that the phases of Venus could not be explained if Earth were at the center of the planets (right, top). Second, he saw that there were four moons orbiting Jupiter (right, bottom). This showed that not everything in the sky revolved around one central object such as Earth.



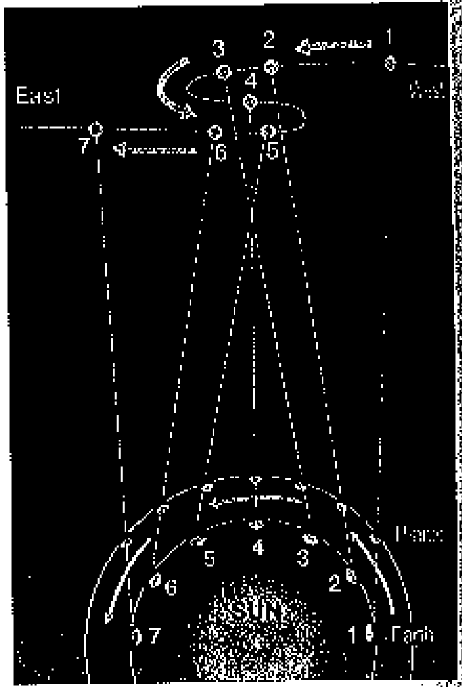


Figure 26.5: *The Copernicus model of the solar system placed the Sun at the center. His model also showed how the apparent paths of the planets were the result of Earth's motion, combined with the motion of the other planets.*

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All objects attract

In 1687, Isaac Newton's addition to our understanding of gravity helped astronomers explain why objects in the solar system orbit each other. **Gravitational force** is the force of attraction between all objects. The gravitational force that you are most familiar with is the one between you and Earth. We call this force your *weight*. But gravitational force is also acting between the Sun, Earth, and the other planets. All objects that have mass attract each other through gravitational forces.

Gravitational force is relatively weak

You don't notice the attractive force between ordinary objects because gravity is a relatively weak force. For example, a gravitational force exists between you and this book, but you cannot feel it because both masses are small (Figure 26.6). It takes a huge mass, such as Earth's, to create gravitational forces that are strong enough to feel and measure.

The law of universal gravitation

The **law of universal gravitation** explains how the strength of the force depends on the mass of the objects and the distance between them. As you can see from the equation below, gravitational force increases as the masses of the objects increase. The distance between objects also affects gravitational force but in an inverse way. The closer objects are to each other, the stronger the gravitational force between them. The farther apart, the weaker the gravitational force.

GRAVITY

$$F = G\frac{m_1 - m_2}{R^2}$$

Force (N)
Mass 1 (kg)
Mass 2 (kg)
Gravitational constant (6.67×10^{-11} N•m²/kg²)
Distance between mass 1 and mass 2 (m)

Gravity on Earth and the Moon

The strength of gravity on the surface of Earth is 9.8 N/kg. Like pounds, newtons are a measure of force. There are 4.448 newtons per one pound. Earth and a 1-kilogram object attract each other with 9.8 newtons of force. In comparison, the strength of gravity on the Moon is only 1.6 N/kg. Your weight on the Moon would be one-sixth what it is on Earth. The Moon's mass is much less than Earth's, so it creates less gravitational force.

VOCABULARY

gravitational force - the force of attraction between all objects.

law of universal gravitation - states that the strength of the gravitational force depends on the mass of the objects and the distance between them.

Comparing Gravitational Forces

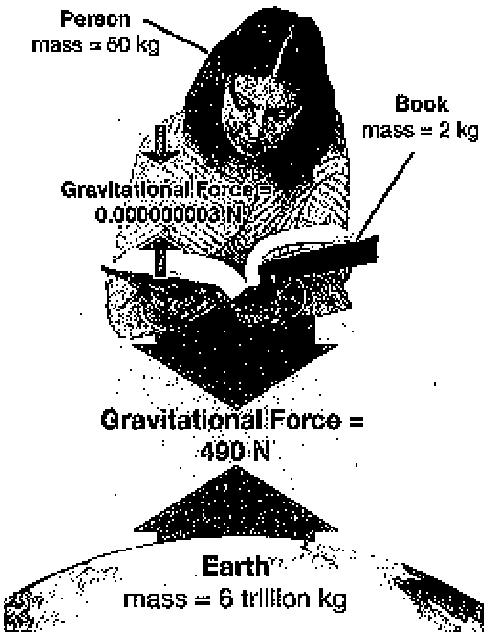


Figure 26.6: *The gravitational force between you and Earth is stronger than the force between you and your book because of Earth's large mass.*

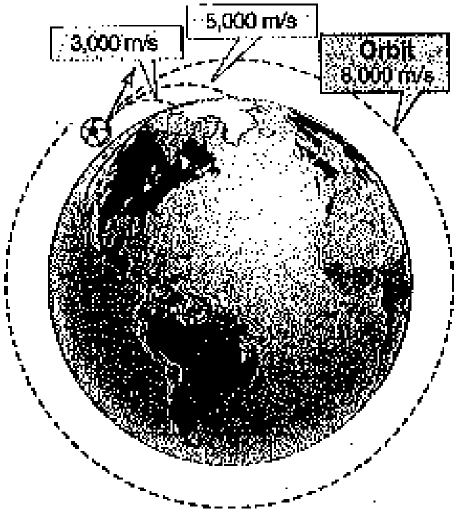
Orbits

Kepler and orbits

An **orbit** is a regular, repeating path that an object in space follows around another object. In 1600, German mathematician Johannes Kepler determined that the orbits of the planets were not perfect circles but *slightly* elliptical in shape. This explained the small irregularities in the path of the planets across the sky. Kepler also explained that a planet orbits more slowly when it is farther from the Sun and faster when it is closer to it.

Why the Moon does not fall to Earth

Earth and the other planets in our solar system orbit the Sun. The Moon orbits Earth. Why doesn't the force of gravity pull Earth into the Sun (or the Moon into Earth)? To answer this question, imagine kicking a ball off the ground at an angle. If you kick it at a slow speed, it curves and falls back to the ground. The faster you kick the ball, the farther it goes before hitting the ground. If you could kick it fast enough, the curve of the ball's path would match the curvature of Earth. The ball would go into orbit instead of falling back to Earth. An object launched at 8,000 m/s will orbit Earth.



Inertia and gravitational force

Isaac Newton explained that an orbit results from the balance between *inertia* (the forward motion of an object in space), and gravitational force. According to Newton's first law, inertia causes objects to tend to keep moving in a straight line. Force is needed to change an object's speed or direction. Because of inertia, the planets are moving in a direction at a right angle to the pulling force of gravity. This means that without the pull of gravitational force, a planet would travel off into space in a straight line. The balance between the planet's inertia and the gravitational force between the planet and the Sun results in the planet's orbit (Figure 26.7).

VOCABULARY

orbit - a regular, repeating path that an object in space follows around another object.

Two of Kepler's laws

1. The orbits of the planets are not perfect circles but are slightly elliptical.
2. A planet moves more slowly when it is farther from the Sun and faster when it is closer to it.

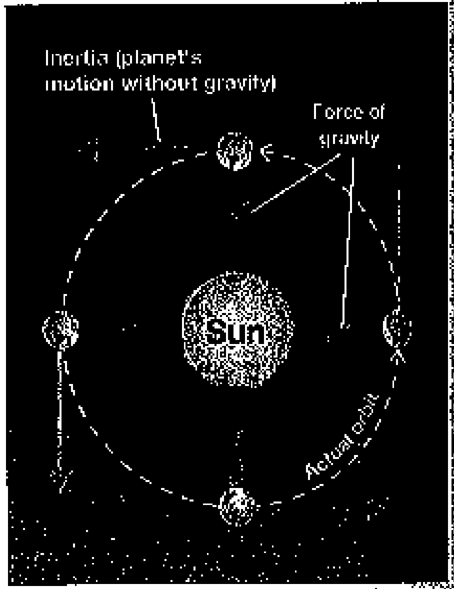


Figure 26.7: *An orbit results from the balance between inertia and gravitational force.*

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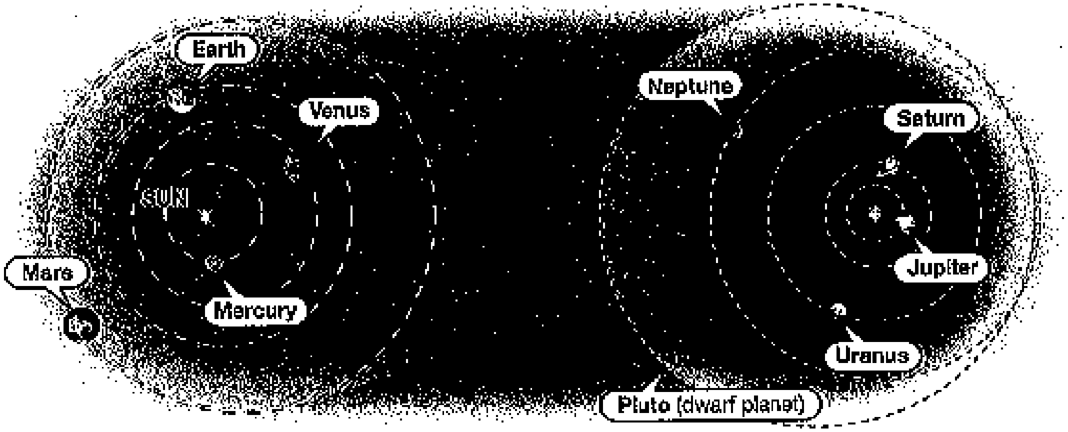
he discovery of two additional planets

At the time of Copernicus and Galileo, astronomers thought that there were only six planets: Mercury, Venus, Earth, Mars, Jupiter, and Saturn. The distant planets Uranus and Neptune are far from the Sun and don't reflect much light back to Earth. These planets were not discovered until telescopes became powerful enough to see very faint objects.

Solar system definition

Today, we define the **solar system** as the Sun and all objects that are bound by gravitational force to the Sun. The gravitational force of the Sun keeps the solar system together just as gravity keeps the Moon in orbit around Earth. The solar system includes eight major planets and their moons, and a large number of smaller objects (dwarf planets, asteroids, comets, and meteors).

The Inner Solar System **The Outer Solar System**



Inner and outer planets

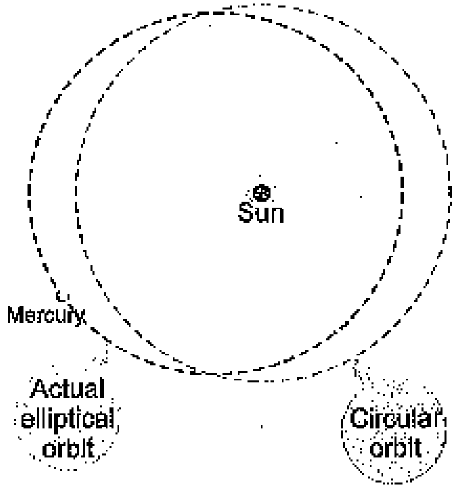
The solar system is roughly divided into the *inner planets* (Mercury, Venus, Earth, and Mars) and the *outer planets* (Jupiter, Saturn, Uranus, and Neptune). The dwarf planet Pluto is the oldest known member of a smaller group of frozen worlds orbiting beyond Neptune. The diagram above shows the orbits of the planets (the planets are not shown to scale). Notice that Neptune is farther from the Sun than the dwarf planet Pluto over part of Neptune's orbit.

VOCABULARY

solar system - the Sun and all objects that are bound by gravitational force to the Sun.

SCIENCE FACT

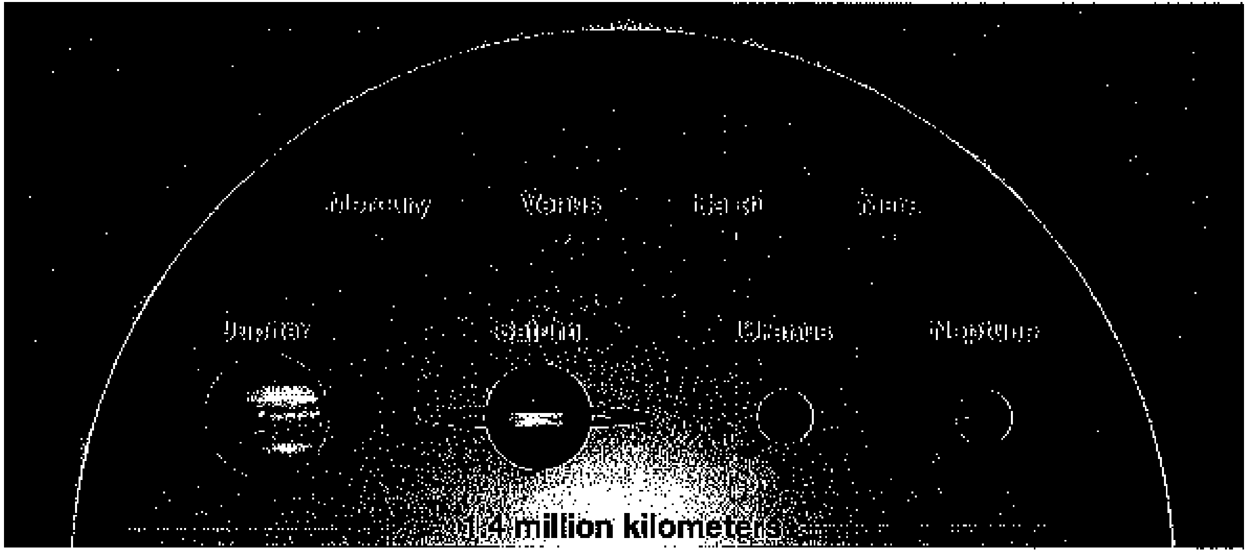
The orbits of the planets are not true circles, but ellipses. An *ellipse* is shaped like an oval. While the actual paths are nearly true circles, the Sun is not at the center, but is off slightly to one side. For example, Mercury's orbit is shifted 21 percent to one side of the Sun.



Comparing sizes and distances in the solar system

Relative sizes The Sun, which will be discussed in Chapter 27, is by far the largest object in the solar system. The next largest objects are the planets Jupiter, Saturn, Uranus, and Neptune. As you can see from the scale diagram below, the planets Mercury, Venus, Earth, and Mars appear as small specks when compared with the size of the Sun.

The sizes of planets relative to the Sun



Planet photos courtesy of NASA/JPL

Distance Astronomers often use the average distance of Earth from the Sun as a measurement of distance in the solar system. One **astronomical unit** (AU) is equal to 150 million kilometers, or the average distance from Earth to the Sun. Mercury averages 58 million kilometers from the Sun. To convert this distance to astronomical units, divide this distance by 150 million kilometers. Mercury is therefore, 0.39 AU from the Sun (Figure 26.8). Figure 26.9 lists the planets and their average distance from the Sun in astronomical units.

VOCABULARY

astronomical unit - equal to 150 million km, or the average distance from Earth to the Sun.

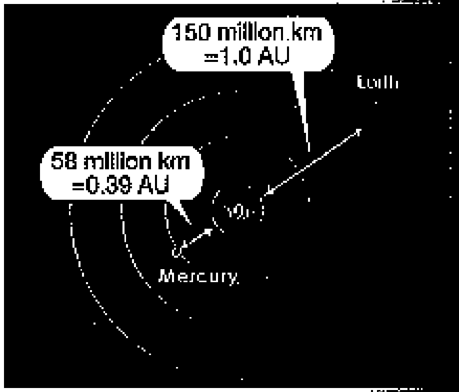


Figure 26.8: *One AU is equal to 150 million kilometers. If Earth is 1.0 AU from the Sun, then Mercury, with a distance of 58 million kilometers, is 0.39 AU from the Sun.*

Planet	Average Distance from the Sun (AU)
Mercury	0.39
Venus	0.72
Earth	1.0
Mars	1.5
Jupiter	5.2
Saturn	9.5
Uranus	19.2
Neptune	30.0

Figure 26.9: *Average distances of the planets from the Sun in AU.*

26.1 Section Review

1. How did ancient astronomers distinguish the planets from other stars in the night sky?
2. How did Ptolemy explain the apparent motion of the planets among the constellations?
3. How is Copernicus' model different than Ptolemy's model of the solar system?
4. What important contribution did Newton make to our solar system model?
5. What important contribution did Kepler make to our solar system model?
6. What makes planets visible in the night sky?
7. Name the planets in order of how far they are from the Sun, starting with the planet nearest to the Sun.
8. The force that holds the solar system together is called ________.
9. What is an astronomical unit?
10. Gravitational force gets weaker as _____ increases and gets stronger as the _____ of the objects increases.
11. Gravity exists between all objects with mass. Why, then, don't you notice the force of gravity between you and all of the objects around you?
12. What is inertia?
13. The orbit of a planet is a balance between the planet's _______ and the gravitational force between the planet and the ________.
14. Is a satellite orbiting Earth free from Earth's gravity? Why or why not?

SOLVE IT!

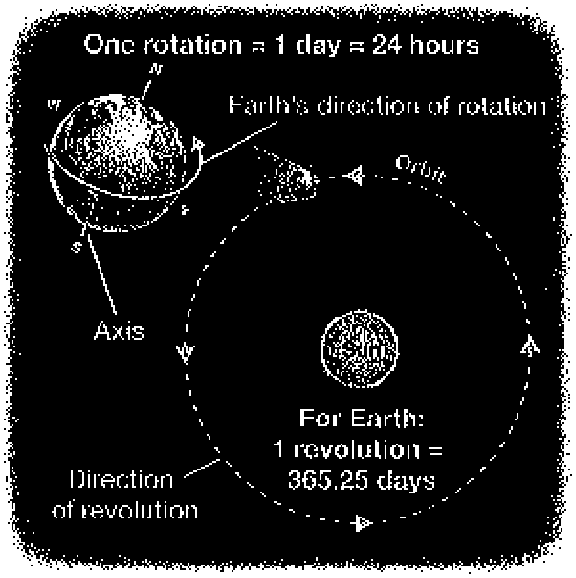
Astronomical Distances

Solve the following distance problems using the information in Figure 26.9.

1. The average distance of Jupiter from the Sun is 5.2 AU. What is Jupiter's average distance from the Sun in kilometers? (Hint: 1 AU = 150,000,000 km)
2. What is the average distance of Neptune from the Sun in kilometers?
3. The average distance of dwarf planet Pluto from the Sun is 5,913,520,000 km. How far is Pluto from the Sun in AU?
4. The minimum distance of Mars from Earth is 56,000,000 km. Express this distance in AU.

26.2 Motion and Astronomical Cycles

Everything in the solar system is moving. Earth spins on its axis at about 1,600 kilometers per hour at the equator. To make a complete trip around the Sun in one year, Earth must orbit at an average speed of about 108,000 kilometers per hour! In this section, you will learn how motion affects the astronomical cycles we observe. Please note that illustrations are not drawn to scale.



Rotation and revolution

The shape of orbits Recall that the orbits of the planets around the Sun are slightly elliptical. What's more significant is that the Sun is at a point called the *focus* that is offset from the center of the orbit. This causes the distance from the Sun to vary as a planet orbits. Figure 26.10 depicts Earth's orbit and distances from the Sun.

Rotation An **axis** is the imaginary line that passes through the center of a planet from pole to pole. The spinning of a planet on its axis is called its **rotation**. Earth, like most of the other planets, spins from west to east. One complete rotation is called a *day*. One Earth day is exactly 23 hours, 56 minutes, and 4.09 seconds long. This means it takes Earth almost 24 hours to complete one rotation on its axis. A day on Jupiter, the fastest rotator of the planets, is only about 10 hours long.

Revolution and years All of the planets orbit, or revolve, around the Sun in the same direction (counter-clockwise). A **year** is the time it takes a planet to complete one revolution around the Sun. A year on Earth takes approximately 365.25 days. A year on Mars takes 686.98 Earth days. The farther a planet is from the Sun, the longer it takes it to complete one revolution. One year on Neptune, the outermost planet, is 164.81 Earth years long!

VOCABULARY

axis - the imaginary line that passes through the center of a planet from pole to pole.

rotation - the spinning of a planet on its axis.

year - the amount of time it takes for a planet to complete one revolution around the Sun.

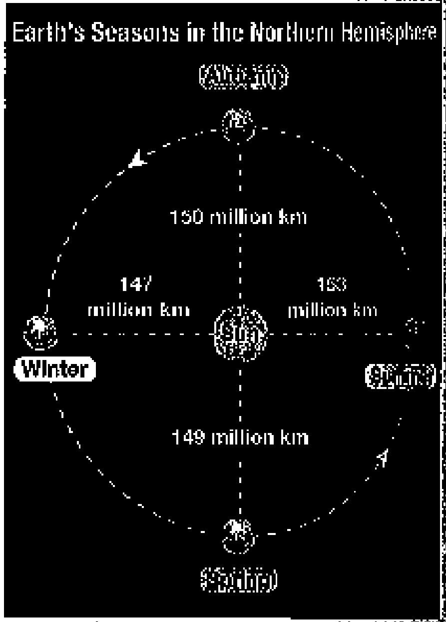


Figure 26.10: *Orbits are almost circular (ellipses). The Sun is at the focus that is offset from the center. The diagram above shows Earth's distance from the Sun at the start of each season in the northern hemisphere.*

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tion and keeping track of time

Calendars A *calendar* is a means of keeping track of all the days in a year. Ancient civilizations developed calendars based on their observations of the Sun, Moon, and stars. Many such civilizations independently invented almost identical calendars. (See the sidebar at the right).

Years and days Recall that one year is the amount of time it takes Earth to complete one revolution around the Sun. This is approximately 365.25 days. Each day is one rotation of Earth on its axis. Since Earth spins from west to east, the Sun appears to travel across the sky from east to west. Ancient observers thought that the Sun really did move across the sky. Can you see why?

Leap years The ancient Egyptian calendar described in the sidebar added up to 365 days and eventually evolved into the calendar we use today. However, because we know that one year is approximately 365.25 days long, our calendar adjusts for this. It has eleven months with 30 or 31 days each, and one month—February—with 28 days. In a *leap year*, February has 29 days. The extra day every four years makes up for the extra 0.25 day that occurs each year.

The time of day A *clock* is a device that is used to mark the division of the day into equal parts (Figure 26.11). The *sundial* is the oldest known "clock." A sundial uses the shadow of a pointer that moves from one side of the base to the other as the Sun appears to travel from east to west during the day. Markers are placed around the base to determine the hour. Water clocks were stone containers with sloping sides that allowed water to drip at a constant rate through a small hole in the bottom. Markings on the inside surface of the container measured the passage of "hours."

Modern clocks Today, we divide each rotation of Earth into 24 equal parts called *hours*. Each hour is divided up into 60 parts called *minutes* and each minute into 60 parts called *seconds*. Like the water clock, modern clocks use a constant, repetitive action or process to keep track of equal increments of time. Where the water clock used the constant dripping of water, modern clocks use a pendulum, vibrating crystal, balance wheel, electromagnetic waves, or even atoms to mark time.

Calendars Throughout History

7,000 BCE. Babylonians kept a calendar with 29- and 30-day months. They needed to add an extra month every eight years.

4,000 BCE. The Egyptians adopted a calendar with 365 days in a year, divided into 12 months, each with 30 days, and an extra five days at the end.

2,000 BCE. Mayans of Central America calculated that there were 365.25 days in a year.

700 BCE. The Roman calendar consisted of 10 months in a year of 304 days. It ignored the remaining 61 days, which fell in the middle of winter.

46 BCE. Romans adopted the Julian calendar, named after Julius Caesar. It is close to the Gregorian calendar, adopted in the 1500s and still used today.

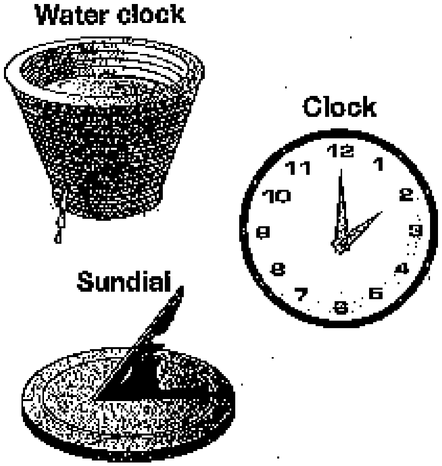


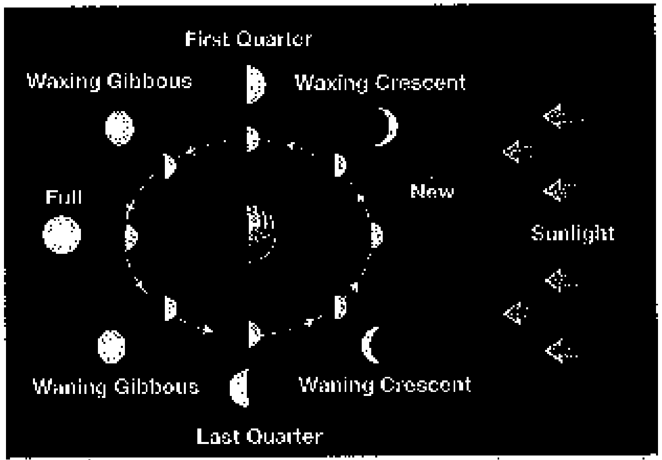
Figure 26.11: *Three types of clocks.*

The lunar cycle

What is the lunar cycle? The revolution of the Moon around Earth makes the Moon appear as if it is gradually changing shape each night. The cycle of change in the appearance of the Moon is called the **lunar cycle**. The lunar cycle occurs because of the relative positions of Earth, the Moon, and the Sun.

What causes the lunar cycle? The orbit of the Moon is tilted about 5 degrees from Earth's orbit (Figure 26.12). This means the Moon is not in Earth's shadow except during a rare *lunar eclipse*. The Sun-facing side of the Moon is lit by sunlight almost all the time. The lunar cycle is caused by the *angle* the Moon makes with Earth and the Sun as the Moon orbits Earth, not by Earth's shadow falling on the Moon.

Moon phases What you see when you look at the Moon depends on its location in relationship to the Sun and Earth. As the Moon revolves, we see a different fraction of sunlight being reflected from the Moon to Earth. Remember, the Moon doesn't give off light; it reflects the light of the Sun. Although the lunar cycle is a continuous process, there are eight recognized *phases*. *Waxing* means the lit portion of the Moon is getting larger and *waning* means it is getting smaller.



Inner circle - viewed from above Earth   Outer circle - viewed while on Earth

The length of the lunar cycle The lunar cycle—from new Moon to new Moon—takes 29.5 days to complete (above). This roughly corresponds to one month. However, if we based our calendar on the lunar cycle, we would soon get ahead of an Earth year. Why? Because a year of lunar cycles adds up to only 354 days, not 365.25, leaving a balance of 11.25 days each year!

VOCABULARY

lunar cycle - the cycle of change in the appearance of the Moon due to the positions of Earth, the Moon, and the Sun.

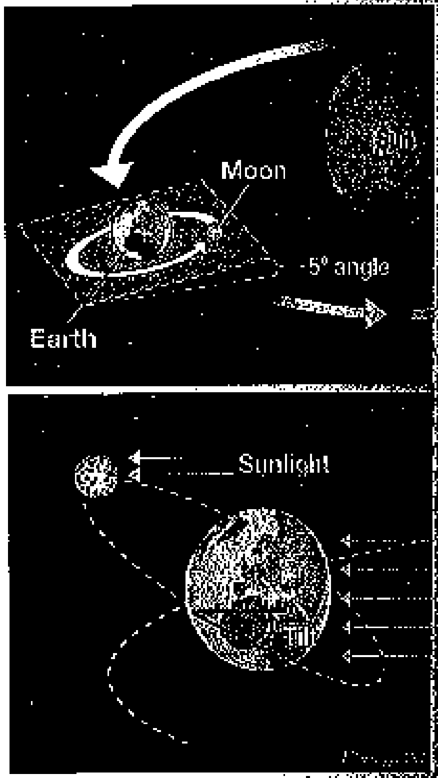


Figure 26.12: *The orbit of the Moon is tilted at a 5 degree angle compared with Earth's orbit around the Sun (upper diagram). This means that the Moon can be either above or below the line from the center of the Sun to the center of Earth (lower diagram).*

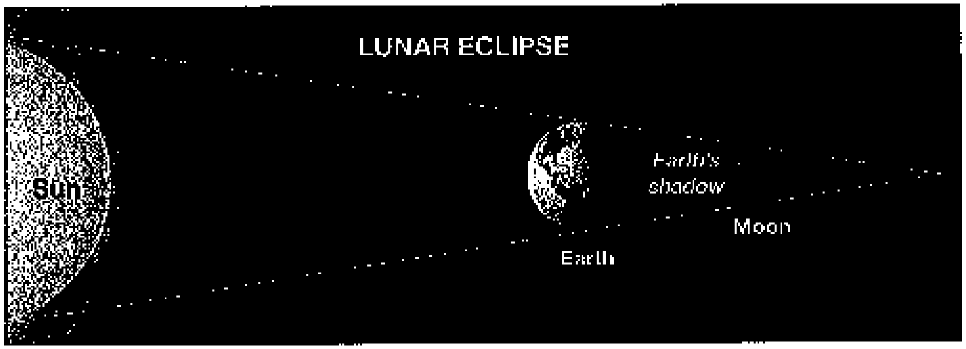
ar eclipses

Moon's orbit is tilted

A **lunar eclipse** occurs when the Moon passes through Earth's shadow. If you look at the lunar cycle diagram on the previous page, you may wonder why Earth's shadow doesn't cover the Moon when it is between the Moon and the Sun. Instead, you get a full Moon (Figure 26.13). The reason a lunar eclipse doesn't occur very often is because of the 5 degree tilt of the Moon's orbit.

unar eclipses

Because of its tilted orbit, in most months, Earth's shadow does not block the sunlight from hitting the Moon. However, sometimes the Moon's orbit is perfectly aligned with Earth's orbit during a full Moon. Because of this alignment, Earth's shadow temporarily blocks the sunlight from hitting the Moon, causing a lunar eclipse. As the Moon continues to move in its orbit, it gradually moves into a position where the sunlight hits it again. During a lunar eclipse, the Moon is still visible and appears reddish because some of the sunlight is being refracted into the shadow by Earth's atmosphere.



al and partial lunar eclipses

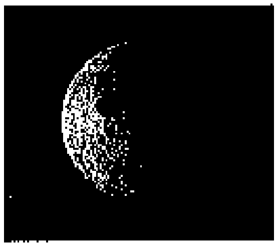


Photo courtesy of NASA

A lunar eclipse can be total or partial and all observers on the dark side of Earth can see it at the same time. A partial eclipse (shown left) occurs when only part of the Moon falls in Earth's shadow. Figure 26.14 shows an alignment for a partial eclipse.

VOCABULARY

lunar eclipse - an event that occurs when the Moon passes through Earth's shadow.

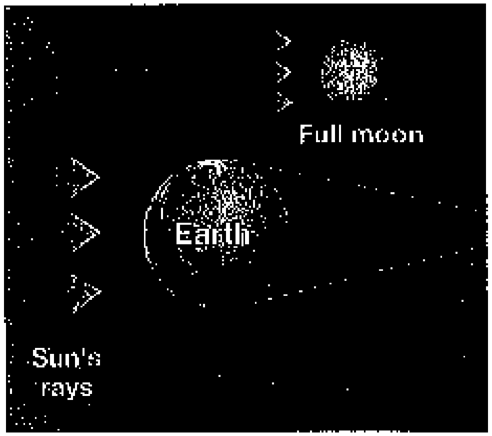


Figure 26.13: *This alignment results in a Full Moon.*

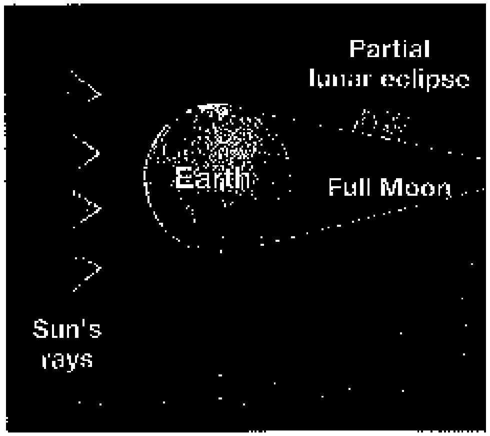
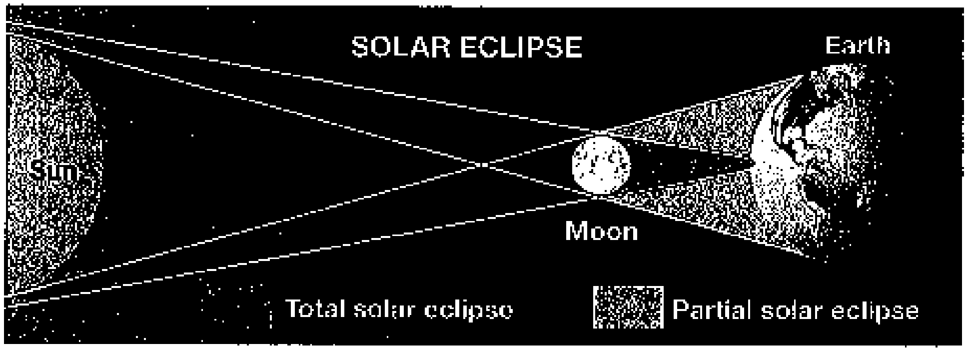


Figure 26.14: *This alignment results in a partial lunar eclipse.*

Solar eclipses

Solar eclipses A **solar eclipse** occurs when the Moon's shadow falls on Earth. During a new Moon, the Moon lies between Earth and the Sun. At this time, only the unlit side of the Moon faces Earth. Most of the time, however, the Moon appears to be just above or below the Sun in the sky because of the 5 degree tilt of its orbit so at least a portion of its lit side is visible. During a solar eclipse, the new Moon is directly between Earth and the Sun and the Moon's shadow hits part of Earth as shown below.



Total solar eclipse The darkest part of the Moon's shadow is cone-shaped and falls on only a small part of Earth's surface. Viewers in this region experience a total eclipse of the Sun because the light is completely blocked by the Moon. During a total eclipse, the Sun gradually disappears behind the Moon and then gradually reappears (Figure 26.15). This is because the Moon revolves around Earth, so it gradually moves into the path of the sunlight, and then gradually moves out again. The Sun is completely blocked by the Moon's shadow for about two or three minutes.

Partial solar eclipse In the diagram above, you can see that the Moon casts a larger, lighter shadow on Earth's surface. Viewers in this region of the Moon's shadow experience a partial eclipse. During this time, only part of the Sun is blocked. Remember, you should NEVER look directly at the Sun—even during a total or partial eclipse!

VOCABULARY

solar eclipse - an event that occurs when the Moon's shadow falls on Earth.

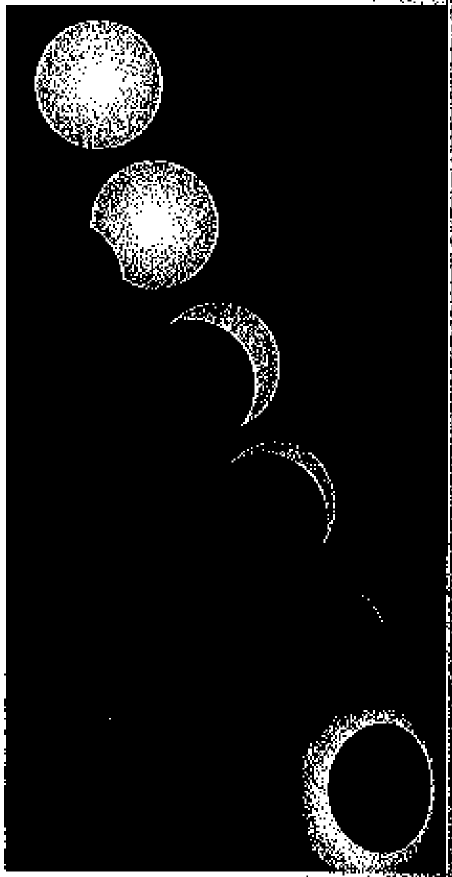


Figure 26.15: *A total eclipse is caused by the Moon blocking out the Sun.*

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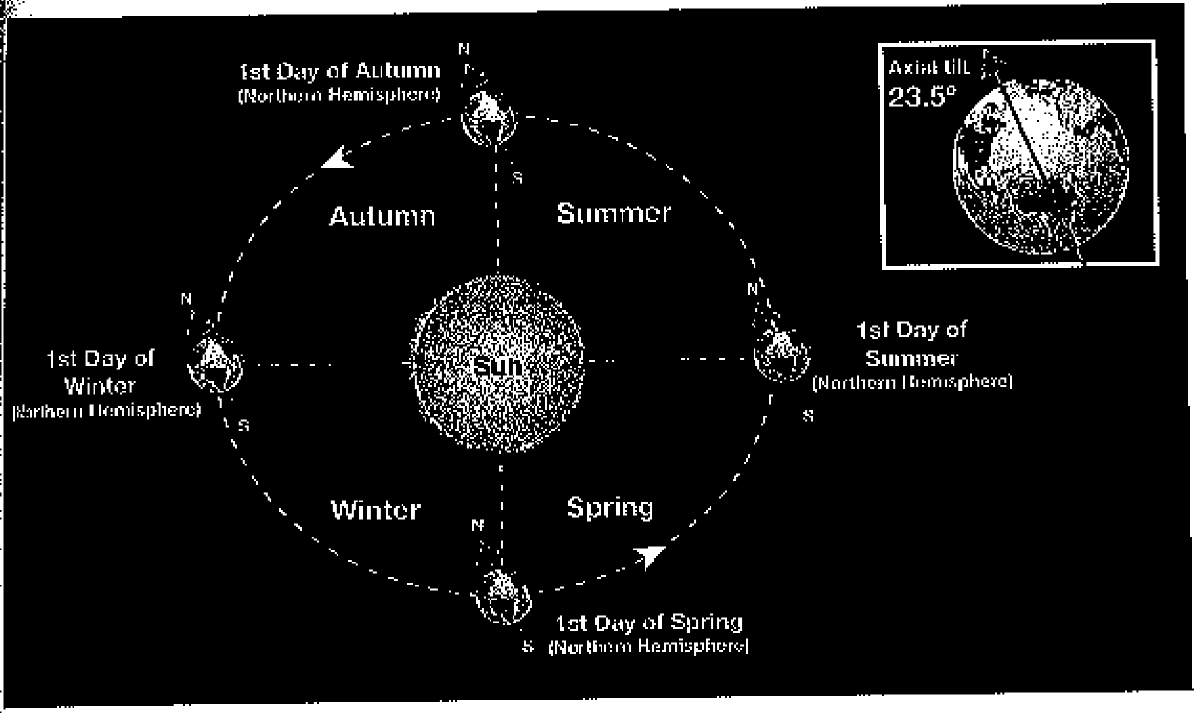
Seasons As Earth revolves around the Sun, we experience different seasons. The seasons are caused by the 23.5 degree tilt of Earth's axis with respect to the plane of its orbit around the Sun. As Earth rotates around the Sun, its axial tilt remains fixed.

The axial tilt causes the seasons During summer in the northern hemisphere, the north end of the axial tilt is facing *toward* the Sun. This results in more direct sunlight and higher temperatures. Six months later, the north end of the axial tilt is facing *away* from the Sun. The sunlight is more spread out and is less intense. This brings winter to the northern hemisphere (Figure 26.16). The opposite happens in the southern hemisphere. The fact that Earth's axial tilt is fixed also explains why the position of the Sun in the sky appears to change over the course of a year (Figure 26.17).



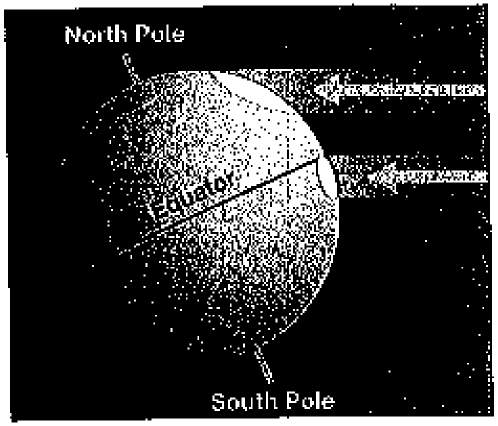


Figure 26.16: *During winter in the northern hemisphere, Earth's axial tilt is facing away from the Sun. This means the sunlight in the northern hemisphere is more spread out and less intense. Therefore, temperatures are lower in winter.*

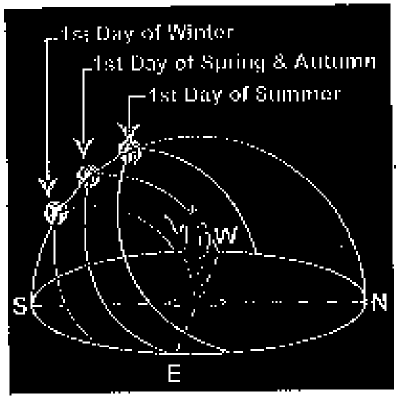


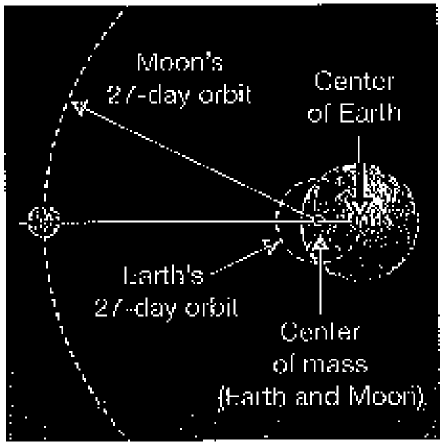
Figure 26.17: *The diagram shows the apparent path of the Sun across the sky in the northern hemisphere during the year.*

Tides

Tides are caused by the Moon's gravity

As Earth rotates beneath the Moon, its mass feels a small, "Moonward" force of 0.00003 N from the Moon's gravity. Earth is made of rock that resists this small force, but because water flows, the Moon causes water to slide toward the place directly under the Moon on Earth's surface (Figure 26.18). In most places, ocean levels rise and fall twice each day as the Moon revolves around Earth and Earth rotates. The daily cycle of rising and falling ocean levels is called a **tide**. The Moon passes overhead once every 24 hours. So, you would expect the tide to rise only once every 24 hours. But the oceans on the side of Earth directly *opposite* the Moon also rise. What causes this "second" tide?

The center of mass



The answer is that the Moon does not really orbit Earth as if Earth were fixed in place. Instead, Earth and the Moon orbit around a common *center of mass*. Imagine balancing Earth and the Moon on a giant see-saw. There is a point at which the see-saw balances even though Earth is much heavier than the Moon. That point is the center of mass of the Earth–Moon system.

Explaining the "second" tide

When you turn a corner sharply in a car, your body slides to the outside of the curve, away from the center. This happens because your body wants to move in a straight line in the direction it was going *before* the turn. This is the explanation for the tide on the side of Earth that does not face the Moon. As Earth revolves around the center of mass, the ocean on the opposite side from the Moon is "flung outward" a little by its own inertia (Figure 26.19).

VOCABULARY

tide - a cycle of rising and falling ocean levels.

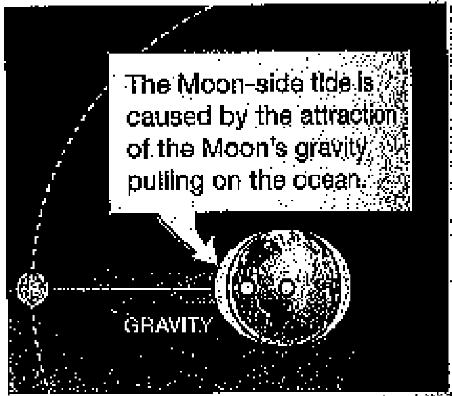


Figure 26.18: *The cause of the Moon-side tide.*

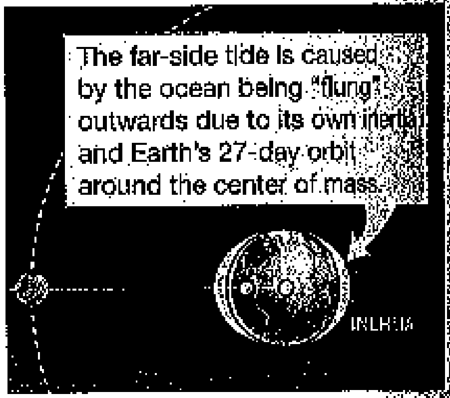
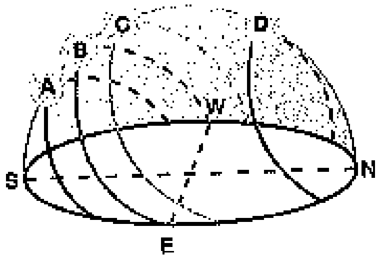


Figure 26.19: *The cause of the far-side tide. Note: The tides shown in the diagram are much larger than actual tides.*

26.2 Section Review

1. Study Figure 26.10. During which season in the northern hemisphere is Earth closest to the Sun?
2. What determines the length of a day on a planet? What determines the length of a year on a planet?
3. Approximately how long does it take Earth to make one revolution around the Sun?
4. Approximately how long, in hours, does it take Earth to make one rotation on its axis?
5. What is a leap year? Why does a leap year occur every four years?
6. The lunar cycle is closely related to which part of our calendar—a year, a month, or a day?
7. True or false: The phases of the Moon are caused by Earth's shadow falling on the Moon?
8. Explain how you could use the shadow of a streetlight pole to track the time of day on a sunny day.
9. Explain the difference between solar and lunar eclipses.
10. Match the letters on the diagram with the correct terms. You may use a letter more than once.



_____First day of summer

_____First day of winter

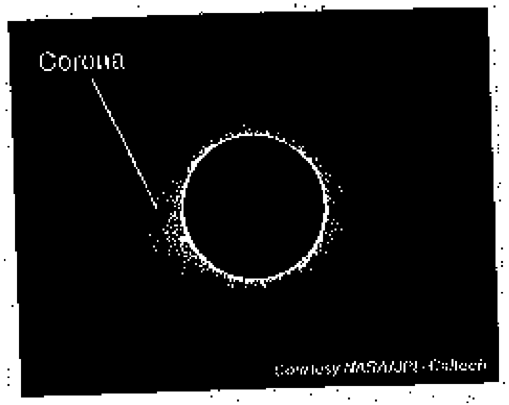
_____First day of spring

_____First day of autumn

11. What are tides? What causes tides on the Moon-side of Earth to occur?

CHALLENGE

The Sun is 400 times larger in diameter than the Moon. It is also 400 times farther away from Earth than the Moon. Because of this coincidence, the Sun and Moon appear to be the same size in the sky.



Courtesy NASA/JPL-Caltech

The photo above shows a total eclipse of the Sun. Using the information above, explain why a solar eclipse occurs.

26.3 Objects in the Solar System

On August 24, 2006, the International Astronomical Union (IAU) passed a new definition of a planet. The new definition excludes Pluto as a planet. According to the new definition, Pluto is classified as a *dwarf planet*. Recently, astronomers have begun to find dozens of objects similar to Pluto—all small, icy, rocky, and with similar orbits. The change in Pluto's status as a planet is a good example of the scientific method in progress. New discoveries sometimes cause scientists to revise scientific knowledge. In this section, you will read about planets, moons, and other objects in the solar system. The Sun will be discussed in Chapter 27.

Planets and moons

Defining a planet A **planet** in the solar system is a celestial body that (1) is in orbit around the Sun; (2) is nearly round in shape; and (3) has cleared its orbit of other objects. What this last part means is that a planet is large enough that, as it revolves around the Sun, the other objects in its orbit have either become part of the planet by fusing with it or have collided with the planet and moved out of the planet's orbit.

Classifying the planets The planets are commonly classified into two groups. The **terrestrial planets** include Mercury, Venus, Earth, and Mars. The terrestrial (rocky) planets are mostly made of rock and metal. They have relatively high densities, slow rotations, solid surfaces, and few moons. The **gas planets** include Jupiter, Saturn, Uranus, and Neptune. They are made mostly of hydrogen and helium. These planets have relatively low densities, rapid rotations, thick atmospheres, and many moons.

Moons Earth has one moon which we call the Moon. Most of the other planets have moons too. A **moon** is a natural satellite that orbits a planet or other body, such as a dwarf planet. The planet the moon orbits is called the *primary*. As of this writing, 240 objects in our solar system are classified as moons. Of those, 166 orbit the eight planets while the rest orbit dwarf planets and smaller solar system objects. Among the largest moons in the solar system are Earth's moon; one of Jupiter's moons, Io, Europa (shown in Figure 26.20), Ganymede, and Callisto; Saturn's moon, Titan; and Neptune's moon, Triton.

VOCABULARY

planet - a celestial body that (1) is in orbit around the Sun; (2) is nearly round in shape; and (3) has cleared its orbit of other objects.

terrestrial planets - Mercury, Venus, Earth, and Mars.

gas planets - Jupiter, Saturn, Uranus, and Neptune.

moon - a natural satellite orbiting a planet or other body, such as a dwarf planet.

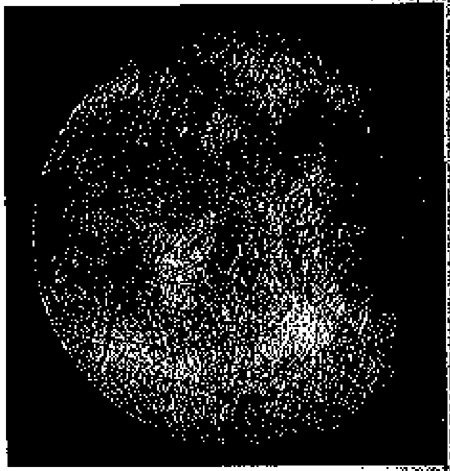


Photo courtesy of

Figure 26.20: *Jupiter's moon, Europa, is one of the largest moons in the solar system.*

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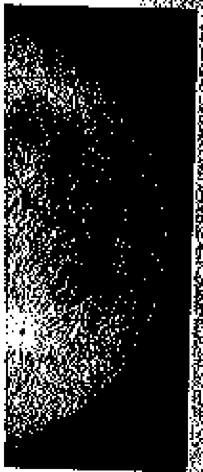

Photo courtesy of NASA

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th and the Moon

Earth statistics Earth's atmosphere is mostly nitrogen (78 percent) and oxygen (21 percent). Earth is one of only two bodies in the solar system known to have liquid water (the other is Europa, a moon of Jupiter). As far as we know, Earth is the only planet in the solar system to support life. Although space probes have begun searching for life on other bodies, no evidence has yet been found.

Moon statistics The Moon, which has no atmosphere, revolves around Earth at an average distance of 384,400 kilometers. The Moon's diameter is 3,476 kilometers, or about one quarter the size of Earth. The Moon's mass is 7.3×10^{22} kilograms, which is about one one-hundredth of Earth's mass. Because of the Moon's relatively small mass, its gravity does not attract an atmosphere. Its density is 3.34 g/cm^3, which is much lower than Earth's. Figure 26.21 compares Earth and the Moon.

Property	Earth	Moon
Diameter	12,756 km	3,476 km
Gravity	9.8 N/kg	1.6 N/kg
Mass	6.0×10^{24} kg	7.3×10^{22} kg
Density	5.52 g/cm^3	3.34 g/cm^3
Rotation period	1 day	27.3 days

Figure 26.21: *Comparing Earth and the Moon.*

Gravitational force The Moon's gravitational force is about one sixth as strong as Earth's. Earth exerts a gravitational force of 9.8 newtons on a 1-kilogram object while the Moon exerts a force of only 1.6 newtons on the same object. This means that a 1-kilogram object weighs 9.8 newtons (2.2 pounds) on Earth and the same object weighs only 1.6 newtons (0.36 pounds) on the Moon.

Gravitational locking If you have ever observed the Moon, you may have noticed that the same side of it faces Earth at all times. This does not mean that the Moon does not rotate. The Moon rotates much more slowly than Earth. Over millions of years, Earth's gravity has *locked* the Moon's rotation to its orbit around Earth. One lunar "day" takes 27.3 Earth days, exactly the same time it takes the Moon to complete one orbit around Earth (Figure 26.22).

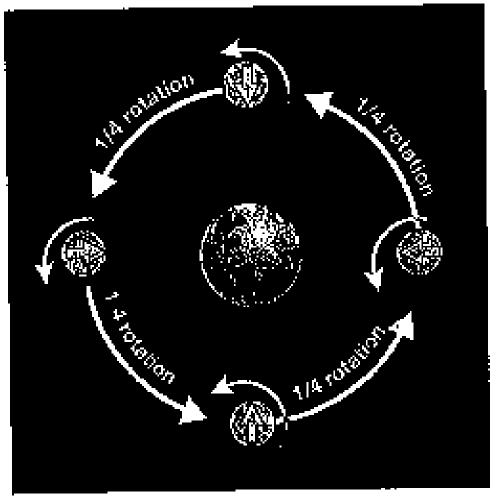

Figure 26.22: *The amount of time it takes the Moon to complete a rotation is the same amount of time it takes it to revolve around Earth. Can you see why only one side of the Moon faces Earth at all times?*

The length of the lunar cycle is different than the Moon's rotation period Why is there a difference between the lunar cycle (29.5 days) and the Moon's rotation period (27.3 days)? As the Moon orbits Earth, the *Earth–Moon system* orbits the Sun. In the 27.3 days it takes the Moon to rotate and orbit Earth, the Earth–Moon system has revolved about 27 degrees (out of 360 degrees in a circle) of its total orbit around the Sun. It takes a few more days for the Moon to move along its orbit to compensate for the change in angle of the Sun's rays. In the meantime, the Earth-Moon system has moved even farther in its orbit around the Sun.

How the Moon was formed

Where did the Moon come from?

Throughout history, there have been many different theories about the origin of the Moon. Before the *Apollo* landings that began in 1969, there were three main theories.

1. Some scientists hypothesized that the Moon split off Earth during a period of very fast rotation.
2. Others thought that the Moon formed somewhere else and was "captured" by Earth's gravity.
3. Still others proposed that the Moon and Earth were formed together from a group of smaller chunks of matter when the solar system formed.

Analyzing lunar rocks

Photo courtesy NASA

When scientists analyzed lunar rocks, they found that they were composed of much less iron and nickel than Earth. Recall that Earth's *core* is composed mostly of iron and nickel. The composition of lunar rocks closely resembled that of Earth's *mantle*. They also found that the Moon's density was the same as Earth's mantle and crust combined.

The giant impact theory

These discoveries gave rise to the **giant impact theory** that is widely accepted today. This theory proposes that about 4.5 billion years ago, an object about the size of Mars collided with Earth, causing material from Earth's mantle and crust to break off. This material, combined with material from the colliding object, was thrown into orbit around Earth and became the Moon. The Moon's spherical shape was a result of gravity and the remaining particles impacted the Moon to form craters. Figure 26.23 shows how the Moon was formed based on this theory.

VOCABULARY

giant impact theory - a scientific theory that explains how the Moon was formed.

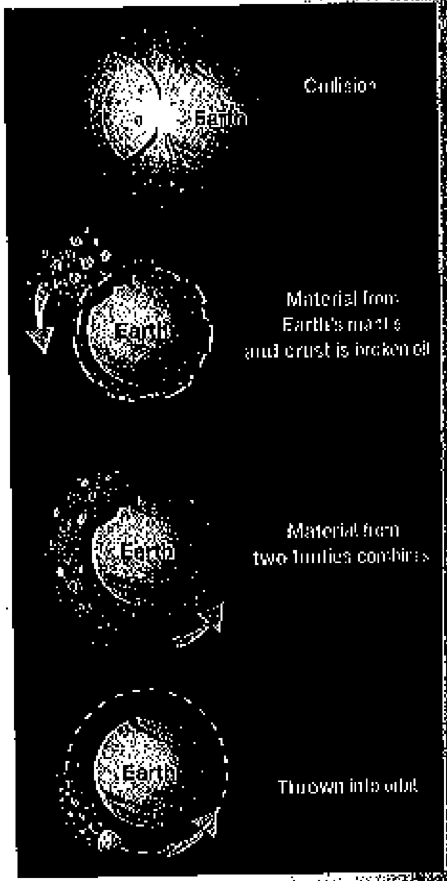

Figure 26.23: *The giant impact theory of the Moon's formation.*

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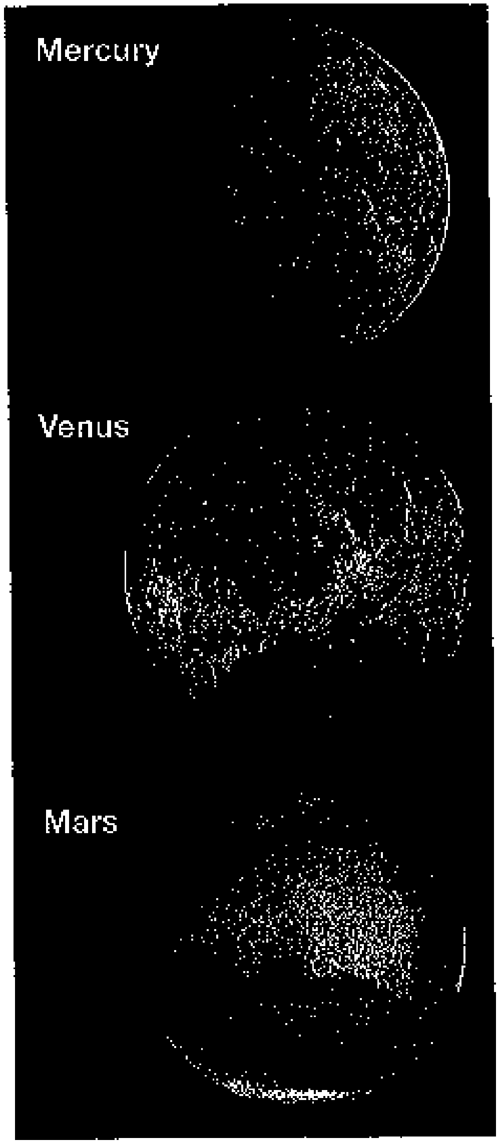
rcury, Venus, and Mars

Mercury Mercury, the closest planet to the Sun, is the smallest in both size and mass. Mercury appears to move quickly across the night sky because its period of revolution is the shortest of all of the planets. Mercury rotates on its axis very slowly—only one and a half times for every revolution around the Sun. This makes one day on Mercury about 59 Earth days, although its year is not much longer—about 88 Earth days! Only 40 percent larger than Earth's moon, Mercury is a rocky, cratered world, more like the Moon than like Earth. Like the Moon, Mercury has almost no atmosphere (except for traces of sodium). Mercury has no moons. The side of Mercury that faces the Sun is very hot, about 400°C, while the other side is very cold, about –170°C.

Venus Venus appears as the brightest planet and the third brightest object in our sky (after the Sun and the Moon). It has a very thick atmosphere and an atmospheric pressure at its surface that is 90 times that at Earth's surface. Because the atmosphere on Venus is 96 percent carbon dioxide, the greenhouse effect makes it the hottest planet in the solar system, with a surface temperature of more than 500°C. Venus rotates "backward," that is, east to west. Its rotation is the slowest of all of the planets; Venus makes a little less than one rotation for each revolution around the Sun. This means that 1 day on Venus is 243 Earth days, while 1 year is shorter—225 Earth days! Like Mercury, Venus has no moons.

Mars Mars appears as a reddish point of light in the night sky. It has a widely varied surface that includes deserts, huge valleys and craters, and volcanic mountains that dwarf those on Earth. The atmosphere of Mars is very thin (about 0.7 percent as thick as that of Earth) and is composed mostly of carbon dioxide, while the rest is nitrogen and argon. The temperatures are below freezing most of the time. Like Earth, Mars has polar ice caps, but they are composed of a combination of water and frozen carbon dioxide. Because it has an axial tilt, Mars experiences seasons like Earth. A day on Mars (24.6 hours) is similar in length to Earth, while a year (687 days) is not. Mars has two small moons named Phobos and Deimos.



Images not to scale *Photos courtesy of NASA*

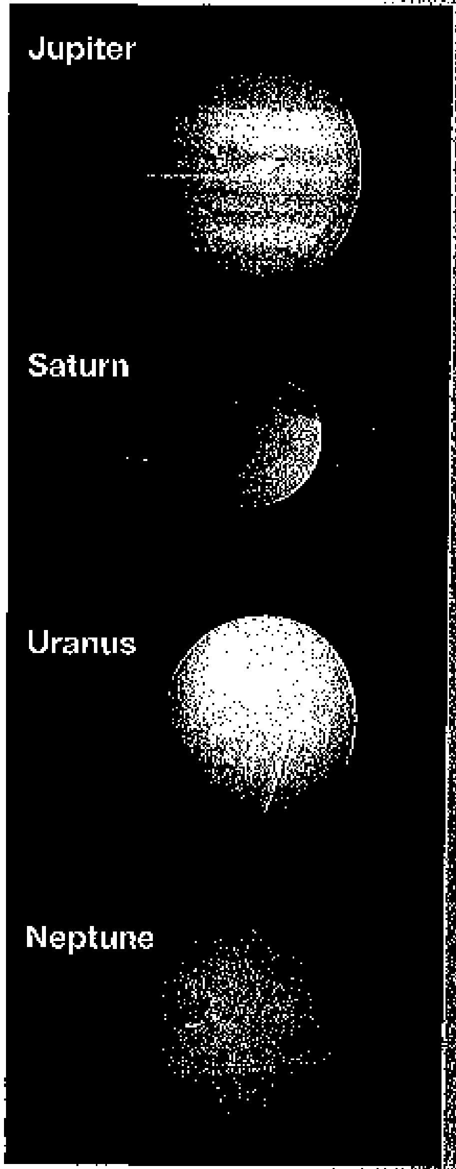
The gas planets

Jupiter Jupiter is the largest of the planets, and the fastest rotator, spinning on its axis about once every 10 hours. A year on Jupiter is about 12 Earth years. Jupiter is more liquid than gaseous or solid—more than half of its volume is an ocean of liquid hydrogen. Its atmosphere is about 88 percent hydrogen and 11 percent helium. It has a stormy atmosphere and one storm, known as the Great Red Spot, has been observed for more than 300 years. Jupiter has 63 moons and a series of rings that were first found by *Voyager 1* in 1979.

Saturn Saturn, at almost 10 times the size of Earth, is the second largest planet. Saturn's atmosphere is made mostly of hydrogen and helium. Saturn is a fast rotator, though slightly slower than Jupiter, with a day on Saturn lasting just longer than 10 Earth hours. A year on Saturn is about 29 Earth years. The most striking feature of Saturn is its system of rings, which are visible from Earth with a telescope. Saturn's rings are made up of billions of particles of rock and ice ranging from microscopic to the size of a house. Although they are hundreds of thousands of kilometers wide, the rings are less than 100 meters thick. Saturn has 47 moons.

Uranus The seventh planet from the Sun, Uranus can barely be seen without a good telescope and was not discovered until 1781. It rotates "backward" and has an axis that is tilted 98 degrees to the plane of its orbit. A day on Uranus is only 18 Earth hours, but a year takes 84 Earth years. Uranus has at least 27 moons, all of them relatively small. Titania, the largest, has only 4 percent of the mass of Earth's moon. Uranus also has a series of faint rings.

Neptune Neptune, the eighth planet from the Sun, is the outermost of the gas planets. It was discovered in 1846 and its discovery almost doubled the diameter of the known solar system because of its great distance from the Sun. A day on Neptune is only 16 hours long, but a year takes 165 Earth years! Neptune has a series of faint rings invisible from Earth but that have been seen in photographs taken by space probes. Neptune has 13 known moons, 6 of which were found in photographs taken by *Voyager 2* in 1989. Of the 13 moons, only Triton is bigger than a few hundred kilometers in diameter.



Images not to scale *Photos courtesy of NASA*
Artist interpretation of the rings of Jupiter, Uranus, and Neptune

mparing the properties of the planets

	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
Diameter *(km)*	4,879	12,104	12,756	6,792	142,984	120,536	51,118	49,528
Mass *(kg)*	3.3×10^{23}	4.9×10^{24}	6.0×10^{24}	6.4×10^{23}	1.9×10^{27}	5.7×10^{26}	8.7×10^{25}	1.2×10^{26}
Density *(g/cm³)*	5.42	5.24	5.52	3.93	1.32	0.69	1.27	1.64
erage distance om the Sun *(km)*	58 million	108 million	150 million	228 million	778 million	1.43 billion	2.87 billion	4.50 billion
Moons *(number of)*	0	0	1	2	63	60	27	13
vitational force *(N/kg)*	3.7	8.9	9.8	3.7	23.1	9.0	8.7	11.0
Surface emperature *(°C)*	–170 to +450	+465	–88 to +48	–89 to –31	–110	–139	–195	–200
Rotation period *(Earth days)*	59	243	1	1.03	0.41	0.44	0.72	0.67
volution period *(Earth years)*	0.24	0.62	1	1.9	12	29.5	84	165
Major gases in atmosphere	Trace He, H_2, O_2, Na	CO_2	N_2, O_2	CO_2	H_2, He, CH_4, NH_3	H_2, He, CH_4, NH_3	H_2, He, CH_4, NH_3	H_2, He, CH_4, NH_3
Orbital velocity *(km/s)*	47.89	35	29.80	24.14	13.1	9.7	6.80	5.43

Planet photos courtesy of NASA/JPL. Planets not shown to scale.

of NASA
Neptune

Triton, Pluto, and the Kuiper Belt

Triton and Pluto

Triton is Neptune's largest moon (Figure 26.24). Pluto is a dwarf planet, and most of the time it is the farthest object from the Sun. Triton and Pluto are similar objects in both composition and size. In fact, Pluto is slightly smaller than Triton and only a fraction larger than Earth's moon. Some astronomers believe Pluto may actually be an "escaped" moon of Neptune. In this section, you will learn about dwarf planets like Pluto and other solar system objects like asteroids and comets.

Pluto

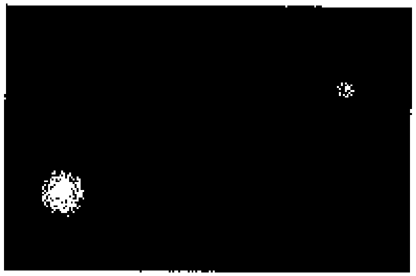


Photo courtesy of NASA

Discovered in 1930 by Clyde Tombaugh, Pluto was named for the Roman god of the underworld. The first dwarf planet discovered, Pluto rotates slowly—one turn every six Earth days—and backward. Its orbit is strongly elliptical and Pluto crosses the path of Neptune for about 20 years out of the 249 years it takes to revolve around the Sun. Their orbits are not in the same plane, so Neptune and Pluto will never collide. Because it is so far away, little is known about Pluto. The image above, from the Hubble Space Telescope, shows Pluto and its single "moon," Charon.

The Kuiper Belt

Artist's concept image courtesy of NASA and G. Bacon (STScI)

Outside the orbit of Neptune is a region called the Kuiper (rhymes with *viper*) Belt (Figure 26.25). The Kuiper Belt stretches from 50 to 1,000 AU out from the Sun and is believed to contain a few Pluto-size objects and many smaller ones. Kuiper Belt Objects (KBOs) are icy bodies found inside the Kuiper Belt and include the dwarf planets found there. As of this writing, it contains at least three dwarf planets: Pluto, Haumea, and Makemake. Quaoar (above left) is the second largest object in the Kuiper Belt at about half the size of Pluto. Unlike Pluto, Quaoar's orbit around the Sun is nearly circular. Quaoar was recognized as a KBO in 2002 by Astronomer Mike Brown and his colleagues who also suggest it is made of ice and rock.

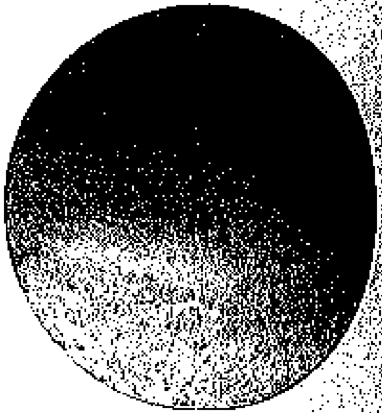


Figure 26.24: *Triton is Neptune's largest moon. Some astronomers believe that Pluto may be an "escaped" moon of Neptune. Photo courtesy of NASA.*

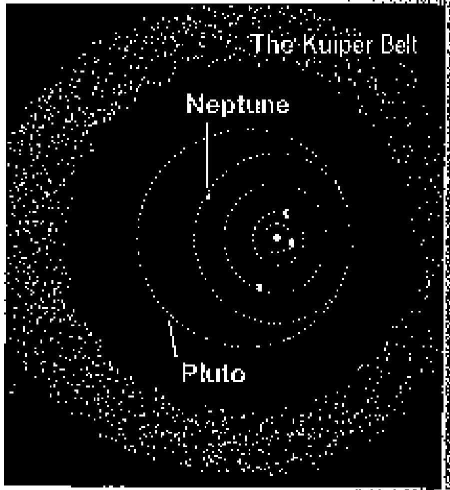
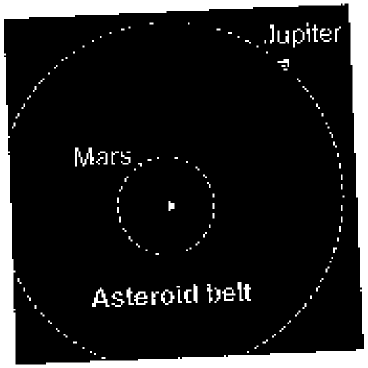


Figure 26.25: *The Kuiper Belt lies beyond Neptune. It is named after astronomer Gerard Kuiper (1905 to 1973).*

teroids and comets

Asteroids



Between Mars and Jupiter, at a distance of 320 million to 495 million kilometers, there is a huge gap that cuts the solar system in two. This gap is called the *asteroid belt* because it is filled with thousands of small, rocky bodies called asteroids. An **asteroid** is an object that orbits the Sun but is too small to be considered a planet. So far, more than 10,000 asteroids have been discovered and more are found each year (Figure 26.26).

The size of asteroids

Most asteroids are small—less than a kilometer in diameter—but many have been found that are over 250 kilometers in diameter. The largest asteroid, named Ceres, is 933 kilometers across. While the majority of asteroids are found in the asteroid belt, many have highly elliptical orbits that allow them to come close to Mercury, Venus, and even Earth. About 65 million years ago, a large asteroid hit Earth near Mexico, leaving a huge crater. Some scientists believe this event led to the extinction of the dinosaurs.

Comets

Scientists believe **comets** are made mostly of ice and dust. Comets revolve around the Sun in highly elliptical orbits. In 1997, the comet Hale-Bopp could be clearly seen in the night sky without a telescope. However, we still know little about the composition and structure of comets. Several recent spacecraft have made close approaches to comets and each new piece of evidence they gather has lead to new insights about what comets are made of and how they formed.

Evolution of a comet

As a comet approaches the Sun, some of its ice turns into gas and dust and forms an outer layer called a *coma*. The inner core of the comet is called the *nucleus*. As a comet nears the Sun, the solar wind (charged particles emitted by the Sun) causes the formation of a *tail*. Comet tails can be over 1 million km long! A comet's tail always faces away from the Sun (Figure 26.27) because of the forces caused by the solar wind. Each time a comet passes the Sun, it loses some of its mass.

VOCABULARY

asteroid - an object that orbits the Sun but is too small to be considered a planet.

comet - an object in space made mostly of ice and dust.

Figure 26.26: *The asteroid shown in this picture, named Ida, is about 54 km wide. Photo courtesy of NASA.*

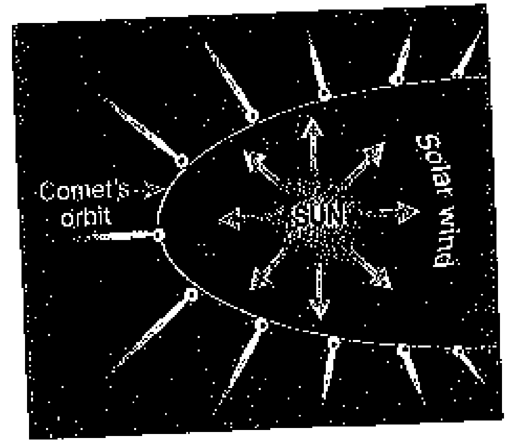


Figure 26.27: *A comet's tail faces away from the Sun and can stretch for millions of kilometers in space.*

Meteors and meteorites

Meteors

Occasionally, chunks of rock or dust break off from a comet or asteroid and form a **meteor.** Imagine a tennis ball traveling at about 48,000 kilometers per hour. That's about the size and speed of most meteors. These chunks of dust or rock travel through space and some of them end up hitting Earth's atmosphere. When this happens, meteors rub against air particles and create friction, heating them to more than 2,000°C. The intense heat vaporizes most meteors, creating a streak of light known as a "shooting star." Occasionally, larger meteors cause a brighter flash called a *fireball.* These sometimes cause an explosion that can be heard up to 48 kilometers away. If you live or find yourself away from any city lights, look at the sky on a clear night and chances are that, if you look long enough, you will see a meteor. On average, a meteor can be seen in the night sky about every 10 minutes.

Meteor showers

When a comet nears the Sun, a trail of dust and other debris burns off and remains in orbit around the Sun. As Earth orbits the Sun, it passes through this debris, creating a *meteor shower* as the small bits of dust burn up in the atmosphere. During a meteor shower, you can see tens and even hundreds of meteors per hour. Because Earth passes the same dust clouds from comets each year, meteor showers can be predicted with accuracy.

Meteorites

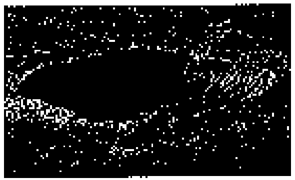


Photo by David J. Roddy, USGS

If a meteor is large enough to survive the passage through Earth's atmosphere and strike the ground, it becomes a **meteorite.** Meteorites are thought to be fragments from collisions involving asteroids. Most meteorites weigh only a few pounds or less and cause little damage when they hit. Most fall into the oceans that cover almost 75 percent of our planet's surface. Meteor Crater in Winslow, AZ (above), is believed to have been caused by a giant, 50-meter-diameter meteorite about 50,000 years ago. The Holsinger meteorite (Figure 26.28) is the largest known piece of this 300,000-ton meteorite, most of which vaporized on impact.

VOCABULARY

meteor - a chunk of burning rock traveling through Earth's atmosphere.

meteorite - a meteor that passes through Earth's atmosphere and strikes the ground.

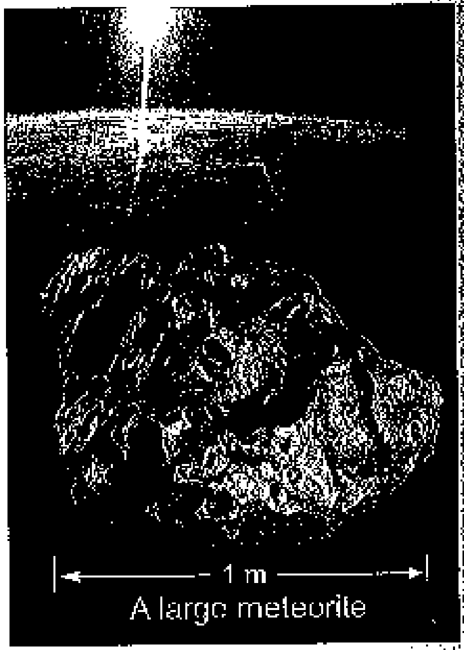


Figure 26.28: *The Holsinger meteorite is a large piece of a much larger meteorite that blasted out Meteor Crater in Arizona about 50,000 years ago. This meteorite, while no taller than your thigh, weighs 1,400 lbs.*

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26.3 Section Review

1. Use the table on page 679 to answer the following questions.
   a. Which planet has the largest diameter? The smallest?
   b. On which planet is gravity the strongest? The weakest?
   c. A day is the time it takes a planet to rotate once on its axis. Which planet has the longest day? The shortest day?
   d. A year is the time it takes a planet to revolve once around the Sun. Which planet has the longest year? The shortest year?
   e. Which planet is the most dense? The least dense?
   f. Which planet is approximately 10 AU from the Sun?
   g. Make a graph of orbital velocity vs. average distance from the Sun. Does your graph support Kepler's ideas about the orbital velocity of planets that you read about on page 662? Explain your answer.
2. Why are we able to see a certain comet one year but not again until many years later?
3. What is the difference between a meteor and a meteorite?
4. What is the asteroid belt and where is it located?
5. Which planet has an atmosphere that consists mostly of carbon dioxide?
6. Compared with Earth's diameter, Saturn's diameter is roughly:
   a) the same b) 5 times larger c) 10 times larger d) 50 times larger
7. What is the Kuiper Belt and where is it located?
8. Which former planet is now considered a dwarf planet?
9. What is a planet?
10. The giant impact theory proposes that about 4.5 billion years ago, an object about the size of Mars collided with Earth, causing material from Earth's mantle and crust to break off. This material, combined with material from the colliding object, was thrown into orbit around Earth and became the Moon. Describe the scientific evidence that supports this theory.

CHALLENGE

Use the data from the table on page 679 to make a graph of surface temperature vs. distance from the Sun for the eight planets. Graph the distance on the *x*-axis and the temperature on the *y*-axis. Use these values for the surface temperature of the four inner planets:

Mercury 167°C; Venus 465°C, Earth 15°C, Mars –65°C.

What does your graph show about the relationship between temperature and distance from the Sun?

Do the planets perfectly follow this relationship?

What other factors might affect the surface temperature of the planets?

JOURNAL

Suppose you were given the opportunity to travel to another planet or a moon of another planet. Would you go? Why or why not? Would you go to Neptune, knowing the trip would last 20 years? What if you could bring along anything and anyone you wanted? Write an essay exploring your answers to these questions.

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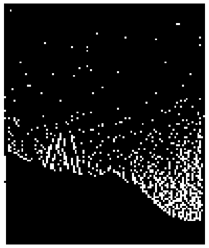
Chapter 27

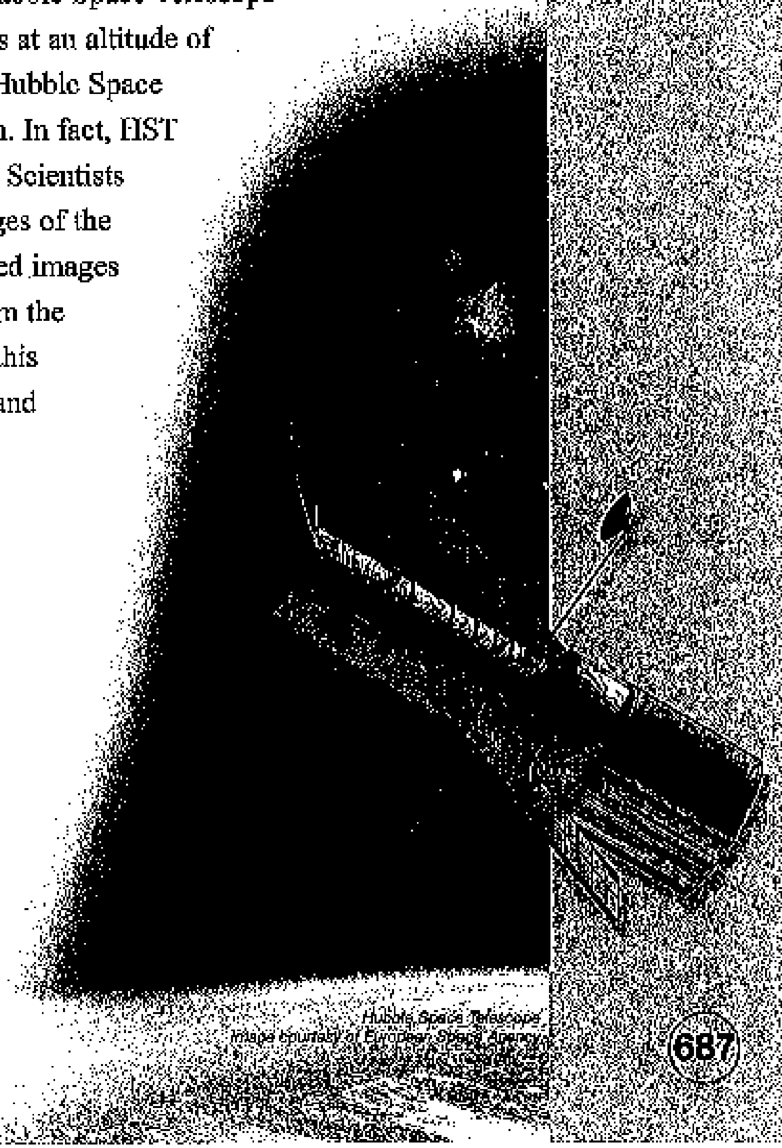
Stars



Stargazing is an awe-inspiring way to enjoy the night sky, but humans can learn only so much about stars from our position on Earth. The Hubble Space Telescope (HST) is a school-bus-size telescope that orbits Earth every 97 minutes at an altitude of 568 kilometers and a speed of about 28,000 kilometers per hour. The Hubble Space Telescope transmits images and data from space to computers on Earth. In fact, HST sends enough data back to Earth each week to fill thousands of books. Scientists store the data on special disks. In January of 2006, HST captured images of the Orion Nebula, a huge area where stars are being formed. HST's detailed images revealed over 3,000 stars that were never seen before. Information from the Hubble will help scientists understand more about how stars form. In this chapter, you will learn all about the star of our solar system, the Sun, and about the characteristics of other stars.

Key Questions

- ✓ *Why do stars shine?*
- ✓ *What kinds of stars exist?*
- ✓ *What is the life cycle of a star?*



Hubble Space Telescope
Image courtesy of European Space Agency

27.1 The Sun

Can you imagine life without the Sun? The Sun is the source of energy that sustains all life on Earth. What is the Sun? Why does it produce so much energy? Read on to find the answers to these questions, and many more.

The Sun is a star

The Sun is a star A **star** is an enormous, hot ball of gas held together by gravity. Gravity squeezes the density of a star so tightly in the core that the electrons are stripped away and the bare nuclei of atoms almost touch each other. At this high density, nuclear fusion occurs, releasing tremendous amounts of energy. The nuclear fusion that powers the Sun combines 4 hydrogen atoms to make helium, converting 2 protons to neutrons in the process (Figure 27.1). The minimum temperature required for fusion to occur is 7 million degrees Celsius. The Sun's core reaches a temperature of 15 million degrees Celsius.

The Sun's dense core The high density and temperature needed for fusion occurs in the center, or core of a star (Figure 27.2). The density at the Sun's core is about 158.0 g/cm^3. This is about 18 times the density of solid copper. In order to reach this high density, a star must have a mass much larger than a planet. For example, the Sun has a mass that's around 330,000 times larger than the mass of Earth.

A medium-size star The Sun is medium-size star. Its diameter is about 1.4 million kilometers. Approximately 1 million Earths could fit inside the Sun! By contrast, one of the star "supergiants" called Betelgeuse sometimes reaches a diameter that is almost 600 times that of the Sun. If the Sun grew to the size of Betelgeuse, it would swallow up Mercury, Venus, Earth, and Mars!

What is the Sun made of? The Sun is about 75 percent hydrogen and 25 percent helium, with very small traces of other elements. Unlike Earth, the Sun does not have a solid surface—instead, it is made completely of gas. Because of its size, the Sun contains 99.8 percent of the mass of the solar system. Because of its mass, the Sun's gravitational force is strong enough to hold the entire solar system—including the planets, dwarf planets, asteroids, and comets—in orbit.

VOCABULARY

star - a giant, hot ball of gas held together by gravity.

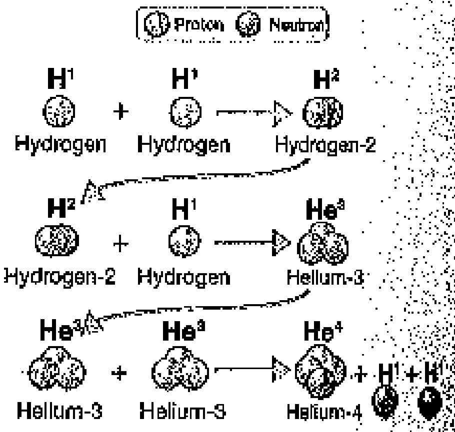


Figure 27.1: *This diagram shows what happens during nuclear fusion inside the Sun.*

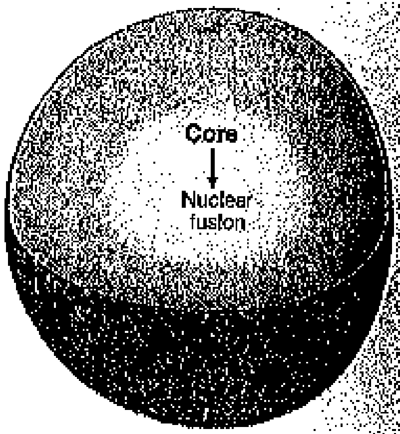


Figure 27.2: *A cross section of a star like the Sun.*

Anatomy

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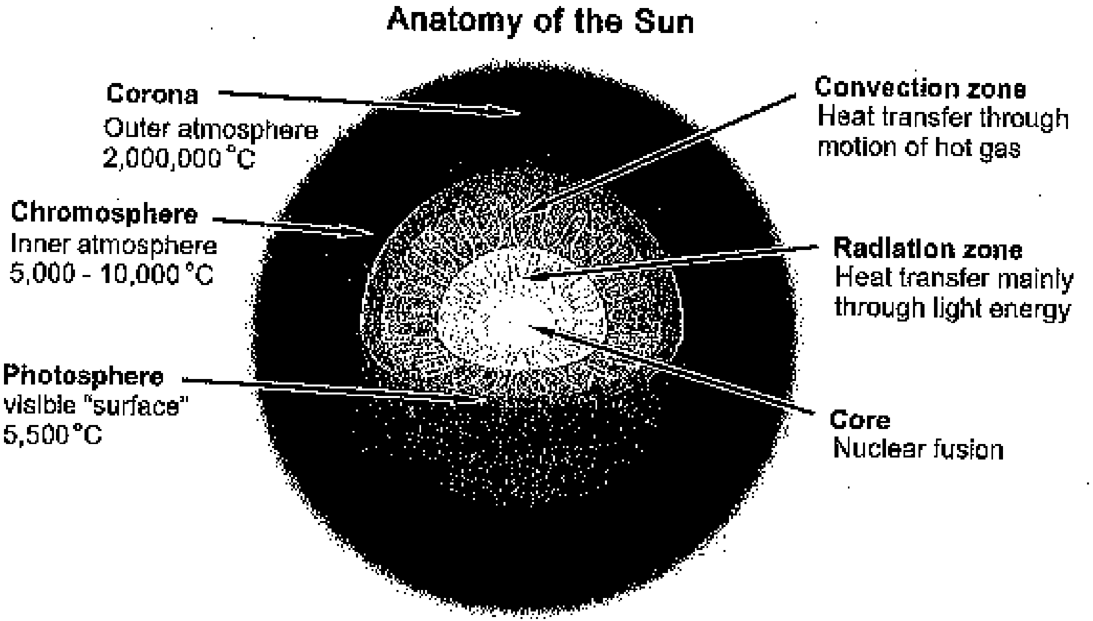
The Sun has three regions

The apparent surface of the Sun that we can see from a distance is called the *photosphere*, which means "sphere of light." Just above it is the **chromosphere**. This is a very hot layer of plasma, a high-energy state of matter. The **corona** is the outermost layer of the Sun's atmosphere, extending millions of kilometers outward.



Sunspots

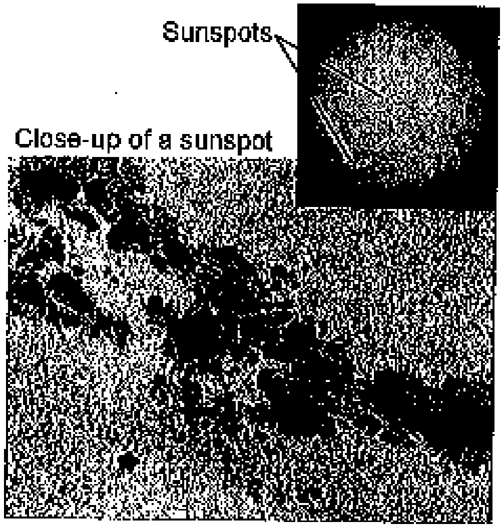
A safe method for viewing the Sun is to use a telescope to project the Sun's image onto a white surface (Remember, you should NEVER look directly at the Sun). When the Sun is observed in this way, small, dark areas can be seen on its surface. These areas, called *sunspots*, may look small, but they can be as large as Earth. A **sunspot** is an area of gas that is cooler than the gases around it. Because they don't give off as much light as the hotter areas, sunspots appear as dark spots on the photosphere (Figure 27.3).

VOCABULARY

chromosphere - the inner atmosphere of the Sun which consists of a very hot layer of plasma.

corona - the outermost layer of the Sun's atmosphere that extends millions of kilometers outward.

sunspot - an area of gas on the Sun that is cooler than the gases around it; sunspots appear as dark spots on the Sun's photosphere.



National Solar Observatory

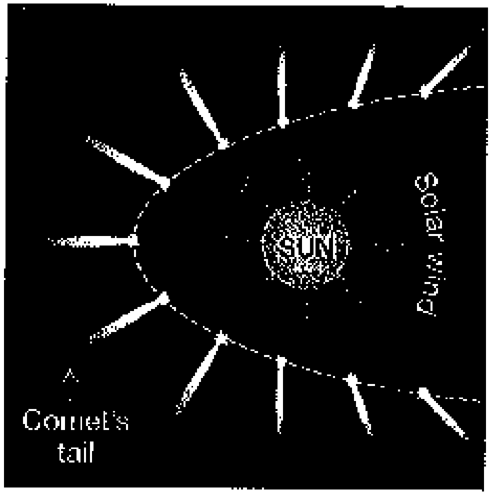
Figure 27.3: *Sunspots appear as dark spots on the photosphere.*

Features of the Sun

Prominences and solar flares

Sunspots are linked to other features of the Sun. Occasionally, large "loops" of gas called *prominences* can be seen jumping up from groups of sunspots. These can be observed during eclipses and appear as loops that extend beyond the chromosphere. Sometimes prominences from different sunspot regions suddenly connect, releasing very large amounts of heat and light known as *solar flares* (Figure 27.4).

Solar wind



The Sun gives off more than just heat and light. It also gives off something called solar wind. *Solar wind* is an electrically charged mixture of protons and electrons. Evidence of solar wind comes from the tails of comets, which always face away from the Sun. A comet's tail, which is made of vaporized gases, acts like a "wind sock" and shows that there is a continuous flow of particles coming from the Sun.

Magnetic storms

Solar flares can greatly increase the amount of solar wind given off by the Sun. These solar wind particles can affect Earth's upper atmosphere, causing *magnetic storms*. Magnetic storms can disrupt radio and television signals, interfere with telephone and cell phone signals, and even cause electrical power problems for homes and businesses.

Auroras

Solar winds sometimes cause a mysterious phenomenon known as an **aurora** to occur. Auroras (known in the northern hemisphere as the northern lights or aurora borealis) occur when the protective layers of our atmosphere are energized by solar winds. This energy causes atoms and molecules in the upper atmosphere to give off light. The most common color produced is a yellow-green caused by oxygen atoms at an altitude of about 60 miles. The aurora appears as curtains of light above the horizon (Figure 27.5).

VOCABULARY

aurora - a phenomenon that occurs when the solar wind energizes the protective layers of the atmosphere

Photo courtesy of NASA/Goddard

Figure 27.4: *Solar flares release large amounts of heat and light.*

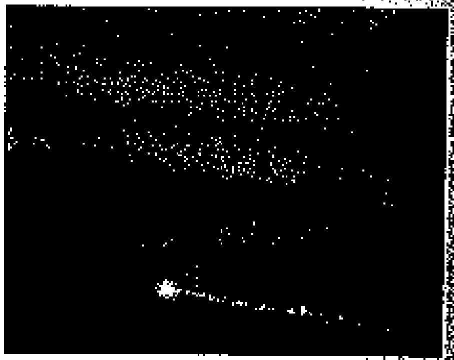


Figure 27.5: *Solar winds can cause auroras to occur.*

olar energy

Solar energy and electromagnetic waves *Solar energy* is a term that refers to radiant energy from the Sun. The radiant energy of the Sun reaches Earth in the form of electromagnetic waves. Recall that we classify these waves according to their energy as shown in Figure 27.6. The type of electromagnetic wave we can detect with our eyes is called *visible light*, a tiny portion of the electromagnetic spectrum. We can use solar energy to heat buildings and generate electricity.

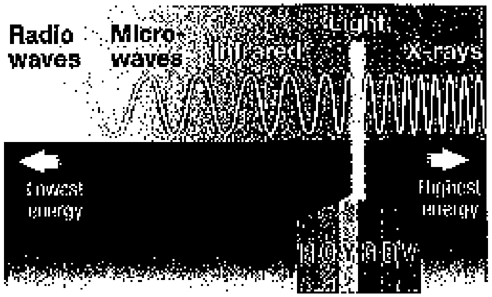
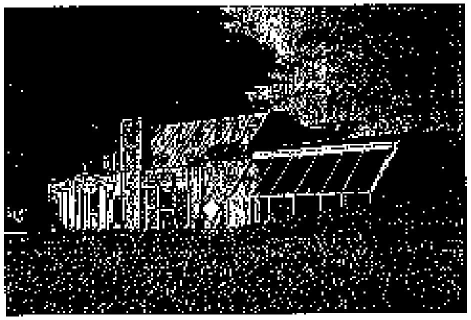


Figure 27.6: *The Sun emits waves in all frequencies of the electromagnetic spectrum. The only waves we can detect with our eyes we call visible light.*

Passive solar heating Buildings that use *passive solar heating* are designed to trap sunlight. Houses can be built with large glass windows that face the direction of the Sun. Sunlight passes through the windows and heats the air in the room. The glass traps the warm air inside, causing a "greenhouse effect."



Circulated solar heating A building that uses *circulated solar heating* has large glass panels covering part of its roof. Underneath the glass panels, a liquid is circulated through tubes. The liquid is heated by radiant energy from the Sun and flows into the building. The heated liquid can also be stored in an insulated tank for use at night.

Solar cells *Photovoltaic (or PV) cells*, also called *solar cells*, are devices that convert sunlight directly into electricity. You may already be using solar cells on calculators, watches, or some outdoor light fixtures. They are made out of at least two layers of a semiconductor material such as silicon. One layer has a positive charge, and the other has a negative charge. When light falls on the cell, some of it is absorbed by the semiconductor atoms, freeing electrons from the solar cells' negative layer. These electrons then flow through an external circuit and back into the positive layer. The flow of electrons produces electric current (Figure 27.7).

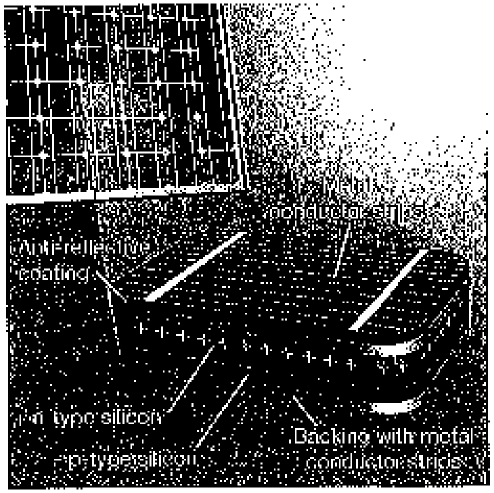


Figure 27.7: *Sunlight enters the PV cells, causing electrons to flow through a circuit to produce electric current.*

More about the Sun's energy

How much energy does the Sun produce?

Each second, about 700 million tons of hydrogen inside the Sun are converted to about 695 million tons of helium through nuclear fusion. Notice that the total mass of helium produced is slightly smaller than the total mass of hydrogen used. The "missing" mass (about 5 million tons) is converted directly into energy. This mass creates an energy output of 3.9 × 10^{26} watts! In 1905, Albert Einstein proposed that matter can be converted into energy. His famous equation ($E = mc^2$) shows how huge amounts of energy can be created from a smaller mass (Figure 27.8). This helps explain why such a huge amount of energy is produced by nuclear fusion.

The solar constant

The amount of this energy from the Sun that reaches the outer edge of Earth's atmosphere is known as the **solar constant**. While the solar constant varies slightly, the accepted value is 1,386 watts per square meter (W/m^2). To visualize this amount of energy, imagine the energy of thirteen 100-watt light bulbs spread over a square meter surface (Figure 27.9).

Theories about sunspots

The number of sunspots seems to vary over an average of 11 years and is known as the sunspot cycle. Many scientists speculate that there is a relationship between the sunspot cycle and variations in our global climate. Two decades of satellite research have shown that at times when there is a higher number of sunspots, the value of the solar constant increases slightly. While sunspots are cooler areas of the Sun, as their numbers increase, so does the number of solar flares that release large amounts of heat.

The Sun powers our energy needs

Except for nuclear power, the original source for almost all of our energy comes from the Sun. Sunlight causes water to evaporate, which later falls as rain into rivers and streams. This flowing water can be used to generate electricity. Energy from the Sun also drives the wind (created by uneven heating of Earth), which also can be used to generate electricity. Even the energy we get from coal, natural gas, petroleum, and wood comes from the Sun. That is because these fuels are created from *photosynthesis*. In this process, plants store energy from the Sun in the form of carbon compounds. The foods you eat also contain energy from the Sun that was trapped by plants using photosynthesis.

VOCABULARY

solar constant - the amount of energy from the Sun that actually reaches the edge of Earth's atmosphere.

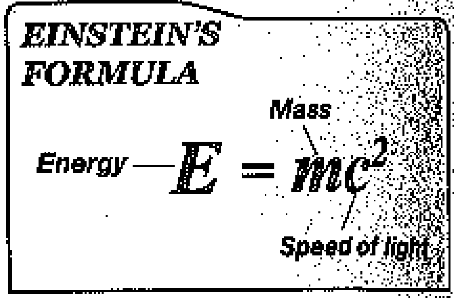


Figure 27.8: *Einstein's famous equation for energy.*

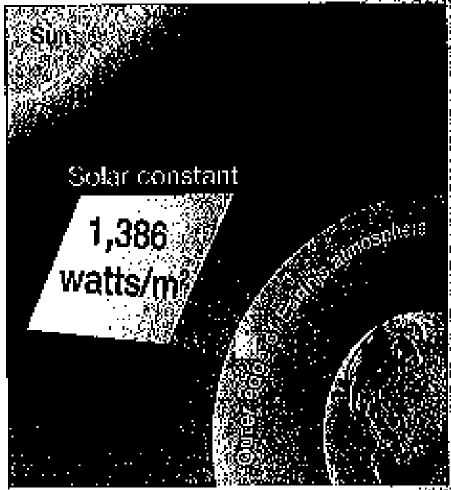


Figure 27.9: *While the solar constant varies slightly, its accepted value is 1,386 watts per square meter of Earth's atmosphere.*

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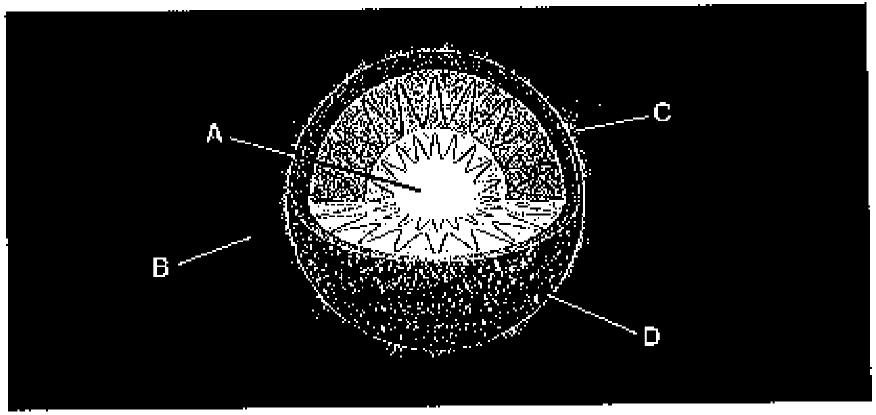
27.1 Section Review

1. What is a star? How is a star different from a planet or a moon?
2. Why does the Sun give off heat and light?
3. The Sun is made mostly from which of the following elements?
   a. helium
   b. lead
   c. hydrogen
   d. nitrogen
4. On the diagram below, label the following: photosphere, chromosphere, core, corona.

Anatomy of the Sun



5. Explain the meanings of the following terms.
   a. sunspot
   b. magnetic storm
   c. solar flare
   d. solar wind
   e. aurora

JOURNAL

Solar Energy Research

There are many ways to collect sunlight and use it to produce energy for our everyday needs. When we use energy from the Sun, it is called solar energy.

Photovoltaic (or PV) cells, also called solar cells, are devices that convert sunlight directly into electricity. You may have seen solar cells on calculators, watches, or some outdoor light fixtures. Research solar cells and find the answers to the following questions.

1. How do solar cells work?
2. How efficient are solar cells at converting sunlight into energy?
3. What are the drawbacks to using solar energy?
4. How are scientists trying to make solar cells more efficient?