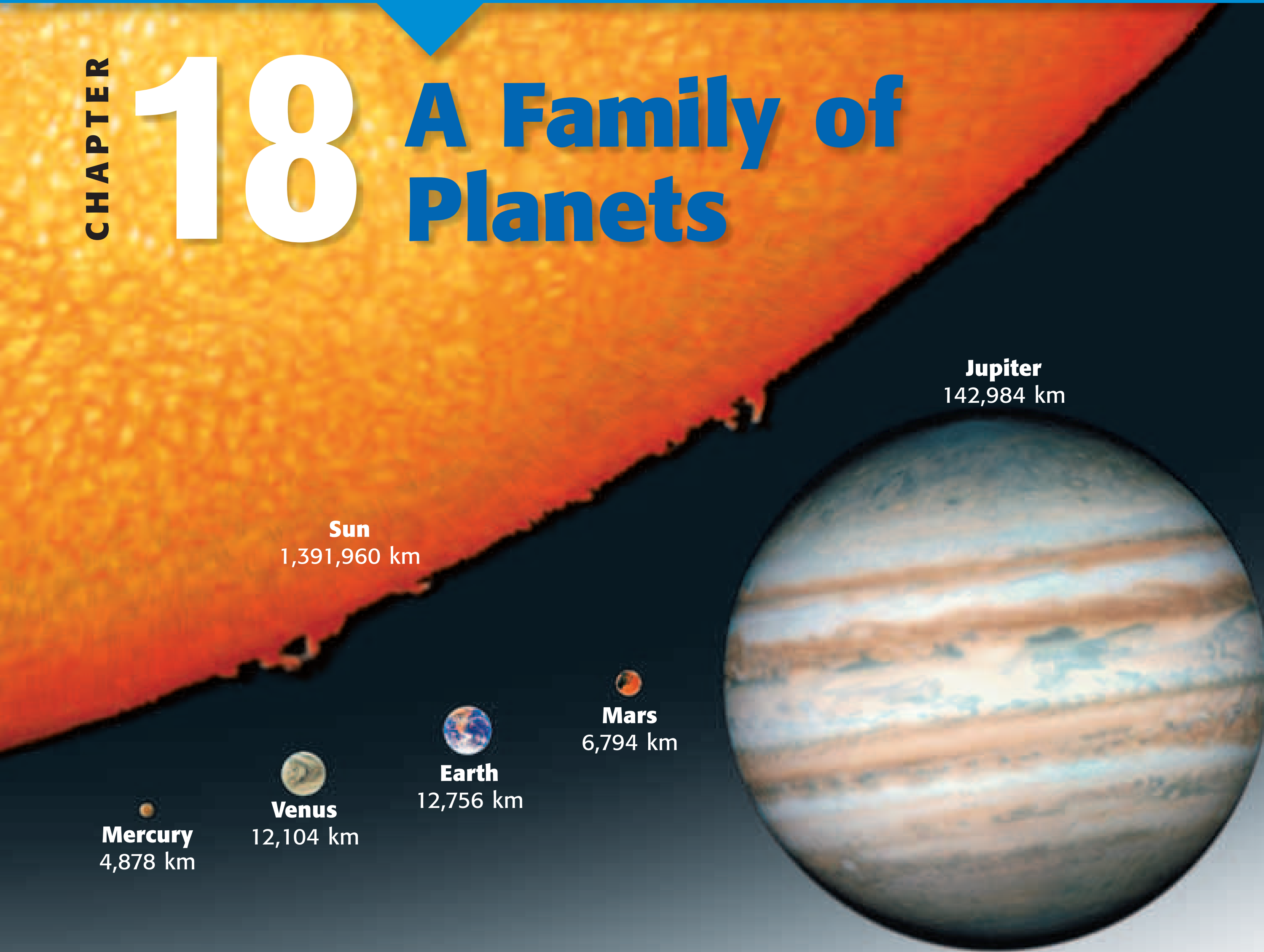
CHAPTER 18

A Family of Planets



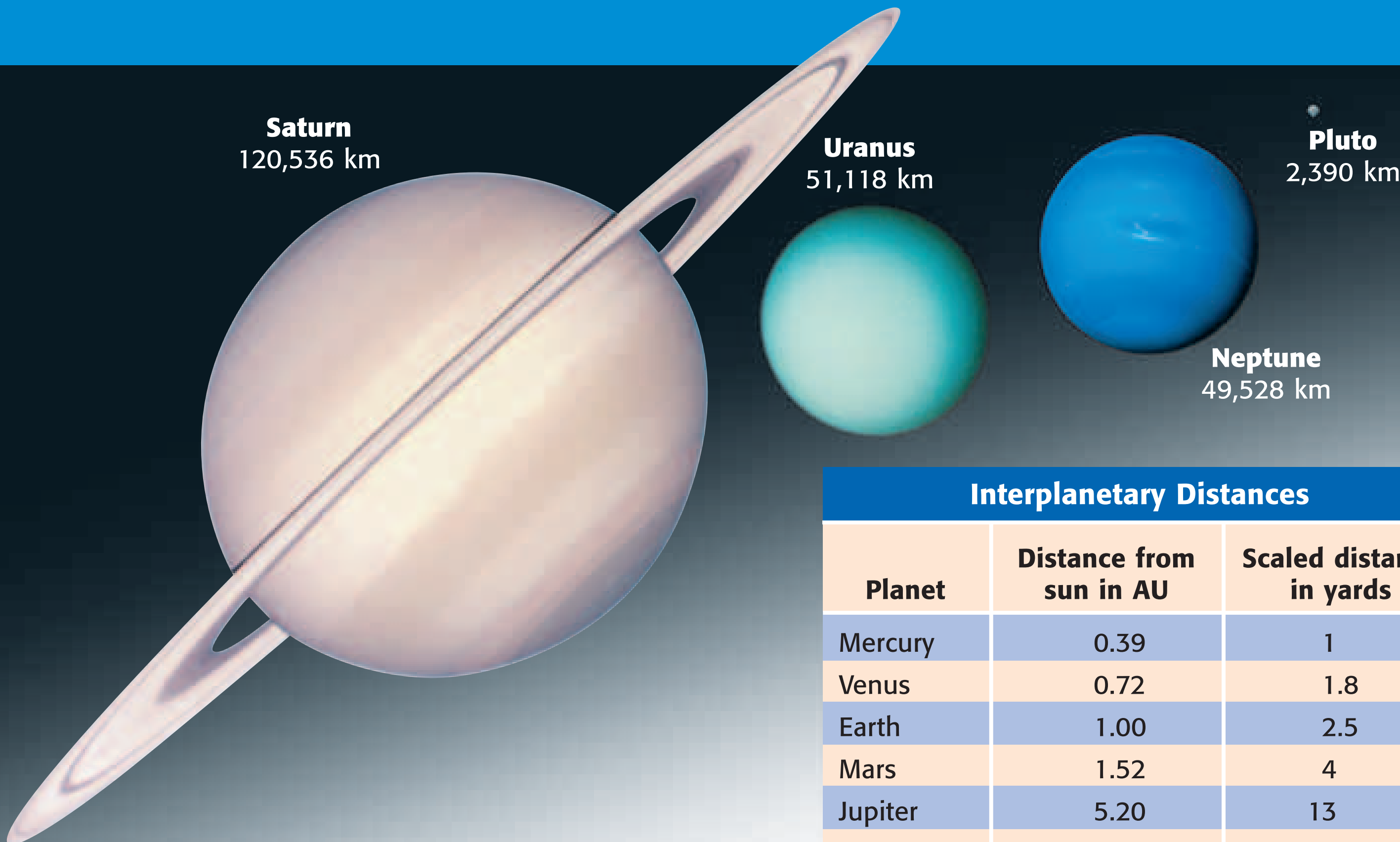
These images show the relative sizes and the diameters of the planets and the sun.

Imagine . . .

Imagine that it is 200 B.C. and you are an apprentice to a Greek astronomer. After years of observing the sky, he knows all of the constellations as well as you know the back of your hand. He shows you how the stars all move together—the whole sky spins slowly as the night goes on.

He also shows you that among the thousands of stars in the sky, some of the brighter ones slowly change their position relative to the other stars. These he names *planetai,* the Greek word for "wanderers." Building on the observations of the ancient Greeks, we now know that the *planetai* are actually planets, not wandering stars.

In this chapter you will learn about all of the bodies of the solar system—the planets and their moons, asteroids, comets, and meteoroids. You will also learn how space missions are making discoveries about our solar system that expand our knowledge of the solar neighborhood in which we live.



Interplanetary Distances

Planet	Distance from sun in AU	Scaled distance in yards
Mercury	0.39	1
Venus	0.72	1.8
Earth	1.00	2.5
Mars	1.52	4
Jupiter	5.20	13
Saturn	9.54	24
Uranus	19.19	49
Neptune	30.06	76
Pluto	39.53	100

Investigate!

Measuring Space

The Earth is about 150 million kilometers from the sun. Another way of describing this distance is 1 AU. AU stands for *astronomical unit,* which is the average distance between the Earth and the sun. Using this unit makes it easier for scientists to describe the large distances between planets in the solar system. Do the following exercise to get a better idea of your solar neighborhood.

Procedure

1. Use **10 stakes** as markers to map the distances between the planets. Attach a **flag** to the top of each stake.
2. Plant a stake at the goal line of a **football field**—this stake represents the sun. Then use the table to plant stakes to represent the position of each planet relative to the sun.

Analysis

3. After you have placed all the "planets" at their relative distances, what do you notice about how the planets are spaced?
4. Besides the way they are spaced, in what other way are most of the outer planets different from the inner planets?

What Do You Think?

In your ScienceLog, try to answer the following questions based on what you already know:

1. What are the differences between planets, moons, asteroids, comets, and meteoroids?
2. How can surface features tell us about a planet's history?

Section 1

The Nine Planets

NEW TERMS

astronomical unit (AU)
terrestrial planets
prograde rotation
retrograde rotation
gas giants

OBJECTIVES

- List the names of the planets in the order they orbit the sun.
- Describe three ways in which the inner and outer planets are different from each other.

Ancient people knew about the existence of planets and could predict their motions. But it wasn't until the seventeenth century, when Galileo used the telescope to study planets and stars, that we began our first exploration of these alien worlds. Since the former Soviet Union launched *Sputnik*—the first artificial satellite—in 1957, over 150 successful missions have been launched to moons, planets, comets, and asteroids. **Figure 1** shows how far we have come since Galileo's time.

Galileo Galilei

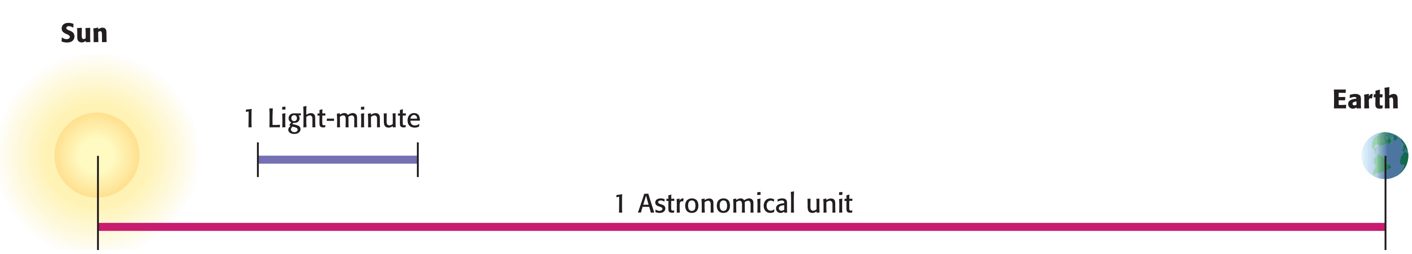
Figure 1 *Galileo Galilei (shown at left) discovered Jupiter's four largest moons using the newly invented telescope in 1610. The* Galileo *spacecraft (shown at right) arrived at Jupiter on December 7, 1995.*

Measuring Interplanetary Distances

As you have seen, one way scientists measure distances in space is by using the astronomical unit. The **astronomical unit (AU)** is the average distance between the Earth and the sun. Another way to measure distances in space is by the distance light travels in a given amount of time. Light travels at about 300,000 km per second in space. This means that in 1 second, light travels a distance of 300,000 km—or about the distance you would cover if you traveled around Earth 7.5 times.

In 1 minute, light travels nearly 18,000,000 km! This distance is also called 1 *light-minute.* For example, it takes light from the sun 8.3 minutes to reach Earth, so the distance from the Earth to the sun is 8.3 light-minutes. Distances within the solar system can be measured in light-minutes and light-hours, but the distances between stars are measured in light-years!

Figure 2 *One astronomical unit equals about 8.3 light-minutes.*



The Inner Planets

The solar system is divided into two groups of planets—the inner planets and the outer planets. Planets and their moons shine because they reflect sunlight. As you learned from the Investigate, the inner planets are more closely spaced than the outer planets. Other differences between the inner and outer planets are their sizes and the materials of which they are made. The inner planets are called **terrestrial planets** because they are like Earth—small, dense, and rocky. The outer planets, except for icy Pluto, are much larger and are made mostly of gases.

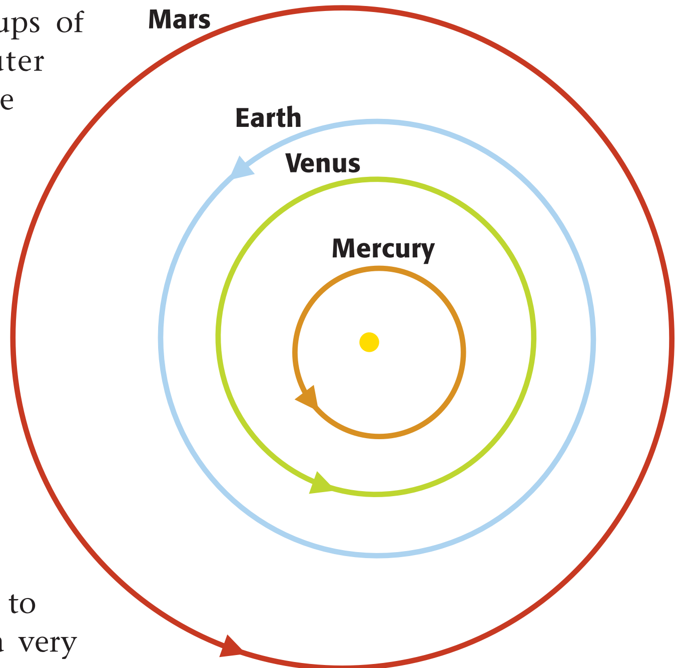
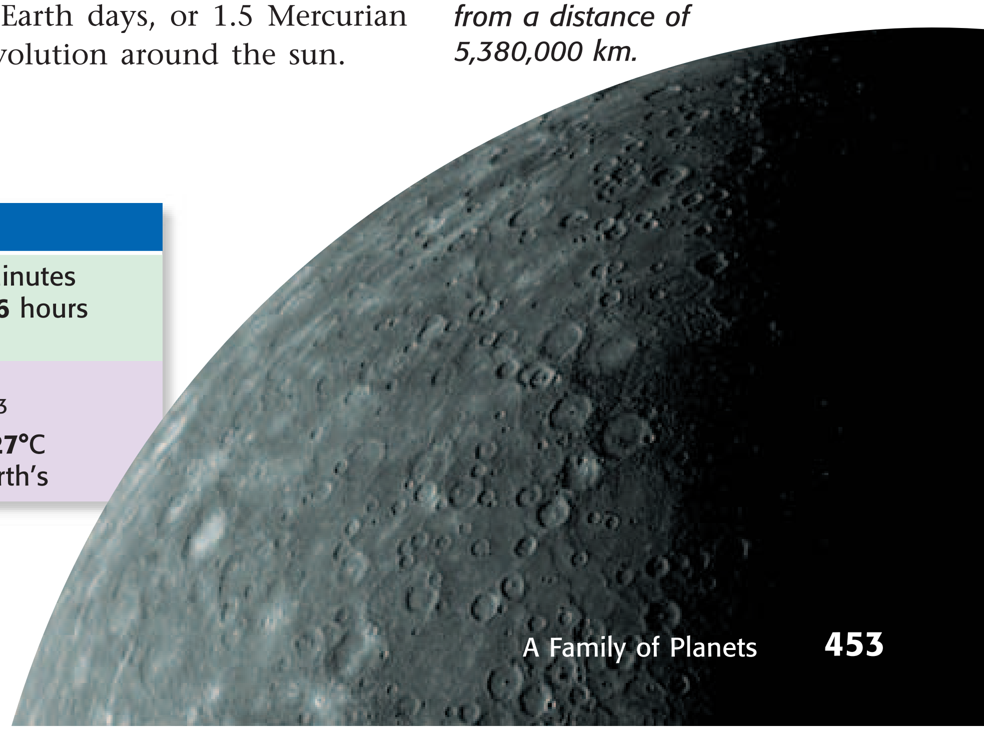


Figure 3 *The lines show orbits of the inner planets. The arrows indicate the direction of motion and the location of each planet on January 1, 2005.*

Mercury—Closest to the Sun If you were to visit the planet Mercury, you would find a very strange world. For one thing, on Mercury you would weigh only 38 percent of what you weigh on Earth. The weight you experience on Earth is due to *surface gravity,* which is less on less massive planets. Also, a day on Mercury would be quite different from a day on Earth. A day on Mercury is almost 59 Earth days long! This is because Mercury spins on its axis much more slowly than Earth does. The spin of an object in space is called *rotation.* The amount of time it takes for an object to rotate once is called its *period of rotation.*

Another curious thing about Mercury is that its year is only 88 Earth days long. As you know, a year is the time it takes for a planet to go around the sun once. The motion of a body as it *orbits* another body in space is called *revolution.* The time it takes for an object to revolve around the sun once is called its *period of revolution.* Every 88 Earth days, or 1.5 Mercurian days, Mercury completes one revolution around the sun.

Figure 4 *This image of Mercury was put together from a series of pictures taken by the* Mariner 10 *spacecraft on March 24, 1974, from a distance of 5,380,000 km.*



Mercury Statistics	
Distance from sun	**3.2** light-minutes
Period of rotation	**58** days, **16** hours
Period of revolution	**88** days
Diameter	**4,878** km
Density	**5.43** g/cm^3
Surface temperature	**−173** to **427**°C
Surface gravity	**38%** of Earth's

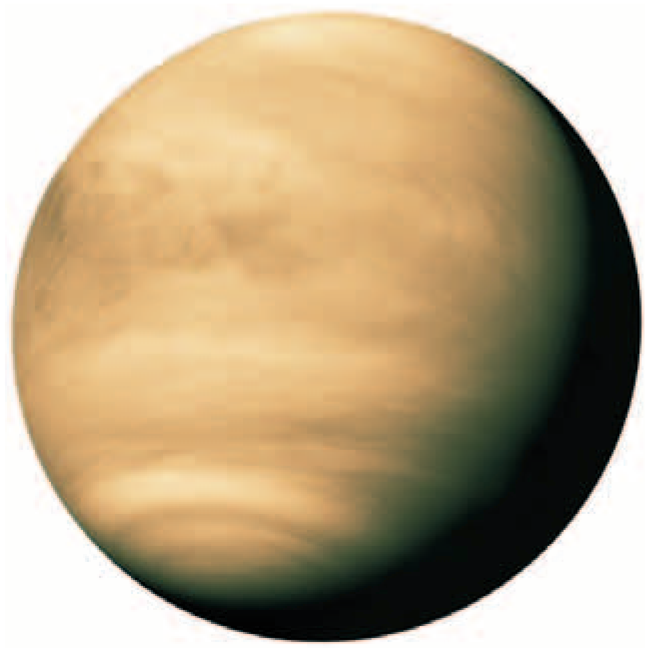
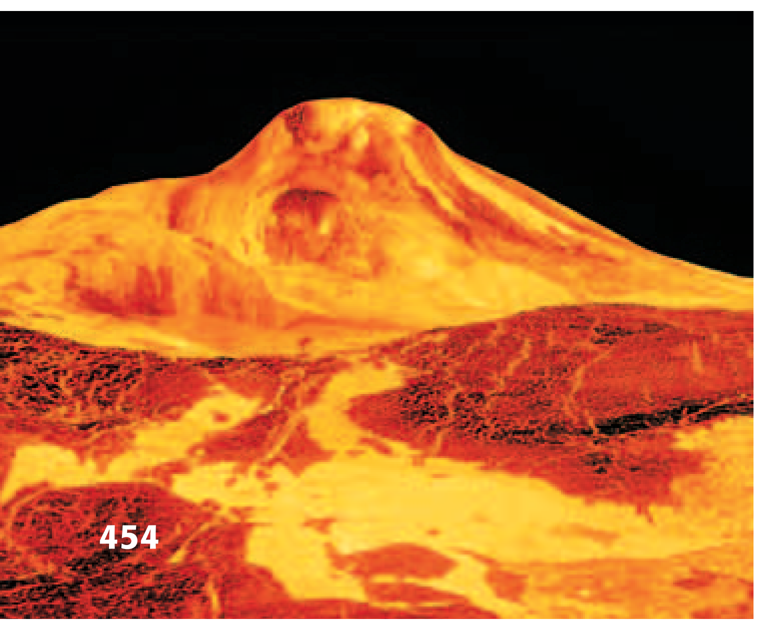


Figure 5 *This image of Venus was made from a series of images taken by* Mariner 10 *on February 5, 1974. The uppermost layer of clouds that blankets the planet consists of sulfuric acid.*

Figure 6 *This false-color, three-dimensional image of the volcano Maat Mons, on the surface of Venus, was made with radar data gathered by the* Magellan *spacecraft. Bright areas indicate massive lava flows.*



Venus Statistics	
Distance from sun	**6.0** light-minutes
Period of rotation	**243** days, (R)*
Period of revolution	**224** days, **17** hours
Diameter	**12,104** km
Density	**5.24** g/cm^3
Surface temperature	**464**°C
Surface gravity	**91**% of Earth's

*R = retrograde rotation

Venus—Earth's Twin? In many ways Venus is more similar to Earth than is any other planet—they have about the same size, mass, and density. But in other ways Venus is very different from Earth. Unlike on Earth, on Venus the sun rises in the west and sets in the east. This is because Venus rotates in the opposite direction that Earth rotates. Earth is said to have **prograde rotation,** because when viewed from above its north pole, Earth appears to spin in a *counterclockwise* direction. If a planet spins in a *clockwise* direction, it is said to have **retrograde rotation.** Venus also rotates much more slowly than Earth. As you can see in the table above, on Venus, a day is longer than an entire year!

At 90 times the pressure of Earth's atmosphere, the atmosphere of Venus is the densest of the terrestrial planets. It consists mostly of carbon dioxide, but it also contains some of the most corrosive acids known. The carbon dioxide in the atmosphere traps heat from sunlight in a process known as the *greenhouse effect.* This is why the surface temperature is so high. With an average temperature of 464°C, Venus has the hottest surface of any planet in the solar system. Because of the extreme pressure, heat, and acidity, even the hardiest of the former Soviet Union's Venera landers lasted little more than 2 hours on the surface!

Between 1990 and 1992, the *Magellan* spacecraft mapped the surface of Venus by using radar waves. The radar waves traveled through the clouds and bounced off the planet's surface. The radar image in **Figure 6** shows that, like Earth, Venus has an active surface.

Earth—An Oasis in Space As viewed from space, Earth is like a sparkling blue oasis suspended in a black sea. Constantly changing weather patterns create the swirls of clouds that blanket the blue and brown sphere we call home. Why did Earth have such good fortune while its two nearest neighbors, Venus and Mars, are unsuitable for life?

Earth is fortunate enough to have formed at just the right distance from the sun. The temperatures are warm enough to prevent most of its water from freezing but cool enough to keep it from boiling away. Liquid water was the key to the development of life on Earth. Water provides a means for much of the chemistry that living things depend on for survival.

You might think the only goal of space exploration is to get away from Earth, but NASA has a program to study Earth using satellites—just as we study other planets. The goal of this project, called the Earth Science Enterprise, is to study the Earth as a system and to determine the effects humans have in changing the global environment. For example, because humans can affect the global environment, does this mean that we can create conditions that would result in Earth's becoming more like Venus or Mars? By studying Earth from space, we hope to understand how different parts of the global system—such as weather, climate, and pollution—interact.

Figure 7 *Earth is the only planet we know of that supports life.*

Figure 8 *This image of Earth was taken on December 7, 1972, by the crew of the* Apollo 17 *spacecraft on the way to the moon. The photograph shows the African and Antarctic continents as well as the Atlantic and Indian Oceans.*

Earth Statistics	
Distance from sun	8.3 light-minutes
Period of rotation	23 hours, 56 minutes
Period of revolution	365 days, 6 hours
Diameter	12,756 km
Density	5.52 g/cm^3
Surface temperature	−13 to 37°C
Surface gravity	100% of Earth's

Mars Statistics	
Distance from sun	**12.7** light-minutes
Period of rotation	**24** hours, **37** minutes
Period of revolution	**1** year, **322** days
Diameter	**6,794** km
Density	**3.93** g/cm^3
Surface temperature	**–123** to **37°C**
Surface gravity	**38%** of Earth's

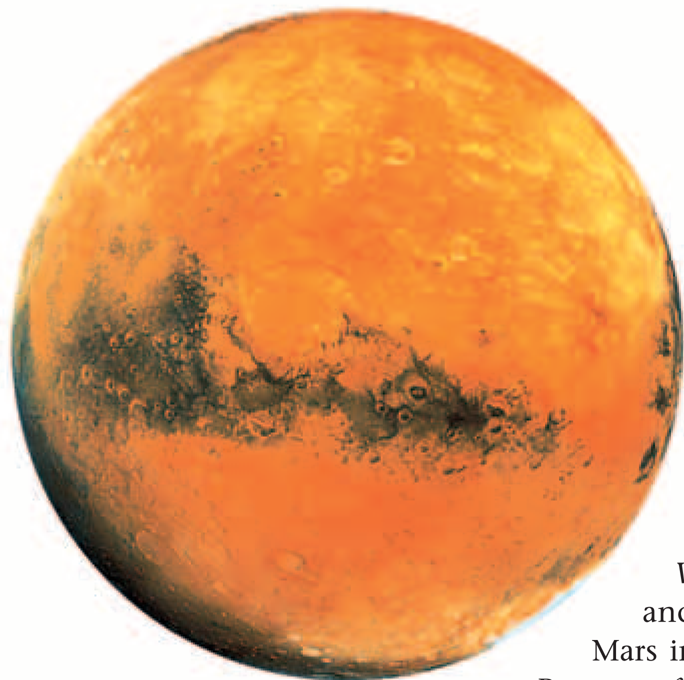


Figure 9 *This* Viking *orbiter image of Mars was made from a series of images. The large circular feature in the center is the impact crater Schiaparelli, with a diameter of 450 km. The southern icecap is just visible at the lower right part of the image.*

Mars—The Red Planet Other than Earth, Mars is perhaps the most studied planet in the solar system. Images from ground-based telescopes and space probes indicate that the surface of Mars has a rich geologic history. Much of our knowledge of Mars has come from information gathered by the *Viking 1* and *Viking 2* spacecraft that landed on Mars in 1976 and from the *Pathfinder* spacecraft that landed on Mars in 1997.

Because of its thin atmosphere and its great distance from the sun, Mars is a cold planet. Mid-summer temperatures recorded by the *Pathfinder* lander ranged from –13°C to –77°C. The atmosphere of Mars is so thin that the air pressure at the planet's surface is roughly equal to the pressure 30 km above Earth's surface—about three times higher than most planes fly. The pressure of Mars's thin atmosphere is so low that any liquid water would quickly boil away. The only water you'll find on Mars is in the form of ice.

Even though liquid water cannot exist on Mars's surface today, there is strong evidence that it did exist there in the past! **Figure 10** shows a region on Mars with features that look like dry river beds on Earth. This means that in the past Mars might have been a warmer place with a thicker atmosphere. Where is the water now?

Figure 10 *This* Viking *orbiter image shows a drainage system on Mars formed by running water.*

Mars has two polar icecaps that contain both frozen water and frozen carbon dioxide, but this cannot account for all the water. Looking closely at the walls of some Martian craters, scientists have found that the debris surrounding the craters looks as if it were made by a mud flow rather than by the movement of dry material. Where does this suggest some of the "lost" Martian water went? Many scientists think it is frozen beneath the Martian soil.

Mars has a rich volcanic history. Unlike on Earth, where volcanoes occur in many places, Mars has only two large volcanic systems. The largest, the Tharsis region, stretches 8,000 km across the planet. The largest mountain in the solar system, Olympus Mons, is an extinct shield volcano similar to Mauna Kea, on the island of Hawaii.

How did a small planet like Mars get such enormous volcanoes? The answer may lie in the fact that Mars formed farther from the sun than Earth did. Mars not only is smaller and cooler than Earth but also has a slightly different chemical composition. Those factors may have prevented the Martian crust from moving around as Earth's crust has, so the volcanoes kept building up in the same spots. Images and data sent back by probes like the *Sojourner* rover, shown in **Figure 11,** are helping to explain Mars's mysterious past.

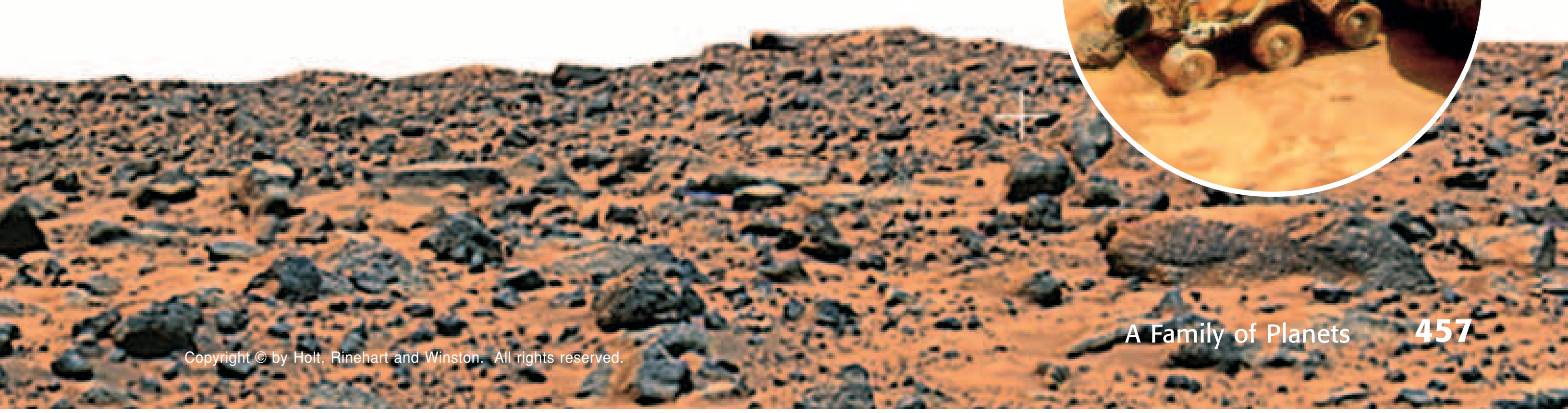
physical science CONNECTION

At sea level on Earth's surface, water boils at 100°C, but if you try to boil water on top of a high mountain, you will find that the boiling point is lower than 100°C. This is because the atmospheric pressure is less at high altitude. The atmospheric pressure on the surface of Mars is so low that liquid water can't exist at all!

REVIEW

1. What three characteristics do the inner planets have in common?
2. List three differences and three similarities between Venus and Earth.
3. **Analyzing Relationships** Mercury is closest to the sun, yet Venus has a higher surface temperature. Explain why this is so.

Figure 11 *The* Sojourner *rover, part of the Pathfinder mission, is shown here creeping up to a rock named Yogi to measure its composition. The dark panel on top of the rover collected the solar energy used to power its motor.*



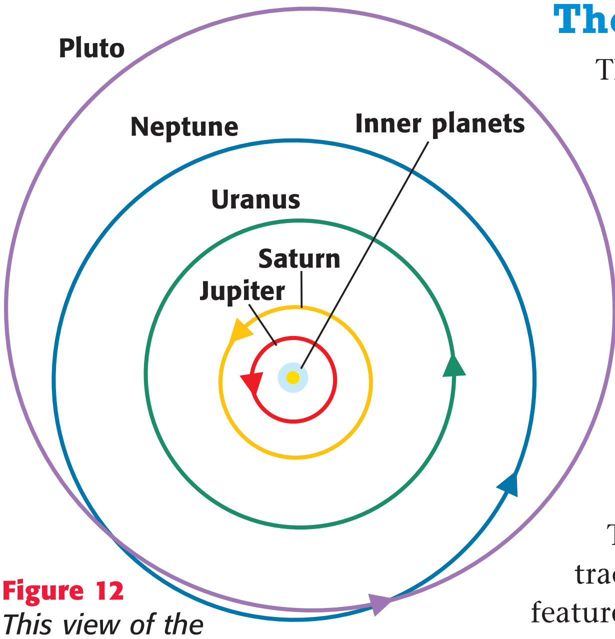


Figure 12 *This view of the solar system shows the orbits and positions of the outer planets on January 1, 2005. The circle in the center represents the region of the inner planets.*

The Outer Planets

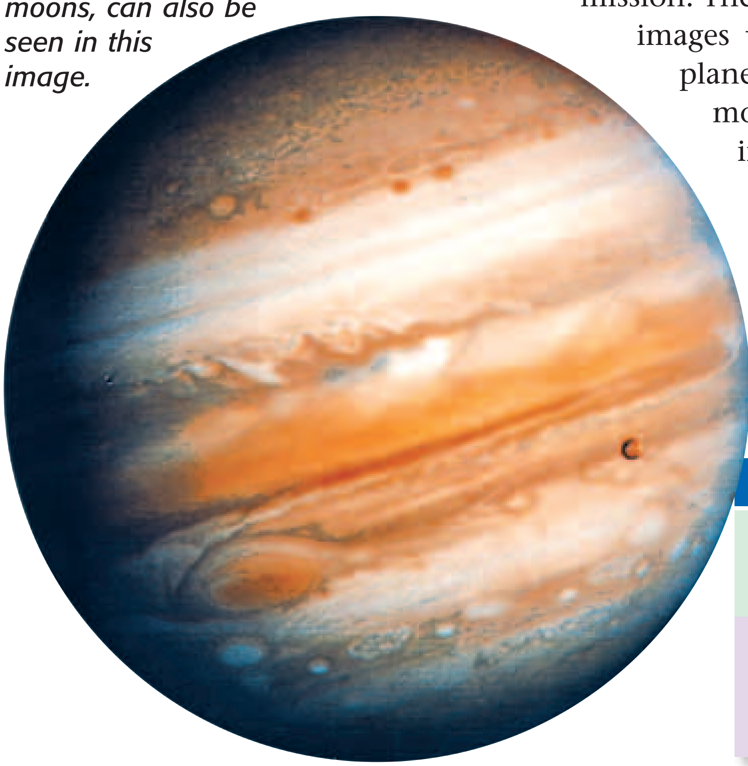
The outer planets differ significantly in composition and size from the inner planets. All of the outer planets, except for Pluto, are gas giants. **Gas giants** are very large planets that don't have any known solid surfaces—their atmospheres blend smoothly into the denser layers of their interiors, very deep beneath the outer layers.

Jupiter—A Giant Among Giants Like the sun, Jupiter is made primarily of hydrogen and helium. The outer part of Jupiter's atmosphere is made of layered clouds of water, methane, and ammonia. The beautiful colors in **Figure 13** are probably due to trace amounts of organic compounds. Another striking feature of Jupiter is the Great Red Spot, which is a long-lasting storm system that has a diameter of about one and a half times that of Earth! At a depth of about 10,000 km, the pressure is high enough to change hydrogen gas into a liquid. Deeper still, the pressure changes the liquid hydrogen into a metallic liquid state.

Unlike most planets, Jupiter radiates much more heat into space than it receives from the sun. This is because heat is continuously transported from Jupiter's interior to its outer atmospheric layers, where it is radiated into space.

There have been five NASA missions to Jupiter—two Pioneer missions, two Voyager missions, and the recent Galileo mission. The *Voyager 1* and *Voyager 2* spacecraft sent back images that revealed a thin faint ring around the planet, as well as the first detailed images of its moons. The *Galileo* spacecraft reached Jupiter in 1995 and released a probe that plunged into Jupiter's atmosphere. The probe sent back data on the atmosphere's composition, temperature, and pressure. The mission found that the relative amounts of hydrogen and helium in Jupiter are very similar to those in the sun.

Figure 13 *This* Voyager 2 *image of Jupiter was taken at a distance of 28.4 million kilometers. Io, one of Jupiter's 16 known moons, can also be seen in this image.*



Jupiter Statistics	
Distance from sun	**43.3** light-minutes
Period of rotation	**9** hours, **50** minutes
Period of revolution	**11** years, **313** days
Diameter	**142,984** km
Density	**1.32** g/cm^3
Temperature	**−153**°C
Gravity	**236%** of Earth's

Saturn Statistics	
Distance from sun	**1.3** light-hours
Period of rotation	**10** hours, **30** minutes
Period of revolution	**29** years, **155** days
Diameter	**120,536** km
Density	**0.69** g/cm^3
Temperature	**−185°**C
Gravity	**92%** of Earth's

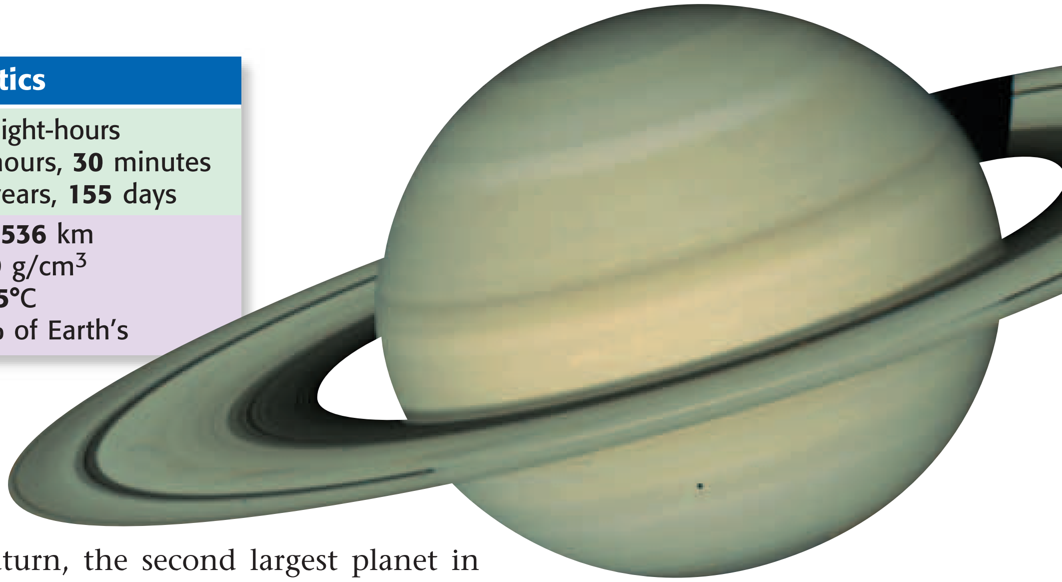


Figure 14 *This* Voyager 2 *image of Saturn was taken from 21 million kilometers away. The dot you see below the rings is the shadow of Tethys, one of Saturn's moons.*

Saturn—Still Forming Saturn, the second largest planet in the solar system, has roughly 764 times the volume of Earth and is 95 times more massive. Its overall composition, like Jupiter's, is mostly hydrogen and helium, with methane, ammonia, and ethane in the upper atmosphere. The colors in the atmosphere are not as brilliant as on Jupiter, and it is harder to see the features. This is because Saturn is colder, and a layer of white ammonia clouds blocks our view. Saturn's interior is probably very similar to that of Jupiter.

Like Jupiter, Saturn gives off a lot more heat than it receives from the sun. Scientists believe that this is because the helium, which is heavier than hydrogen, is raining out of the atmosphere and sinking to the core, releasing heat. In essence, Saturn is still forming!

Although all of the gas giants have rings, Saturn's rings are the largest. Saturn's rings start near the top of Saturn's atmosphere and extend out 136,000 km, yet they are only a few hundred meters thick. The rings consist of icy particles that range in size from a few centimeters to several meters across. **Figure 15** shows a close-up view of Saturn's rings.

The most recent NASA mission to Saturn, called the Cassini mission, was launched in October 1997. The goals of the Cassini mission are to study Saturn's rings, to get close-up images of its moons, and to study its atmosphere.

BRAIN FOOD

More than 300,000 color images of Saturn, its moon Titan, its rings, and its other moons will be sent to Earth during the Cassini mission.

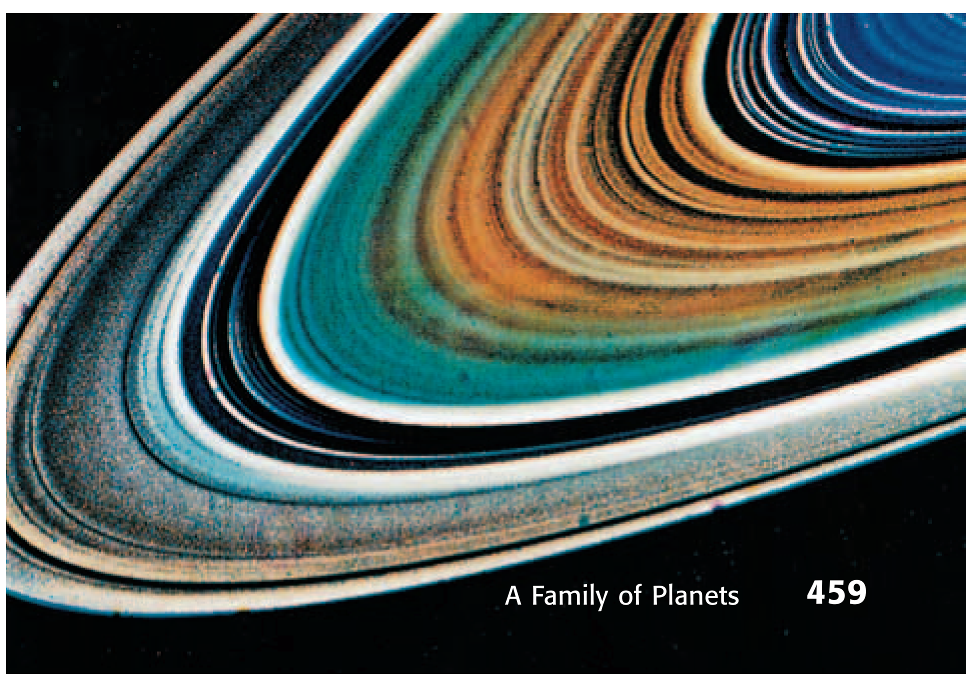


Figure 15 *This false-color image of Saturn's rings was made from data gathered by* Voyager 2 *in 1981. The different colors show differences in the chemical composition of the rings.*

Figure 16 *This image of Uranus was taken by* Voyager 2 *at a distance of 9.1 million kilometers.*

Uranus Statistics	
Distance from sun	**2.7** light-hours
Period of rotation	**17** hours, **14** minutes (R)*
Period of revolution	**83** years, **274** days
Diameter	**51,118** km
Density	**1.32** g/cm^3
Temperature	**–214°**C
Gravity	**89%** of Earth's

*R = retrograde rotation

Uranus—A Giant Impact Uranus (YOOR uh nuhs) has about 63 times the volume of Earth and is nearly 15 times as massive. One especially unusual quality of Uranus is that it is tipped over on its side—the axis of rotation is tilted by almost 90° and lies almost in the plane of its orbit. **Figure 17** shows how far Uranus's axis is inclined. For part of a Uranus year, one pole points toward the sun while the other pole is in darkness. At the other end of Uranus's orbit the poles are reversed.

The moons and the thin rings of Uranus all lie in a disk that is in the same plane as the equator of Uranus. In essence, the orbits of Uranus's moons are all tilted out of the plane of the solar system. Scientists suggest that early in its history, Uranus got hit by a massive object that tipped the planet over.

Uranus, Neptune, and Pluto were not known to ancient people because they were too faint to see with the naked eye. (Actually, if you have good eyesight and you know where to look, you can see Uranus—just barely.) Uranus was discovered by the English amateur astronomer William Herschel in 1781. Viewed through a telescope, Uranus looks like a featureless blue-green disk. The atmosphere is mainly hydrogen and methane gas, which absorbs the red part of sunlight very strongly. Uranus and Neptune are much smaller than Jupiter and Saturn, and yet they have similar densities. This suggests that they have lower percentages of light elements and more water in their interiors.

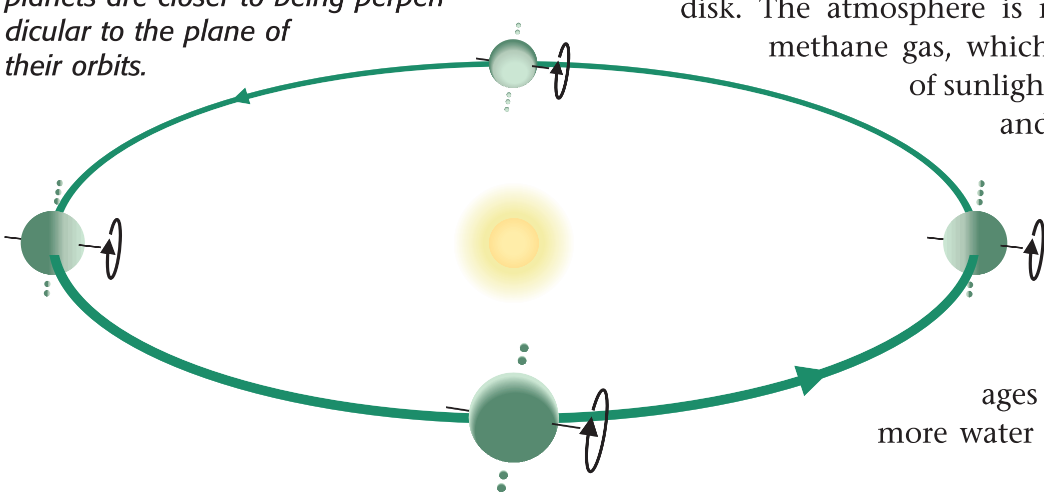
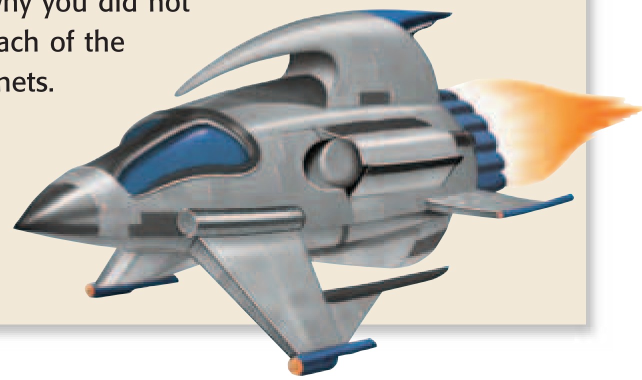


Figure 17 *Uranus's axis of rotation is tilted so that it is nearly parallel to the plane of Uranus's orbit. In contrast, the axes of most other planets are closer to being perpendicular to the plane of their orbits.*

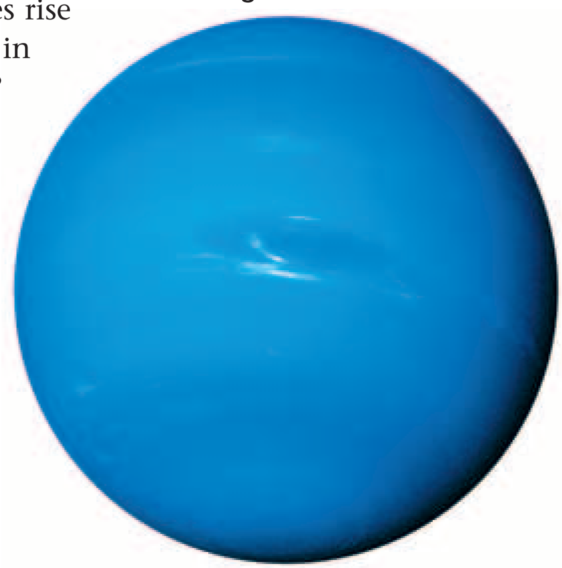
Imagine that it is the year 2120 and you are the pilot of an interplanetary spacecraft on your way to explore Pluto. In the middle of your journey, your navigation system malfunctions, giving you only one chance to land safely. You will not be able to make it to your original destination or back to Earth, so you must choose one of the other planets to land on. Your equipment includes two years' supply of food, water, and air. You will be stranded on the planet you choose until a rescue mission can be launched from Earth. Which planet will you choose to land on? How would your choice of this planet increase your chances of survival? Explain why you did not choose each of the other planets.



Neptune—The Blue World Irregularities in the orbit of Uranus suggested to early astronomers that there must be another planet beyond Uranus whose gravitational force causes Uranus to move off its predicted path. By using the predictions of the new planet's orbit, astronomers discovered the planet Neptune in 1846. Galileo saw Neptune in 1613 while observing Jupiter, but he failed to realize that it was a planet, so the discovery of Neptune did not occur for another 200 years!

The *Voyager 2* spacecraft sent back images that gave us much new information about the nature of Neptune's atmosphere. Although the composition of Neptune's atmosphere is nearly the same as that of Uranus's atmosphere, Neptune's atmosphere contains belts of clouds. At the time of *Voyager 2*'s visit, Neptune had a Great Dark Spot, similar to the Great Red Spot on Jupiter. And like the interiors of Jupiter and Saturn, Neptune's interior releases heat to its outer layers. This helps the warm gases rise and the cool gases sink, setting up the wind patterns in the atmosphere that create the belts of clouds. *Voyager 2* images also revealed that Neptune has a set of very narrow rings.

Figure 18 *This* Voyager 2 *image of Neptune, taken while the spacecraft was more than 7 million kilometers away, shows the Great Dark Spot as well as some bright cloud bands.*



Neptune Statistics	
Distance from sun	**4.2** light-hours
Period of rotation	**16** hours, **7** minutes
Period of revolution	**163** years, **263** days
Diameter	**49,528** km
Density	**1.64** g/cm^3
Temperature	**–225**°C
Gravity	**112%** of Earth's

Figure 19 *This Hubble Space Telescope image is one of the clearest ever taken of Pluto and its moon, Charon.*

Pluto Statistics	
Distance from sun	**5.5** light-hours
Period of rotation	**6** days, **10** hours (R)*
Period of revolution	**248** years
Diameter	**2,390** km
Density	**2.05** g/cm^3
Surface temperature	**–236**°C
Surface gravity	**7%** of Earth's

*R = retrograde rotation

Figure 20 *An artist's view of the sun and Charon from Pluto shows just how little light and heat Pluto receives from the sun.*

Pluto—A Double Planet? Pluto is the farthest planet from the sun. It is also the smallest planet—less than half the size of Mercury. Another reason Pluto is unusual is that its moon, Charon (KER uhn), is more than half its size! In fact, Charon is the largest satellite relative to its planet in the solar system.

From Earth, it is hard to separate the images of Pluto and Charon because they are so far away. **Figure 20** shows just how far away from the sun Pluto and Charon really are—from the surface of Pluto the sun appears to be only a very distant, bright star.

From Pluto's density, we know that it must be made of rock and ice. A very thin atmosphere of methane has been detected. While Pluto is covered by nitrogen ice, Charon is covered by water ice. Pluto is the only planet that has not been visited by a NASA mission, but plans are underway to finally visit this world and its moon in 2010.

Is Pluto Really a Planet?
Pluto is neither a terrestrial planet nor a gas giant, so why do we call it a planet? Turn to page 480 to find out more.

REVIEW

1. How are the gas giants different from the terrestrial planets?
2. What is so unusual about Uranus's axis of rotation?
3. What conclusion can you draw about a planet's properties just by knowing how far it is from the sun?
4. **Applying Concepts** Why is the word *surface* not included in the statistics for the gas giants?

Section 2

Moons

NEW TERMS

satellite
phases
eclipse

OBJECTIVES

- Describe the current theory for the origin of Earth's moon.
- Describe what causes the phases of Earth's moon.
- Explain the difference between a solar eclipse and a lunar eclipse.

Satellites are natural or artificial bodies that revolve around larger bodies like planets. Except for Mercury and Venus, all of the planets have natural satellites called *moons.*

Luna: The Moon of Earth

We know that Earth's moon—also called *Luna*—has a different composition from the Earth because its density is much less than Earth's. This tells us that the moon has a lower percentage of heavy elements than the Earth has. The composition of lunar rocks brought back by Apollo astronauts suggests that the overall composition of the moon is similar to that of the Earth's mantle.

The Surface of the Moon The explorations of the moon's surface by the Apollo astronauts have given us insights about other planets and moons of the solar system. For example, the ages of lunar rocks brought back during the Apollo missions of the 1960s and 1970s were measured using radiometric-dating techniques. The oldest lunar rocks were found to be about 4.6 billion years old. Because these rocks have hardly changed since they formed, we know the solar system itself is about 4.6 billion years old.

In addition, we know that the surfaces of bodies that have no atmospheres preserve a record of almost all the impacts they have had with other objects. As shown in **Figure 22,** the moon's history is written on its face! Because we now know the age of the moon, we can count the number of impact craters on the moon and use that number to calculate the rate of cratering that has occurred since the birth of our solar system. By knowing the rate of cratering, scientists are able to use the number of craters on the surface of any body to estimate how old its surface is—without having to bring back rock samples!

Figure 21 Apollo 17 *astronaut Harrison Schmidt—the first geologist to walk on the moon—samples the lunar soil.*

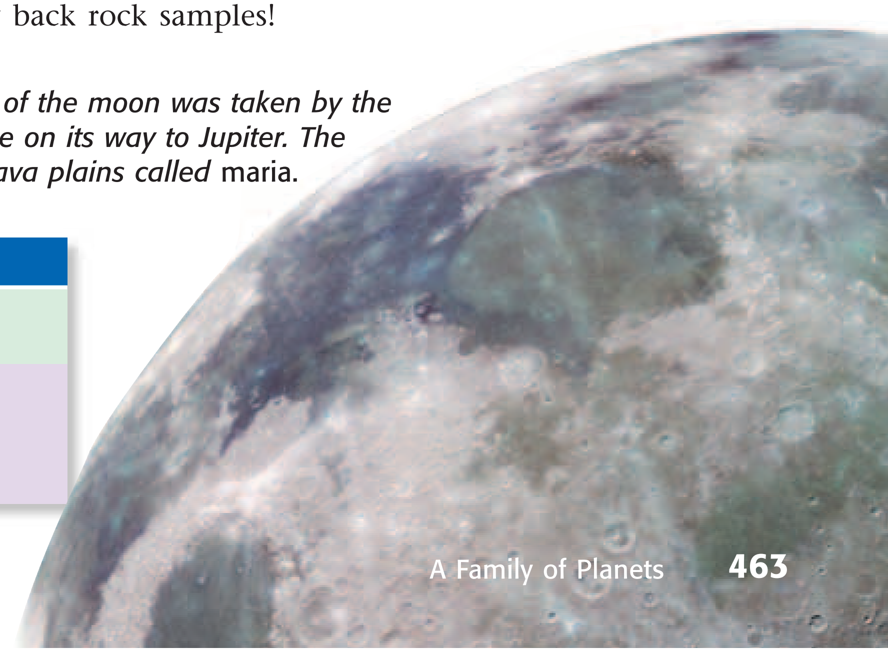


Figure 22 *This image of the moon was taken by the* Galileo *spacecraft while on its way to Jupiter. The large dark areas are lava plains called* maria.

Moon Statistics	
Period of rotation	**27** days, **8** hours
Period of revolution	**27** days, **8** hours
Diameter	**3,476** km
Density	**3.34** g/cm^3
Surface temperature	**−170** to **134**°C
Surface gravity	**17%** of Earth's

physics CONNECTION

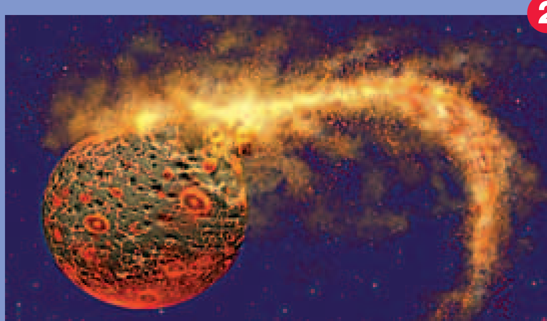
Did you know that the moon is falling? It's true. Because of gravity, every object in orbit around Earth is falling toward the planet. But the moon is also moving forward at the same time it is falling. In fact, it is the Earth's gravity that keeps the moon from flying off in a straight line. The combination of the moon's forward motion and its falling motion results in the moon's curved orbit around Earth.

Lunar Origins Before rock samples from the Apollo missions confirmed the composition of the moon, there were three popular explanations for the formation of the moon: (1) it was a separate body captured by Earth's gravity, (2) it formed at the same time and from the same materials as the Earth, and (3) the newly formed Earth was spinning so fast that a piece flew off and became the moon. Each idea had problems. If the moon were captured by Earth's gravity, it would have a completely different composition from that of Earth, which is not the case. On the other hand, if the moon formed at the same time as the Earth or as a spin off of the Earth, the moon would have exactly the same composition as Earth, which it doesn't.

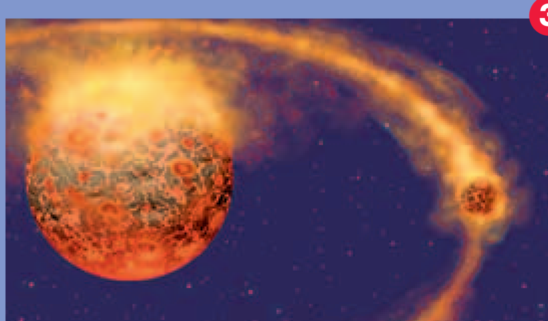
The current theory is that a large, Mars-sized object collided with Earth while the Earth was still forming. The collision was so violent that part of the Earth's mantle was blasted into orbit around Earth. Once in orbit, part of the Earth's mantle material and debris from the impacting body eventually joined

Formation of the Moon

1 Impact
About 4.6 billion years ago, when Earth was still mostly molten, a large body collided with Earth. Scientists reason that the object must have been large enough to blast part of Earth's mantle into space, because the composition of the moon is similar to Earth's mantle.



2 Ejection
The resulting debris began to revolve around the Earth within a few hours of the impact. This debris consisted of mantle material from Earth and the impacting body as well as part of the iron core of the impacting body.



3 Formation
Soon after the giant impact, the clumps of material ejected into orbit around Earth began to join together to form the moon. Much later, as the moon cooled, additional impacts created deep basins and fractured the moon's surface. Lunar lava flowed from those cracks and flooded the basins to form the lunar maria we see today.

to form the moon. The moon would then be a combination of Earth's mantle and the impacting body. This theory is consistent with the composition of the lunar rocks brought back by the Apollo missions and is generally accepted today.

The moon's appearance changes every night, To find out how this occurs, turn to page 591 in your LabBook.

Phases of the Moon From Earth, one of the most noticeable aspects of the moon is its continually changing appearance. Within a month, its Earthward face changes from a fully lit circle to a thin crescent and then back to a circle. These different appearances of the moon result from its changing position with respect to the Earth and the sun. As the moon revolves around the Earth, the amount of sunlight on the side of the moon that faces the Earth changes. The different appearances of the moon due to its changing position are called **phases.** The phases of the moon are shown in **Figure 23.**

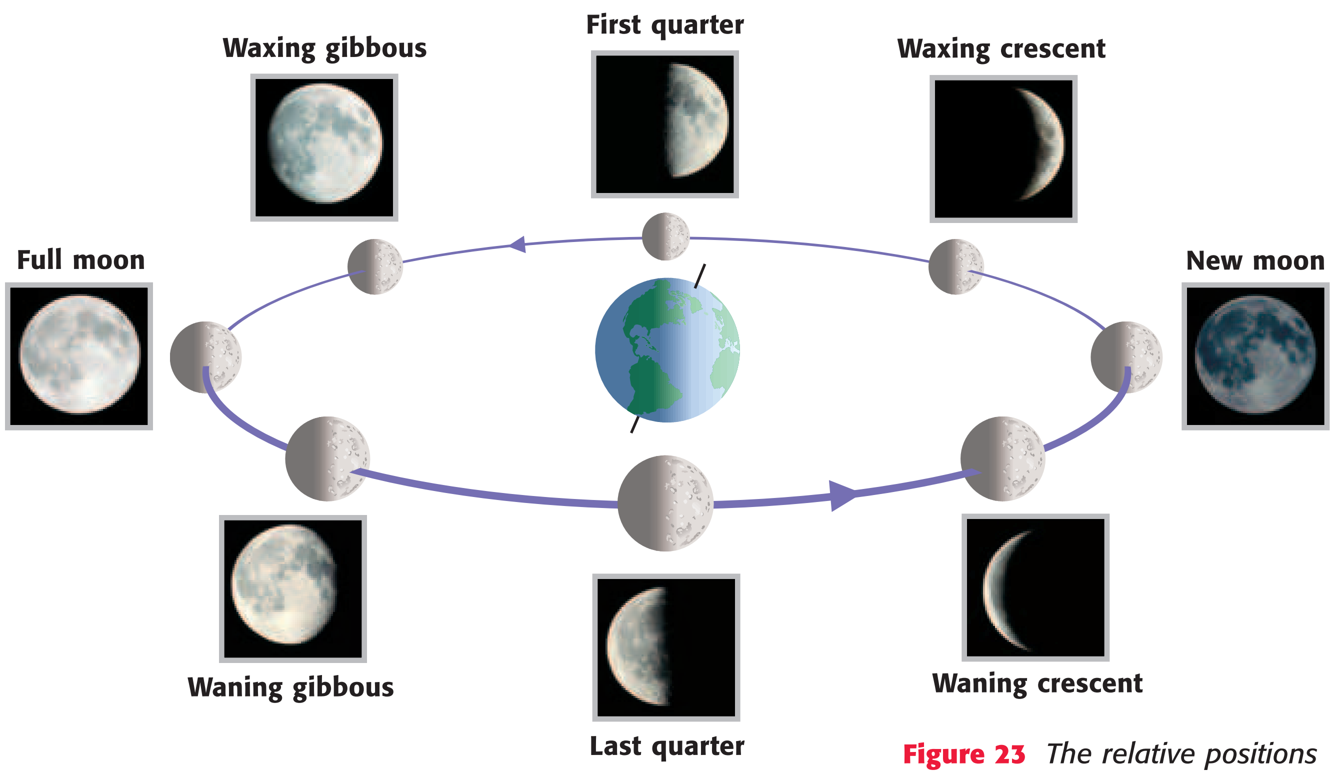


Figure 23 *The relative positions of the moon, sun, and Earth determine which phase the moon is in. The photo insets show how the moon looks from Earth at each phase.*

When the moon is waxing, it means that the sunlit fraction we can see from Earth is getting larger. When it is waning, the sunlit fraction is getting smaller. Notice in Figure 23 that even as the phases of the moon change, the total amount of sunlight the moon gets remains the same. Half the moon is always in sunlight, just as half the Earth is always in sunlight. But because the period of rotation for the moon is the same as its period of revolution, on Earth we always see the same side of the moon. If you lived on the far side of the moon, you would see the sun for half of each lunar day, but you would never see the Earth!

QuickLab

Clever Insight

Pythagoras (540–510 B.C.) and Aristotle (384–322 B.C.) used observations of lunar eclipses and a little logic to figure out that Earth is a sphere. Can you?

1. Cut out a circle of **heavy white paper.** This will represent Earth.
2. Find **two spherical objects** and several other **objects** with different shapes.
3. Hold each object up in front of a **lamp** (representing the sun) so that its shadow falls on the white paper circle.
4. Rotate your objects in all directions, and record the shapes of the shadows they make.
5. Which objects always cast a curved shadow?

NEVER look directly at the sun! You can permanently damage your eyes.

Eclipses An **eclipse** occurs when the shadow of one celestial body falls on another. A *lunar eclipse* happens when the Earth comes between the sun and the moon, and the shadow of the Earth falls on the moon. A *solar eclipse* happens when the moon comes between the Earth and the sun, and the shadow of the moon falls on part of Earth.

By a remarkable coincidence, the moon in the sky appears to be nearly the same size as the sun. Even though the moon is much smaller than the sun, it appears to be the same size because it is so much closer. So during a solar eclipse, the disk of the moon almost always covers the disk of the sun. However, because the moon's orbit is not completely circular, sometimes the moon is farther away from the Earth, and a thin ring of sunlight shows around the outer edge of the moon. This type of solar eclipse is called an *annular eclipse*. **Figure 24** illustrates the position of the Earth and the moon during a solar eclipse.

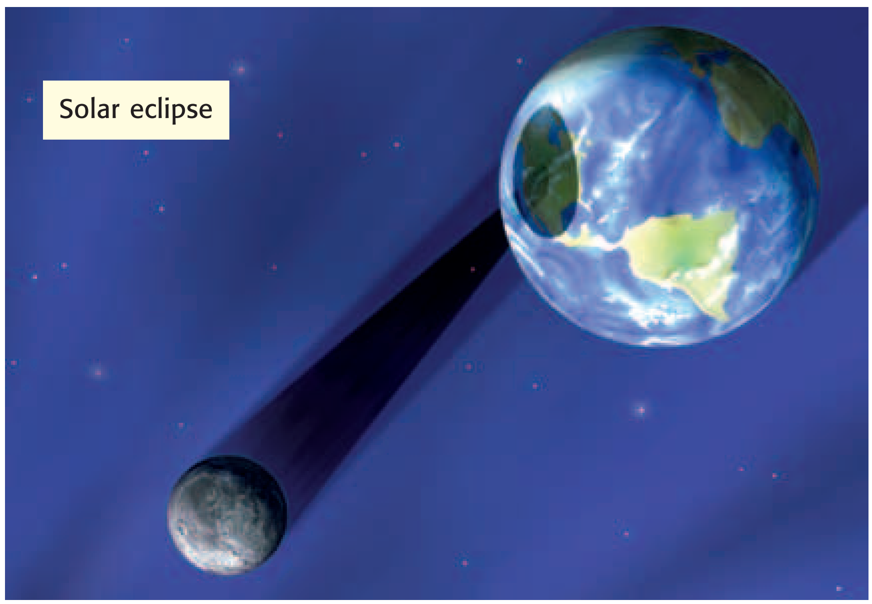


Figure 24 *Because the shadow of the moon on Earth is small, a solar eclipse can be viewed from only a few locations.*

Figure 25 *This is an image of the sun's corona during the February 26, 1998, eclipse in the Caribbean. The solar corona is visible only when the entire disk of the sun is blocked by the moon.*

As you can see in **Figure 26,** the view during a lunar eclipse is also spectacular. During the hours of a total lunar eclipse, the moon often appears to turn a deep red color. Earth's atmosphere acts like a lens and bends some of the sunlight into the Earth's shadow, and the interaction of the sunlight with the molecules in the atmosphere filters out the blue light. With the blue part of the light removed, most of the remaining light that illuminates the moon is red.

Figure 26 *Because of atmospheric effects on Earth, the moon can have a reddish color during a lunar eclipse.*

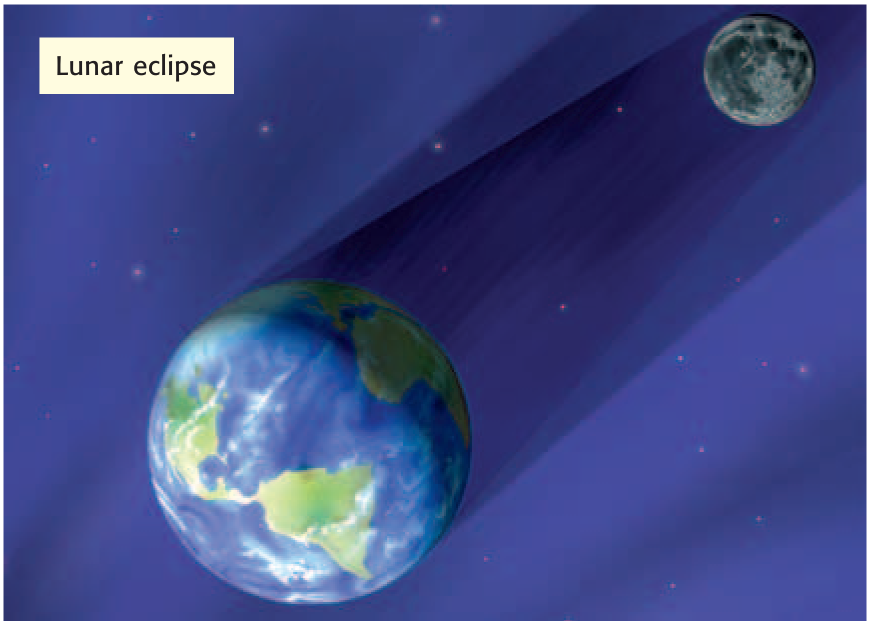


Figure 27 *During a lunar eclipse, the moon passes within the Earth's shadow.*

From our discussion of the moon's phases, you might now be asking the question, "Why don't we see solar and lunar eclipses every month?" The answer is that the moon's orbit around the Earth is tilted—by about 5°—with respect to the orbit of the Earth around the sun. This tilt of the moon's orbit is enough to place the moon out of Earth's shadow for most full moons and the Earth out of the moon's shadow for most new moons.

REVIEW

1. What evidence suggests that Earth's moon formed from a giant impact?
2. Why do we always see the same side of the moon?
3. How are lunar eclipses different from solar eclipses?
4. **Analyzing Methods** How does knowing the age of a lunar rock help astronomers estimate the age of the surface of a planet like Mercury?

MATH BREAK

Orbits Within Orbits

The average distance between the Earth and the moon is about 384,400 km. As you have read, the average distance between the Earth and the sun is 1 AU, or about 150,000,000 km. Assume that the orbit of the Earth around the sun and the orbit of the moon around the Earth are perfectly circular. Using the distances given above, calculate the maximum and minimum distances between the moon and the sun.

The Moons of Other Planets

The moons of the other planets range in size from very small to as large as terrestrial planets. All of the gas giants have multiple moons, and scientists are still discovering new moons. Some moons have very elongated, or elliptical, orbits, and some even revolve around their planet backward! Many of the very small moons may be captured asteroids. As we are learning from recent space missions, moons can be some of the most bizarre and interesting places in the solar system!

Figure 28 *Above is Mars's largest moon, Phobos, which is 28 km long. At right is the smaller moon, Deimos, which is 16 km long.*

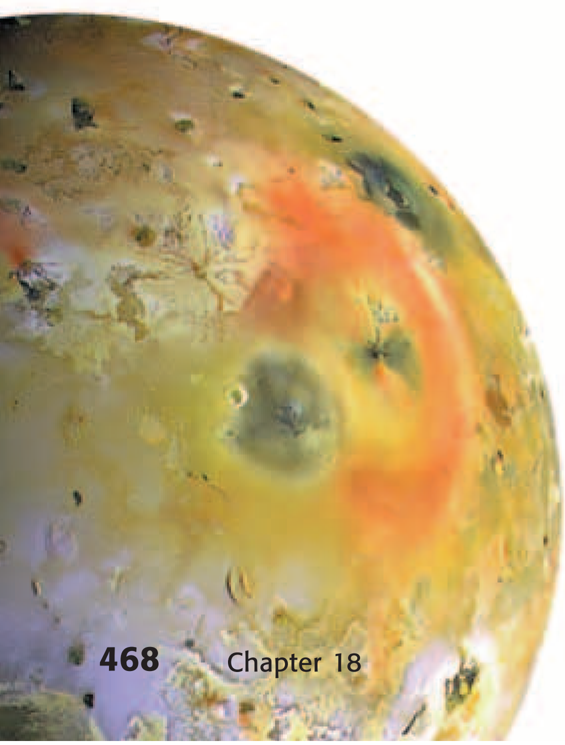
The Moons of Mars Mars's two moons, Phobos and Deimos, are both small satellites that have irregular shapes. The two moons have very dark surfaces that reflect even less light than asphalt does. The surface materials are very similar to those found in asteroids, and scientists speculate that these two moons are probably captured asteroids.

Could you possibly live on Io? To find out how a person could learn to adapt to this harsh environment, turn to page 481.

The Moons of Jupiter Jupiter has a total of 17 known moons. The four largest—Ganymede, Callisto, Io, and Europa—were discovered in 1610 by Galileo and are known as the Galilean satellites. The largest moon, Ganymede, is even larger than the planet Mercury! The Galilean satellites are accompanied by at least 12 smaller satellites. These satellites are probably captured asteroids.

Moving outward from Jupiter, the first Galilean satellite is Io (IE oh), a truly bizarre world. Io is caught in a gravitational tug of war between Jupiter and Io's nearest neighbor, the moon Europa. This constant tugging stretches Io a little, causing it to heat up. Because of this, Io is the most volcanically active body in the solar system!

Recent pictures of the moon Europa support the idea that liquid water may lie beneath the moon's icy surface. This has many scientists wondering if life could have evolved in the subterranean oceans of Europa.



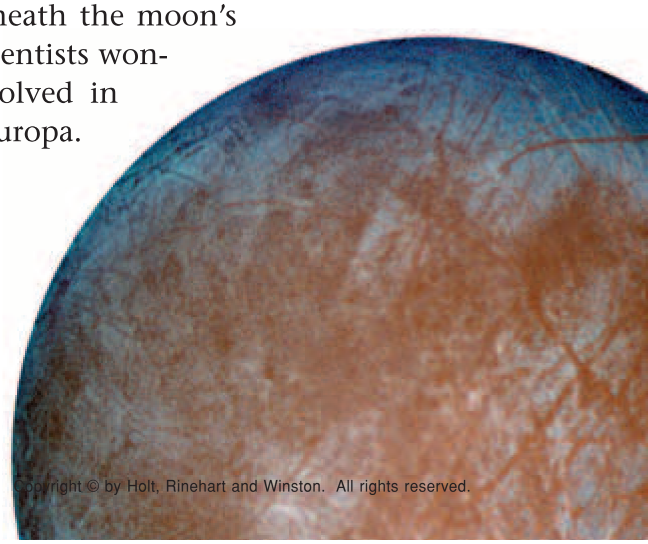


Figure 29 *At left is a* Galileo *image of Jupiter's innermost moon, Io. At right is a* Galileo *image of Jupiter's fourth largest moon, Europa.*

The Moons of Saturn Saturn has a total of 22 known moons. Most of these moons are small bodies made mostly of water ice with some rocky material. The largest satellite, Titan, was discovered in 1655 by Christiaan Huygens. In 1980, the *Voyager 1* spacecraft flew past Titan and discovered a hazy orange atmosphere, similar to what Earth's atmosphere may have been like before life began to evolve. In 1997, NASA launched the *Cassini* spacecraft to study Saturn and its moons, including Titan. The Cassini mission includes a probe, called the *Huygens* probe, that will parachute through Titan's thick atmosphere and land on its frozen surface. By studying the "primordial soup" of hydrocarbons on Titan, scientists hope to answer some of the questions about how life began on Earth.

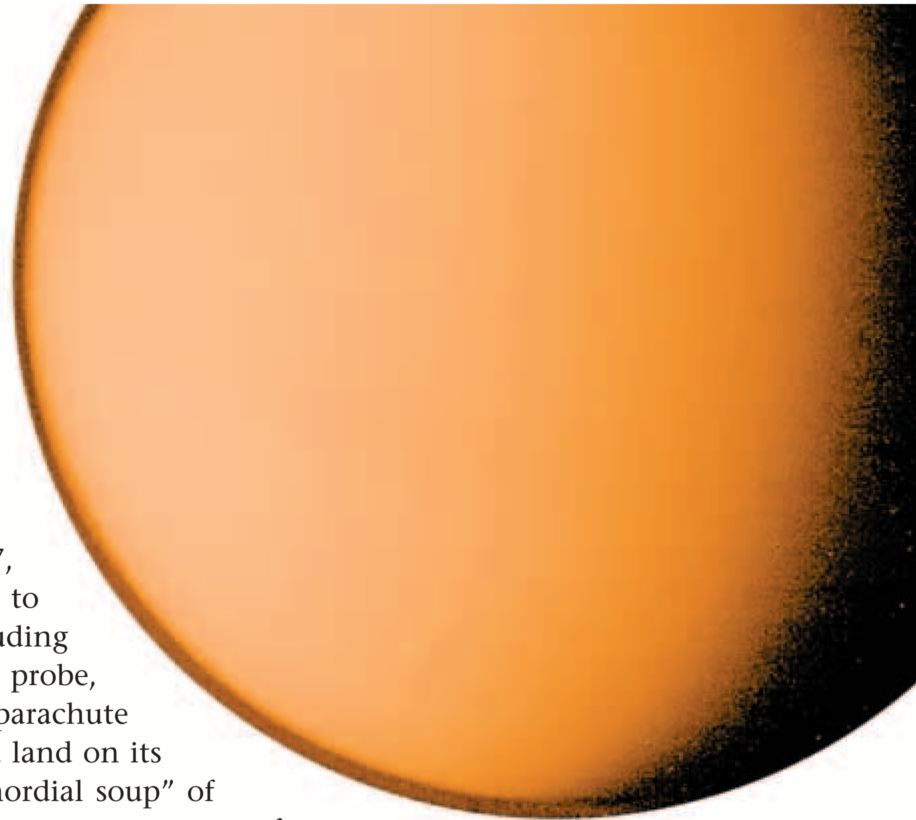


Figure 30 *Titan is one of only two moons that have a thick atmosphere—in fact, its atmosphere is thicker than Earth's! This hazy orange atmosphere is made of nitrogen plus several other gases, such as methane.*

Self-Check

What is one major difference between Titan and the early Earth that would suggest that there probably isn't life on Titan right now? *(See page 596 to check your answer.)*

The Moons of Uranus Uranus has 21 moons, three of which were just discovered by ground-based telescopes during the summer of 1999. Like the moons of Saturn, the four largest moons are made of ice and rock and are heavily cratered. The little moon Miranda, shown in **Figure 31,** has some of the most unusual features in the solar system. Miranda's surface includes smooth, cratered plains as well as regions with grooves and cliffs up to 20 km high. Current ideas suggest that Miranda may have been hit and broken apart in the past but was able to come together again, leaving a patchwork surface.

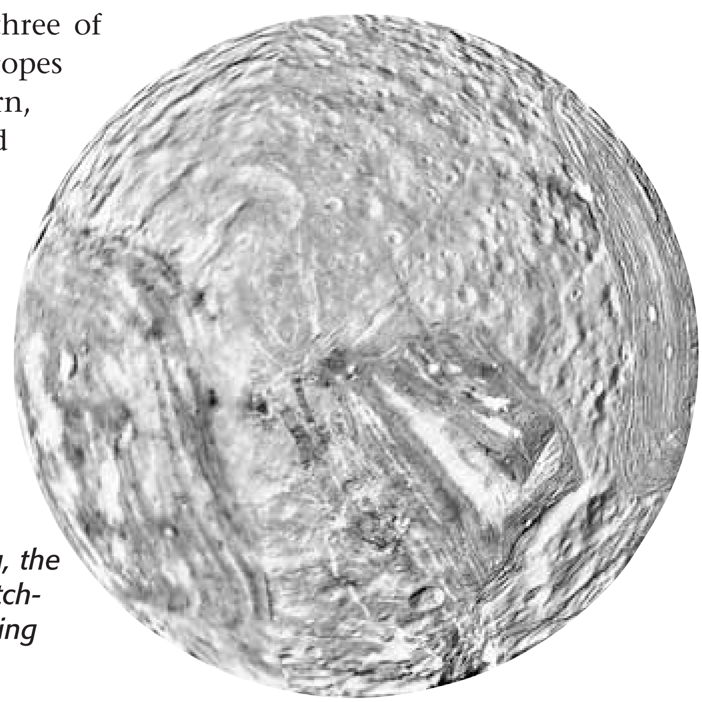
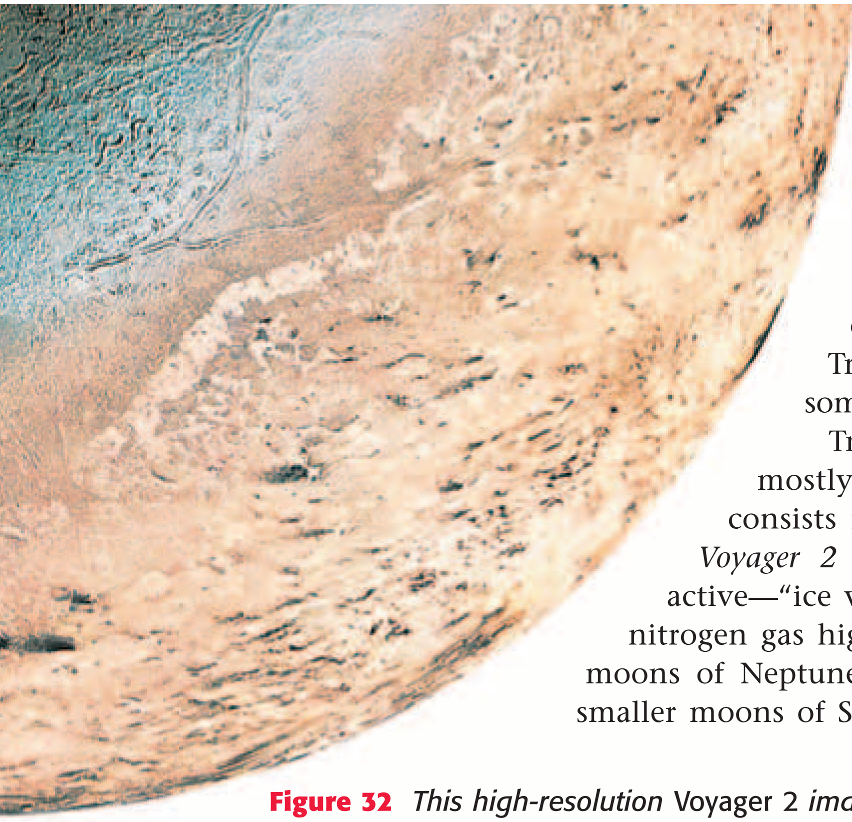


Figure 31 *This* Voyager 2 *image shows Miranda, the most unusual moon of Uranus. Miranda is a patchwork of several different types of terrain, indicating that this small moon has a violent history.*



The Moons of Neptune Neptune has eight moons, only one of which is large. This moon, Triton, revolves around the planet in a *retrograde,* or "backward," orbit, suggesting that it may have been captured by Neptune's gravity. Because of Triton's unusual orbital properties, its poles sometimes point directly toward the sun.

Triton has a very thin atmosphere made mostly of nitrogen gas. The surface of Triton consists mainly of frozen nitrogen and methane. *Voyager 2* images revealed that it is geologically active—"ice volcanoes," or geysers, were seen ejecting nitrogen gas high into the atmosphere. The other seven moons of Neptune are small, rocky worlds much like the smaller moons of Saturn and Jupiter.

Figure 32 *This high-resolution* Voyager 2 *image shows Neptune's largest moon, Triton. The polar icecap currently facing the sun may have a slowly evaporating layer of nitrogen ice, adding to Triton's thin atmosphere.*

The Moon of Pluto Pluto's only moon, Charon, was discovered in 1978. Charon's period of revolution is the same as Pluto's period of rotation—about 6.4 days. This means that one side of Pluto always faces Charon. In other words, if you stood on the surface of Pluto, Charon would always occupy the same place in the sky. Imagine Earth's moon staying in the same place every night! Because Charon's orbit around Pluto is tilted with respect to Pluto's orbit around the sun, as seen from Earth, Pluto is sometimes eclipsed by Charon. But don't hold your breath; this happens only once every 120 years!

environmental science CONNECTION

While scientists continue to gather data to determine whether global warming is happening on Earth, an MIT researcher has discovered that this process is actually occurring on Neptune's largest moon, Triton. Triton is entering an unusually warm summer in which its southern polar icecap is receiving more direct sunlight than usual. This extra sunlight causes some of the ice to vaporize and become part of Triton's atmosphere. The thicker its atmosphere, the warmer Triton gets. Scientists say that the surface temperature of Triton has risen by about 5 percent in the last 10 years.

REVIEW

1. What makes Io the most volcanically active body in the solar system?
2. Why is Saturn's moon Titan of so much interest to scientists studying the origins of life on Earth?
3. What two properties of Neptune's moon Triton make it unusual?
4. **Identifying Relationships** Charon always stays in the same place in Pluto's sky, but the moon always moves across Earth's sky. What causes this difference?

Section 3

Small Bodies in the Solar System

NEW TERMS

comet
perihelion
aphelion
asteroid
asteroid belt
meteoroid
meteorite
meteor

OBJECTIVES

- Explain why comets, asteroids, and meteoroids are important to the study of the formation of the solar system.
- Compare the different types of asteroids with the different types of meteoroids.
- Describe the risks to life on Earth from cosmic impacts.

In addition to planets and moons, the solar system contains many other types of objects, including comets, asteroids, and meteoroids. Some of these relatively small objects have orbits that bring them very close to Earth as they revolve around the sun. As you will see, these objects play an important role in the study of the origins of the solar system.

Comets

A **comet** is a small body of ice, rock, and cosmic dust loosely packed together. Because of their composition, some scientists refer to comets as "dirty snowballs." Unlike the planets, comets are very small and originate from the cold, outer solar system. Nothing much has happened to them since the birth of the solar system some 4.6 billion years ago. Comets are probably the leftovers from the process of planet formation. Each comet is a sample of the early solar system. Scientists want to learn more about comets in order to piece together the chemical and physical history of the solar system.

When a comet passes close enough to the sun, solar radiation heats the water ice so that the comet gives off gas and dust in the form of a long tail, as shown in **Figure 33.** As the gases flow away from the comet they can cause the cosmic dust to escape into space too. Sometimes this process can give a comet two tails—an *ion tail* and a *dust tail*. The ion tail consists of electrically charged particles that are blown directly away from the sun by the solar wind, which also consists of charged particles. The solid center of a comet is called its *nucleus*. Comet nuclei can range in size from less than half a kilometer to more than 100 km in diameter. **Figure 34** shows the different features a comet may have when it passes close to the sun.

Figure 33 *Comet Hale-Bopp appeared in North American skies in the spring of 1997.*

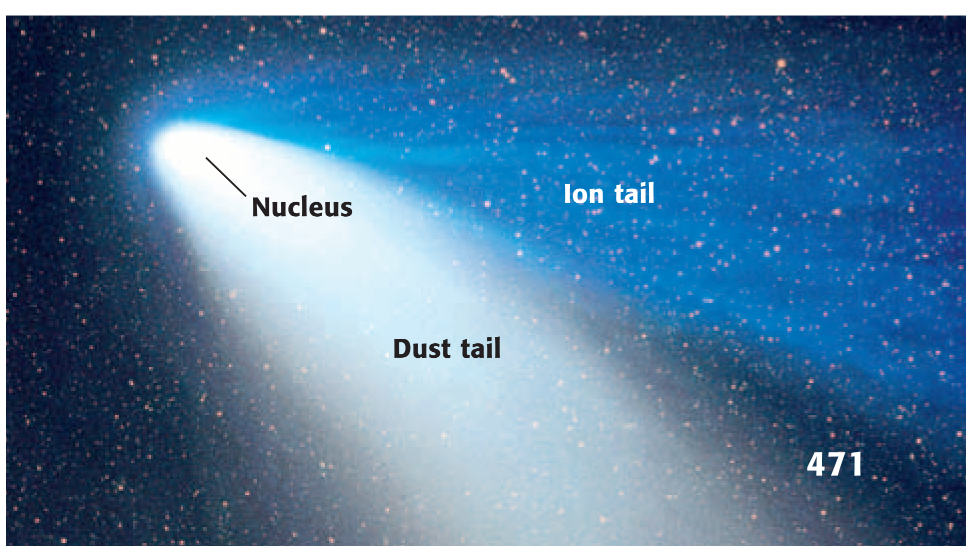


Figure 34 *The image at right shows the physical features of a comet when it is close to the sun. The nucleus of a comet is hidden by brightly lit gases and dust.*

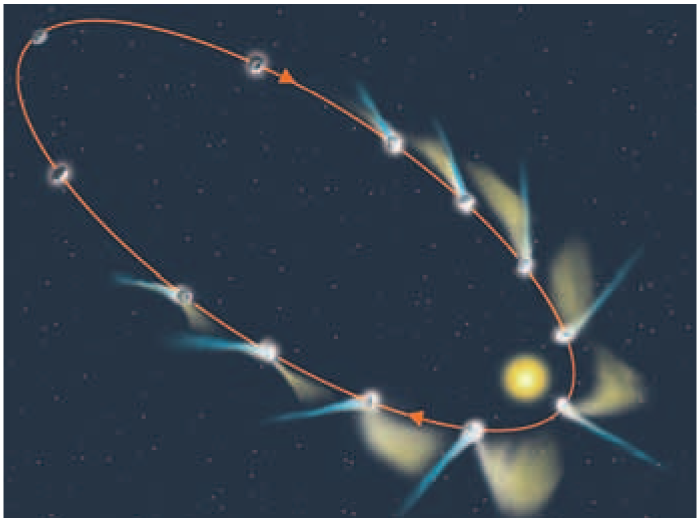


Figure 35 *When a comet's highly elliptical orbit carries it close to the sun, it can develop one or two tails. As shown here, the ion tail is blue and the dust tail is yellow.*

All orbits are *ellipses*—circles that are somewhat stretched out of shape. Whereas the orbits of most planets are nearly circular, comet orbits are highly elliptical—they are very elongated. When a body, such as a comet, is at the point in its orbit closest to the sun, it is said to be at **perihelion** (PER i HEE lee uhn). The point in an orbit farthest from the sun is called the **aphelion** (uh FEE lee uhn). When a comet is at perihelion its tail can extend millions of kilometers through space!

Notice in **Figure 35** that a comet's ion tail always points directly away from the sun. This is because the ion tail is blown away from the sun by the solar wind. The dust tail tends to follow the comet's orbit around the sun and does not always point away from the sun.

Where do comets come from? Many scientists think they may come from a spherical region, called the *Oort* (ohrt) *cloud,* that surrounds the solar system. When the gravity of a passing planet or star disturbs part of this cloud, comets can be pulled in toward the sun. These distant members of the solar system then assume a smaller orbit around the sun. Another recently discovered region where comets exist is called the *Kuiper* (KIE per) *belt,* which is the region outside the orbit of Neptune. These two regions where comets orbit are shown in **Figure 36.**

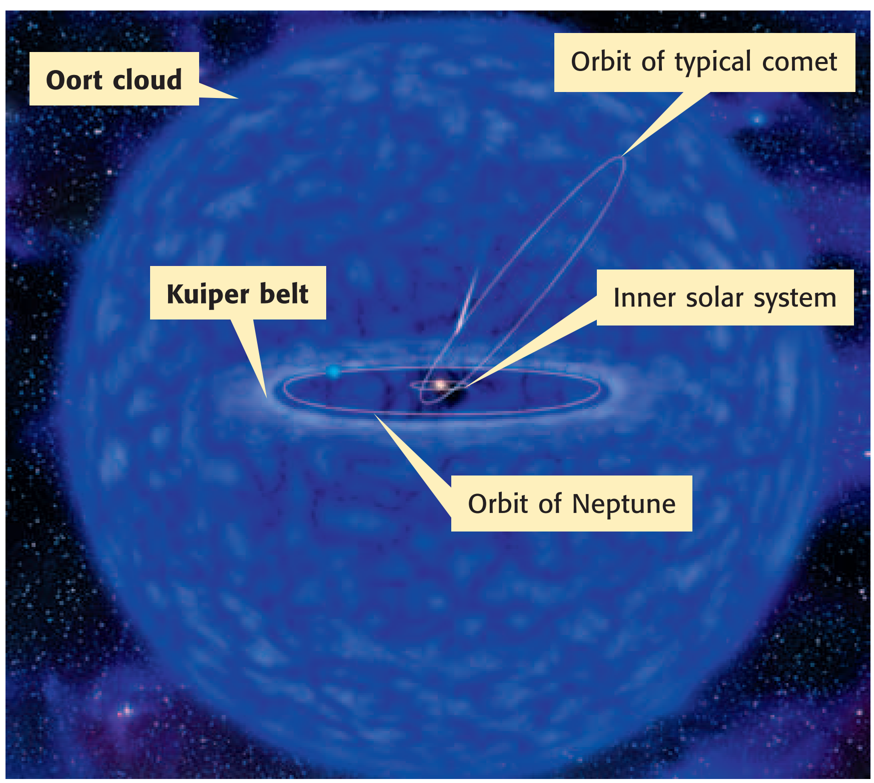


Figure 36 *The Kuiper belt is a disk-shaped region that extends outward from the orbit of Neptune. The Oort cloud is a spherical region far beyond the orbit of Pluto.*

Asteroids

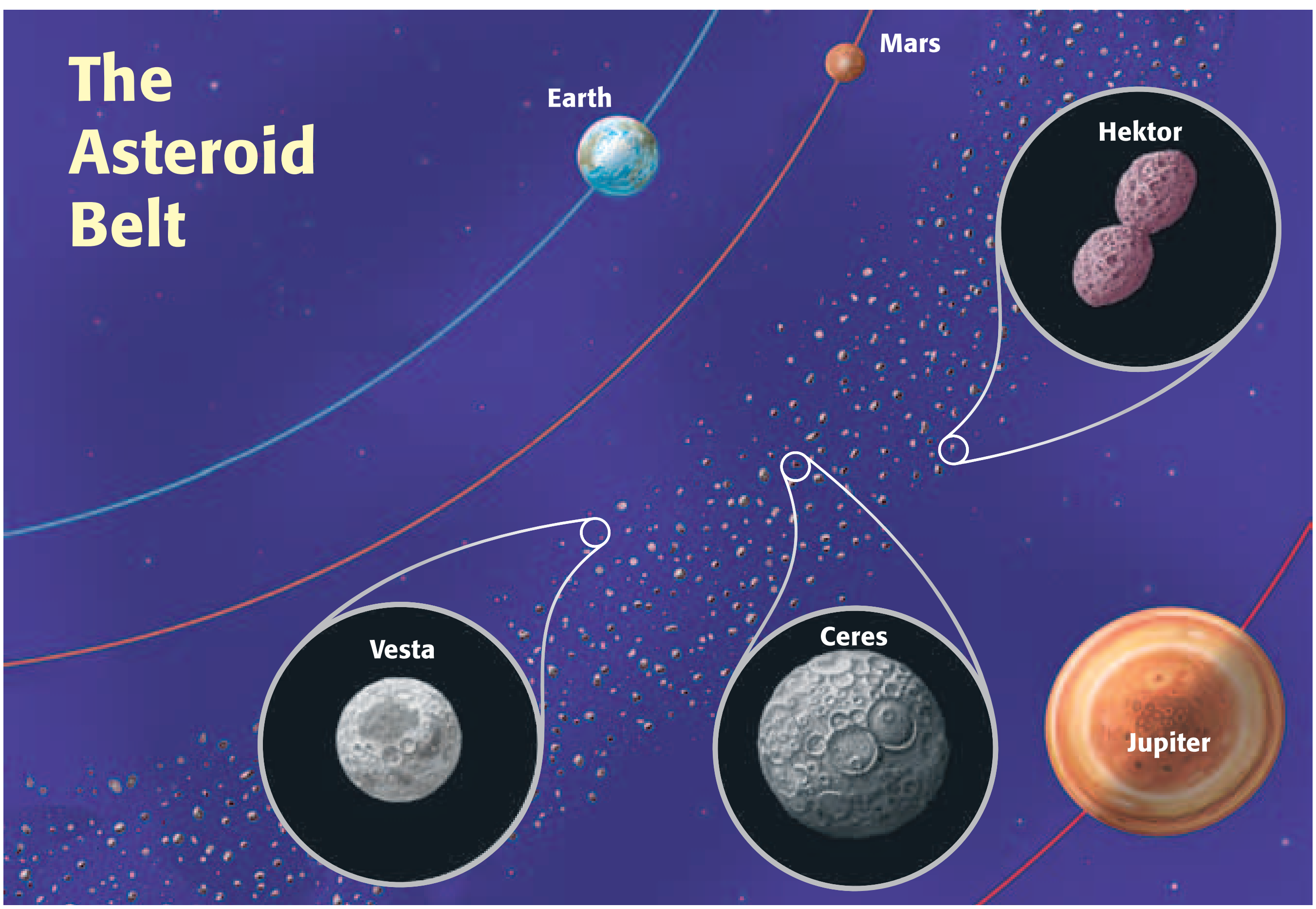
Asteroids are small, rocky bodies in orbit around the sun. They range in size from a few meters to more than 900 km in diameter. Asteroids have irregular shapes, although some of the larger ones are spherical. Most asteroids orbit the sun in a wide region between the orbits of Mars and Jupiter, called the **asteroid belt.**

Asteroids can have a variety of compositions, depending on where they are located within the asteroid belt. In the outermost region of the asteroid belt, asteroids have dark reddish brown to black surfaces, which may indicate that they are rich in organic material. A little closer to the sun, asteroids have dark gray surfaces, indicating that they are rich in carbon. In the innermost part of the asteroid belt are light gray asteroids that have either a stony or metallic composition. **Figure 38** shows some examples of what some of the asteroids may look like.

Like comets, asteroids are thought to be material left over from the formation of the solar system. NASA's NEAR (Near Earth Asteroid Rendezvous) mission was the first in a series of missions to send spacecraft to study asteroids. Scientists hope data gathered on these missions will help us better understand the way our solar system formed.

Figure 37 *The asteroid Ida has a small companion asteroid that orbits it called Dactyl. Ida is about 52 km long.*

Figure 38 *The asteroid belt is a disk-shaped region located between the orbits of Mars and Jupiter.*



The total mass of meteorites that fall to Earth each year is between 10,000 and 1 million metric tons!

Meteoroids

A **meteoroid** is a small, rocky body orbiting the sun. Meteoroids are similar to asteroids, but they are much smaller. In fact, most meteoroids probably come from asteroids. If a meteoroid enters Earth's atmosphere and strikes the ground, it is then called a **meteorite.** When a meteoroid falls into Earth's atmosphere, it is usually traveling at such a high speed that its surface heats up and melts. As it burns up, the meteoroid glows and gives off an enormous amount of light and heat. From the ground, we see a spectacular streak of light, or a shooting star. The bright streak of light caused by a meteoroid or comet dust burning up in the atmosphere is called a **meteor.**

Many of the meteors that we see come from very small (dust-sized to pebble-sized) rocks and can be seen on almost any night if you are far enough away from the city to avoid the glare of its lights. At certain times of the year, you can see large numbers of meteors, as shown in **Figure 39.** These events are called *meteor showers*. Meteor showers occur when Earth passes through the dusty debris left behind in the orbit of a comet. During some meteor showers, alert observers can see up to several thousand meteors per hour!

Some kinds of meteorites are easy to recognize because they are very dense. If you pick up a rock that is especially heavy for its size, it might be a meteorite. Like their relatives the asteroids, meteorites have a variety of compositions. The three major types of meteorites—stony, metallic, and stony-iron—are shown in **Figure 40.** Many of the stony meteorites probably come from carbon-rich asteroids and may contain organic materials and water. Scientists use meteorites to study the early solar system. Like comets and asteroids, meteoroids are some of the building blocks of planets.

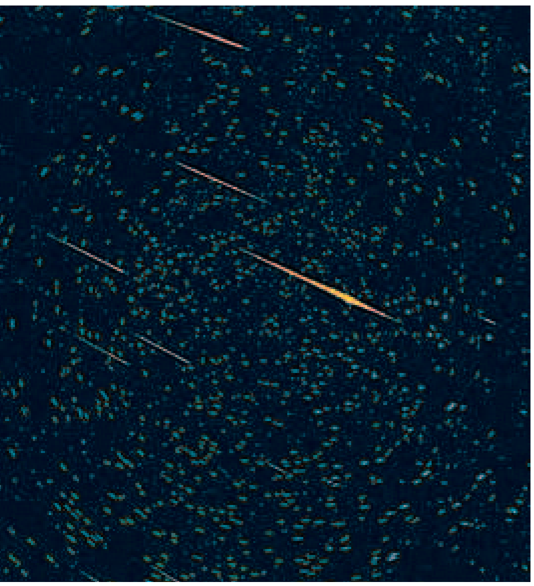


Figure 39 *Meteors are the streaks of light caused by meteoroids as they burn up in Earth's atmosphere.*

Figure 40 *There are three major types of meteorites.*

Stony meteorite
rocky material

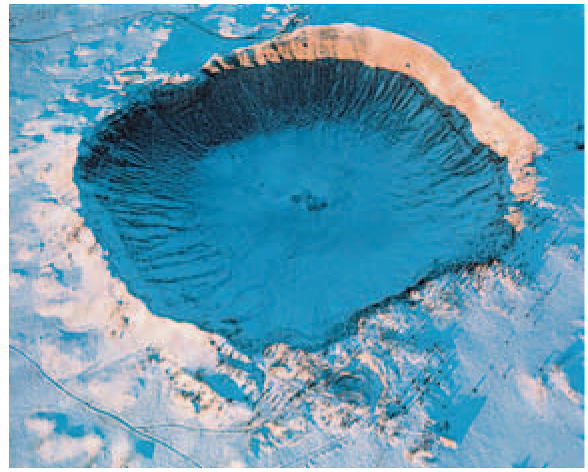
Metallic meteorite
iron and nickel

Stony-iron meteorite
rocky material, iron and nickel

The Role of Impacts in the Solar System

Planets and moons that have no atmosphere have many more impact craters than those that do have atmospheres. Look at **Figure 41.** The Earth's moon has many more impact craters than the Earth because it has no atmosphere or tectonic activity. Fewer objects land on Earth because Earth's atmosphere acts like a shield. Smaller bodies burn up before they ever reach the surface. On the moon, there is nothing to stop them! Also, most craters left on Earth have been erased due to weathering, erosion, and tectonic activity.

Objects smaller than about 10 m across usually burn up in the atmosphere, causing a meteor. Larger objects are more likely to strike Earth's surface. In order to estimate the risk of cosmic impacts, we need to consider how often large impacts occur. The solar system still contains a large amount of small debris—most of which we enjoy as meteor showers. The number of large objects that could collide with Earth is relatively small. Scientists estimate that impacts powerful enough to cause a natural disaster might occur once every few thousand years. An impact large enough to cause a global catastrophe—such as the extinction of the dinosaurs—is estimated to occur once every 30 million to 50 million years on average.



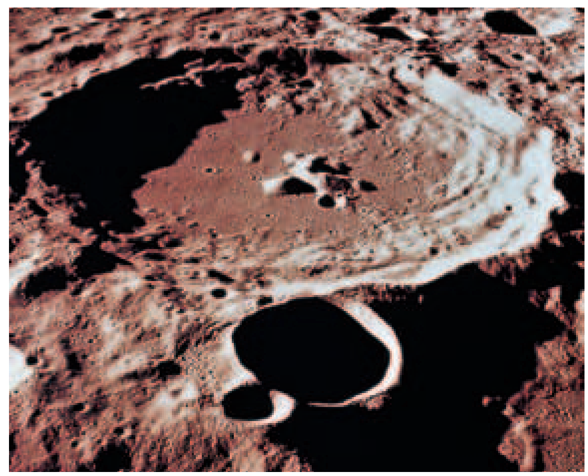


Figure 41 *The Earth and the moon are about the same age, but unlike the Earth's surface, shown here covered with snow, the surface of the moon preserves a record of billions of years of cosmic impacts.*

REVIEW

1. Why is the study of comets, asteroids, and meteoroids important in understanding the formation of the solar system?
2. Why do a comet's two tails often point in different directions?
3. What is the difference between an asteroid and a meteoroid?
4. Describe one reason asteroids may become a natural resource in the future.
5. **Analyzing Viewpoints** Do you think the government should spend money on programs to search for asteroids and comets with Earth-crossing orbits? Discuss why.

Chapter Highlights

SECTION 1

Vocabulary

astronomical unit (AU) *(p. 452)*
terrestrial planets *(p. 453)*
prograde rotation *(p. 454)*
retrograde rotation *(p. 454)*
gas giants *(p. 458)*

Section Notes

- The solar system has nine planets.
- Distances within the solar system can be expressed in astronomical units (AU) or in light-minutes.
- The inner four planets, called the terrestrial planets, are small and rocky.
- The outer planets, with the exception of Pluto, are gas giants.
- By learning about the properties of the planets, we get a better understanding of global processes on Earth.

Labs

Why Do They Wander? *(p. 588)*

SECTION 2

Vocabulary

satellite *(p. 463)*
phases *(p. 465)*
eclipse *(p. 466)*

Section Notes

- Earth's moon probably formed from a giant impact on Earth.
- The moon's phases are caused by the moon's orbit around the Earth. At different times of the month, we view different amounts of sunlight on the moon because of the moon's position relative to the sun and the Earth.
- Lunar eclipses occur when the Earth's shadow falls on the moon.

Skills Check

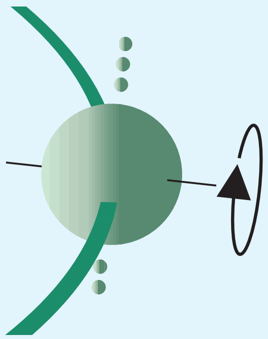
Math Concepts

INTERPLANETARY DISTANCES The distances between planets are so vast that scientists have invented new units of measurement to describe them. One of these units is the astronomical unit (AU). One AU is equal to the average distance between the Earth and the sun—about 150 million kilometers. If you wanted to get to the sun from the Earth in 10 hours, you would have to travel at a rate of 15,000,000 km/h!

$$\frac{150 \text{ million kilometers}}{15 \text{ million kilometers/hour}} = 10 \text{ hours}$$

Visual Understanding

AXIAL TILT A planet's axis of rotation is an imaginary line that runs through the center of the planet and comes out its north and south poles. The tilt of a planet's axis is the angle between the planet's axis and the plane of the planet's orbit around the sun.

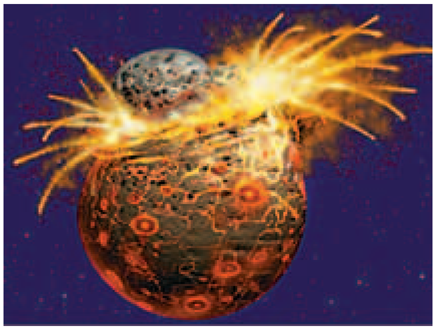


SECTION 2

- Solar eclipses occur when the moon is between the sun and the Earth, causing the moon's shadow to fall on the Earth.
- The plane of the moon's orbit around the Earth is tilted by 5° relative to the plane of the Earth's orbit around the sun.

Labs

Eclipses *(p. 590)*
Phases of the Moon *(p. 591)*



SECTION 3

Vocabulary

comet *(p. 471)*
perihelion *(p. 472)*
aphelion *(p. 472)*
asteroid *(p. 473)*
asteroid belt *(p. 473)*
meteoroid *(p. 474)*
meteorite *(p. 474)*
meteor *(p. 474)*

Section Notes

- Comets are small bodies of water ice and cosmic dust left over from the formation of the solar system.
- When a comet is heated by the sun, the ices convert to gases that leave the nucleus and form an ion tail. Dust also comes off a comet to form a second kind of tail called a dust tail.
- All orbits are ellipses—circles that have been stretched out. The point on an orbit closest to the sun is called the perihelion. The point on an orbit farthest from the sun is the aphelion.
- Asteroids are small, rocky bodies that orbit the sun between the orbits of Mars and Jupiter.
- Meteoroids are small, rocky bodies that probably come from asteroids.
- Meteor showers occur when Earth passes through the dusty debris along a comet's orbit.
- Impacts that cause natural disasters occur once every few thousand years, but impacts large enough to cause global extinctions occur once every 30 million to 50 million years.

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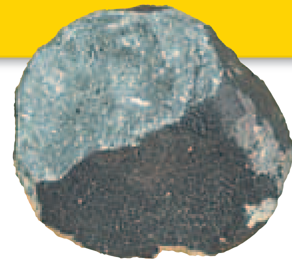
TOPIC: The Nine Planets	***sci*LINKS NUMBER:** HSTP605
TOPIC: Studying Earth from Space	***sci*LINKS NUMBER:** HSTP610
TOPIC: The Earth's Moon	***sci*LINKS NUMBER:** HSTP615
TOPIC: The Moons of Other Planets	***sci*LINKS NUMBER:** HSTP620
TOPIC: Comets, Asteroids, and Meteoroids	***sci*LINKS NUMBER:** HSTP625

Chapter Review



USING VOCABULARY

For each pair of terms, explain the difference in their meaning.

1. aphelion/perihelion
2. asteroid/comet
3. meteor/meteorite
4. satellite/moon
5. Kuiper belt/Oort cloud

To complete the following sentences, choose the correct term from each pair of terms listed below:

6. The average distance between the sun and the Earth is 1 __?__. *(light-minute,* or *AU)*
7. A small rock in space is called a __?__. *(meteorite, meteor,* or *meteoroid)*
8. The time it takes for the Earth to __?__ around the sun is one year. *(rotate* or *revolve)*
9. Most lunar craters are the result of __?__. *(volcanoes* or *impacts)*

UNDERSTANDING CONCEPTS

Multiple Choice

10. When do annular eclipses occur?
    - **a.** every solar eclipse
    - **b.** when the moon is closest to the Earth
    - **c.** only during full moon
    - **d.** when the moon is farthest from the Earth

11. Of the following, which is the largest body?
    - **a.** the moon
    - **b.** Pluto
    - **c.** Mercury
    - **d.** Ganymede

12. Which is not true about impacts?
    - **a.** They are very destructive.
    - **b.** They can bring water to dry worlds.
    - **c.** They only occurred as the solar system formed.
    - **d.** They can help us do remote geology.

13. Which of these planets does not have any moons?
    - **a.** Mercury
    - **b.** Mars
    - **c.** Uranus
    - **d.** none of the above

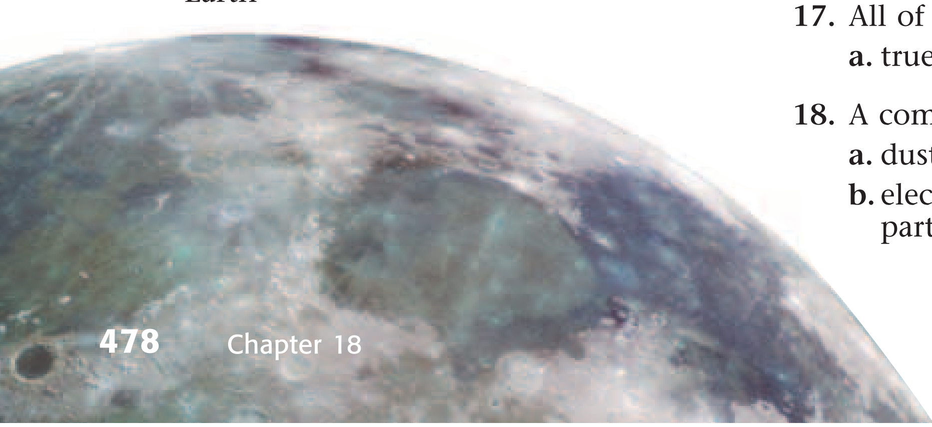
14. What is the most current theory for the formation of Earth's moon?
    - **a.** The moon formed from a collision between another body and the Earth.
    - **b.** The moon was captured by the Earth.
    - **c.** The moon formed at the same time as the Earth.
    - **d.** The moon formed by spinning off from the Earth early in its history.

15. Liquid water cannot exist on the surface of Mars because
    - **a.** the temperature is too hot.
    - **b.** liquid water once existed there.
    - **c.** the gravity of Mars is too weak.
    - **d.** the atmospheric pressure is too low.

16. Which of the following planets is not a terrestrial planet?
    - **a.** Mercury
    - **b.** Mars
    - **c.** Earth
    - **d.** Pluto

17. All of the gas giants have ring systems.
    - **a.** true
    - **b.** false

18. A comet's ion tail consists of
    - **a.** dust.
    - **b.** electrically charged particles of gas.
    - **c.** light rays.
    - **d.** comet nuclei.

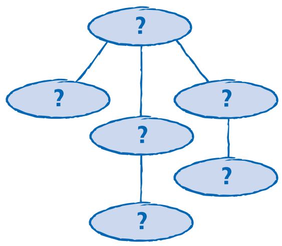


Short Answer

19. Do solar eclipses occur at the full moon or at the new moon? Explain why.
20. How do we know there are small meteoroids and dust in space?
21. Which planets have retrograde rotation?

Concept Mapping

22. Use the following terms to create a concept map: solar system, terrestrial planets, gas giants, moons, comets, asteroids, meteoroids.



CRITICAL THINKING AND PROBLEM SOLVING

23. Even though we haven't yet retrieved any rock samples from Mercury's surface for radiometric dating, we know that the surface of Mercury is much older than that of Earth. How do we know this?
24. Where in the solar system might we search for life, and why?
25. Is the far side of the moon always dark? Explain your answer.
26. If we could somehow bring Europa as close to the sun as the Earth is, 1 AU, what do you think would happen?

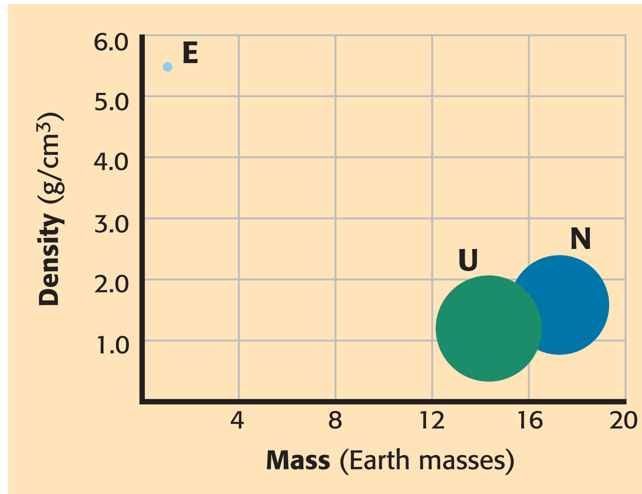
MATH IN SCIENCE

27. Suppose you have an object that weighs 200 N (45 lbs.) on Earth. How much would that same object weigh on each of the other terrestrial planets?

INTERPRETING GRAPHICS

The graph below shows density versus mass for Earth, Uranus, and Neptune. Mass is given in Earth masses—the mass of Earth equals one. The relative volumes for the planets are shown by the size of each circle.

Density vs. Mass for Earth, Uranus, and Neptune



28. Which planet is denser, Uranus or Neptune? How can you tell?
29. You can see that although Earth has the smallest mass, it has the highest density. How can Earth be the densest of the three when Uranus and Neptune have so much more mass?

NOW What Do You Think?

Take a minute to review your answers to the ScienceLog questions on page 451. Have your answers changed? If necessary, revise your answers based on what you have learned since you began this chapter.

SCIENTIFIC DEBATE

Is Pluto Really a Planet?

We have all learned that Pluto is the planet farthest from the sun in our solar system. Since it was discovered in 1930, astronomers have grouped it with the outer planets. However, Pluto has not been a perfect fit in this group. Unlike the other outer planets, which are large and gaseous, Pluto is small and made of rock and ice. Pluto also has a very elliptical orbit that is unlike its neighboring planets. These and other factors once fueled a debate as to whether Pluto really is a planet and how it should be classified.

A composite drawing of Pluto, Charon, Triton, and Halley's comet

Kuiper Belt

In 1997, astronomers discovered a belt of comets outside the orbit of Neptune. The belt was named the Kuiper Belt in honor of Gerard Kuiper, a Dutch-born American astronomer. So what does this belt have to do with Pluto? Given its proximity to Pluto, some astronomers thought Pluto may actually be a large comet that escaped the Kuiper Belt.

Comet?

Comets are basically dirty snowballs made of ice and cosmic dust. Pluto is about 30 percent ice and 70 percent rock. This is much more rock than is in a normal comet. Also, at 2,390 km in diameter, Pluto is much larger than a comet. For example, Halley's comet is only about 20 km in diameter. Even so, Pluto's orbit is very similar to that of a comet. Both have orbits that are very elliptical.

Escaped Moon?

Pluto and its moon, Charon, have much in common with Neptune's moon, Triton. All three have atmospheres made of nitrogen and methane, which suggests that they share a similar origin. And since Triton has a "backward" orbit compared with Neptune's other moons, it may have been captured by Neptune's gravity. Some astronomers thought Pluto might also have been captured by Neptune but broke free by some cataclysmic event.

New Category of Planet?

Some astronomers suggested that perhaps we should create a new subclass of planets, such as the ice planets, to add to the Jovian and terrestrial classification we currently use. Pluto would be the only planet in this class, but scientists think we are likely to find others.

As there are more new discoveries, astronomers will likely continue to debate the issues. To date, however, Pluto is still officially considered a planet. This decision is firmly grounded by the fact that Pluto has been called a planet since its discovery.

You Decide

▶ Do some additional research about Pluto, the Kuiper Belt, and comets. What do you think Pluto should be called?

Science Fiction

"The Mad Moon"

by Stanley Weinbaum

The third largest satellite of Jupiter, called Io, can be a hard place to live. Although living comfortably is possible in the small cities at the polar regions, most of the moon is hot, humid, and jungle-like. There is also *blancha,* a kind of tropical fever that causes hallucinations, weakness, and vicious headaches. Without proper medication a person with *blancha* can go mad or even die.

Just 2 years ago, Grant Calthorpe was a wealthy hunter and famous sportsman. Then the gold market crashed, and he lost his entire fortune. What better way for an experienced hunter and explorer to get a fresh start than to set out for a little space travel? The opportunity to rekindle his fortune by gathering ferva leaves so that they can be converted into useful human medications lures Calthorpe to Io.

There he meets the loonies—creatures with balloon heads and silly grins atop *really* long necks. The parcat Oliver quickly becomes Calthorpe's pet and helps him cope with the loneliness and the slinkers. The slinkers, well, they would just as soon *not* have Calthorpe around at all, but they are pretty good at making even this famous outdoorsman wonder why he ever took this job.

In "The Mad Moon," you'll discover a dozen adventures with Grant Calthorpe as he struggles to stay alive—and sane. Read Stanley Weinbaum's story "The Mad Moon" in the *Holt Anthology of Science Fiction.* Enjoy your trip!