Section 23.1

1 FOCUS

Section Objectives

23.1 **List** the major differences between the terrestrial and Jovian planets.

23.2 **Explain** how the solar system formed.

Reading Focus

Build Vocabulary L2

Word Part Analysis Teach students that *terr-* means "Earth," and *-ial* and *-ian* mean "of, or related to" so *terrestrial* means "Earthly" or "Earth-like." Terrestrial planets are those similar to Earth while Jovian planets are those similar to Jupiter.

Advise students that *nebula* is related to the word *nebulous*, which means "hazy" or "unclear." The word *nebula* is used to describe a "hazy mass of gases and dust seen among the stars." Tell students that *infinitesimal* means "infinitely small," and have them predict the meaning of *planetesimal*. *(Planetesimals are small solid bodies that combine to form planets.)*

Reading Strategy L2

a. The sun formed at the center of a disk.
b. Matter collided to form planetesimals.
c. Planetesimals eventually grow into planets.

2 INSTRUCT

Use Visuals L1

Figure 1 This diagram shows the orbits of all 8 planets around the sun. Ask: **Which planet is the closest to the sun?** *(Mercury)* **The asteroid belt is found between which two planets?** *(Mars and Jupiter)*

Direct students to observe the scale along the bottom of the figure that shows the scale distances from planet to planet. Tell students that the inner planets are those found before the asteroid belt, and the outer planets are found after the asteroid belt. Ask: **How does the distance between the inner planets differ from the distance between the outer planets?** *(The inner planets are much closer together than the outer planets.)*
Visual

23.1 The Solar System

Reading Focus

Key Concepts

- How do terrestrial planets differ from Jovian planets?
- How did the solar system form?

Vocabulary

- terrestrial planet
- Jovian planet
- nebula
- planetesimal

Reading Strategy

Relating Text and Diagrams As you read, refer to Figure 3 to complete the flowchart on the formation of the solar system.

Cloud of dust and gas began rotating. → a. __?__ → b. __?__ → c. __?__

The sun is the hub of a huge rotating system of planets, their satellites, and numerous smaller bodies. An estimated 99.85 percent of the mass of our solar system is contained within the sun. The planets collectively make up most of the remaining 0.15 percent. As Figure 1 shows, the planets, traveling outward from the sun, are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

Guided by the sun's gravitational force, each planet moves in an elliptical orbit, and all travel in the same direction. The nearest planet to the sun—Mercury—has the fastest orbital motion at 48 kilometers per second, and it has the shortest period of revolution. By contrast, the most distant planet, Neptune, has an orbital speed of 5 kilometers per second, and it requires 165 Earth-years to complete one revolution.

Imagine a planet's orbit drawn on a flat sheet of paper. The paper represents the planet's orbital plane. The orbital planes of seven planets lie within 3 degrees of the plane of the sun's equator. Mercury's orbit is inclined by 7 degrees.

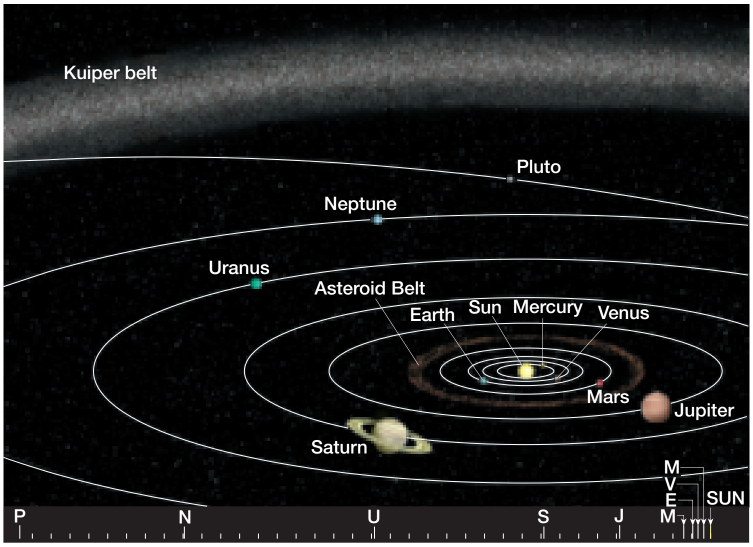

Figure 1 Orbits of the Planets and Pluto The positions of the planets and Pluto are shown to scale along the bottom of the diagram.

The Planets: An Overview

Careful examination of Table 1 shows that the planets fall quite nicely into two groups. The **terrestrial planets**—Mercury, Venus, Earth, and Mars—are relatively small and rocky. (*Terrestrial* = Earth-like.)The **Jovian planets**—Jupiter, Saturn, Uranus, and Neptune—are huge gas giants. (*Jovian* = Jupiter-like.)

Size is the most obvious difference between the terrestrial and the Jovian planets. The diameter of the largest terrestrial planet, Earth, is only one-quarter the diameter of the smallest Jovian planet, Neptune. Also, Earth's mass is only 1/17 as great as Neptune's. Hence, the Jovian planets are often called giants. Because of their distant locations from the sun, the four Jovian planets are also called the outer planets. The terrestrial planets are closer to the sun and are called the inner planets. As we shall see, there appears to be a correlation between the positions of these planets and their sizes.

Density, chemical makeup, and rate of rotation are other ways in which the two groups of planets differ. The densities of the terrestrial planets average about five times the density of water. The Jovian planets, however, have densities that average only 1.5 times the density of water. One of the outer planets, Saturn, has a density only 0.7 times that of water, which means that Saturn would float if placed in a large enough water tank. The different chemical compositions of the planets are largely responsible for these density differences.

Reading Checkpoint *Compare the densities of terrestrial planets and Jovian planets.*

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Table 1 Planetary Data

Planet	Average Distance from Sun AU	Average Distance from Sun Millions of km	Period of Revolution	Orbital Velocity km/s	Period of Rotation	Diameter (km)	Relative Mass (Earth = 1)	Average Density (g/cm³)	Number of Known Satellites*
Mercury	0.39	58	88^d	47.5	59^d	4878	0.06	5.4	0
Venus	0.72	108	225^d	35.0	244^d	12,104	0.82	5.2	0
Earth	1.00	150	365.25^d	29.8	$23^h\ 56^m\ 04^s$	12,756	1.00	5.5	1
Mars	1.52	228	687^d	24.1	$24^h\ 37^m\ 23^s$	6794	0.11	3.9	2
Jupiter	5.20	778	12^{yr}	13.1	$9^h\ 50^m$	143,884	317.87	1.3	63
Saturn	9.54	1427	29.5^{yr}	9.6	$10^h\ 14^m$	120,536	95.14	0.7	56
Uranus	19.18	2870	84^{yr}	6.8	$17^h\ 14^m$	51,118	14.56	1.2	27
Neptune	30.06	4497	165^{yr}	5.3	$16^h\ 03^m$	50,530	17.21	1.7	13
Pluto**	39.44	5900	248^{yr}	4.7	6.4^d	approx. 2300	0.002	1.8	3

*Includes all satellites discovered as of December 2006.

**Pluto is included for purposes of comparison.

The Planets: An Overview

Build Reading Literacy L1

Refer to **p. 642D**, which provides guidelines for this reading strategy.

Compare and Contrast Have students create a chart comparing the characteristics of the terrestrial planets and the Jovian planets. Have them start with what they observed about the distances between planets in the **Use Visuals** activity on p. 644, and use the reading, tables, and figures on pp. 645–647. For example:

Terrestrial Planets	Jovian Planets
Orbits are close together	Orbits are far apart
Smaller diameter	Larger diameter
More dense	Less dense
Rotate slower	Rotate faster
Thin or no atmosphere	Thick atmosphere
Composed mostly of rocky and metallic substances, with few gases and ices	Mostly made of gases, liquids, and ices, but with rocky and metallic materials in their cores

Visual, Verbal

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Customize for Inclusion Students

Learning Disabled Help students complete Compare and Contrast activities by providing them with scaffolding. Give them a chart to fill in that lists the categories they should be comparing. For example, these students could be given a chart such as the one below to use for the Compare and Contrast activity on this page.

Characteristic	Terrestrial Planets	Jovian Planets
Distance from one planet to the next		
Diameter		
Density		
Rotation rate		
Atmosphere		
Composition		

Answer to . . .

Reading Checkpoint *The terrestrial planets have greater densities than the Jovian planets.*

Use Visuals

L1

Figure 2 Have students study Figure 2 and answer the caption question. Ask: **Which planet is the smallest?** *(Mercury)* **Which planet is the largest?** *(Jupiter)* **How does the size of the largest planet compare to the size of the sun?** *(Jupiter is much smaller than the sun.)*
Visual

Address Misconceptions

L2

Many students think that the solar system and outer space are very crowded. Help students overcome this misconception by using Table 1 Planetary Data. Have students look at the column describing the distance from the sun. Point out to them that the distances are given in *millions* of kilometers. Tell students that if they chose a point in the solar system at random, it is unlikely it would be near a planet.
Visual, Verbal

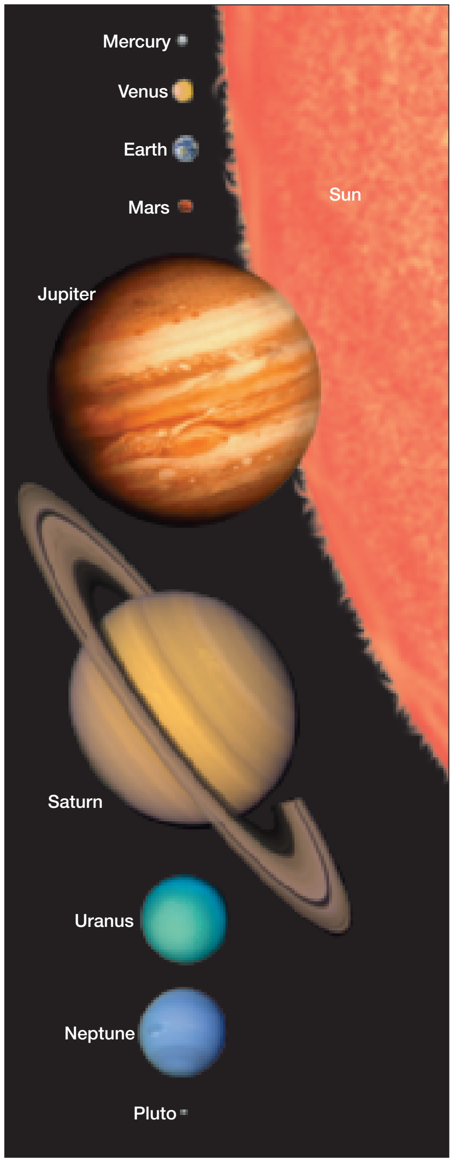


Figure 2 The planets and Pluto are drawn to scale.
Interpreting Diagrams ***How do the sizes of the terrestrial planets compare with the sizes of the Jovian planets?***

The Interiors of the Planets The planets (and Pluto) are shown to scale in Figure 2. The substances that make up the planets are divided into three groups: gases, rocks, and ices. The classification of these substances is based on their melting points.

1. The gases—hydrogen and helium—are those with melting points near absolute zero (−273°C or 0 kelvin).
2. The rocks are mainly silicate minerals and metallic iron, which have melting points above 700°C.
3. The ices include ammonia (NH_3), methane (CH_4), carbon dioxide (CO_2), and water (H_2O). They have intermediate melting points. For example, H_2O has a melting point of 0°C.

The terrestrial planets are dense, consisting mostly of rocky and metallic substances, and only minor amounts of gases and ices. The Jovian planets, on the other hand, contain large amounts of gases (hydrogen and helium) and ices (mostly water, ammonia, and methane). This accounts for their low densities. The outer planets also contain substantial amounts of rocky and metallic materials, which are concentrated in their cores.

The Atmospheres of the Planets The Jovian planets have very thick atmospheres of hydrogen, helium, methane, and ammonia. By contrast, the terrestrial planets, including Earth, have meager atmospheres at best. A planet's ability to retain an atmosphere depends on its mass and temperature, which accounts for the difference between Jovian and terrestrial planets.

Simply stated, a gas molecule can escape from a planet if it reaches a speed known as the escape velocity. For Earth, this velocity is 11 kilometers per second. Any material, including a rocket, must reach this speed before it can escape Earth's gravity and go into space.

A comparatively warm body with a small surface gravity, such as our moon, cannot hold even heavy gases, like carbon dioxide and radon. Thus, the moon lacks an atmosphere. The more massive terrestrial planets of Earth, Venus, and Mars retain some heavy gases. Still, their atmospheres make up only a very small portion of their total mass.

Facts and Figures

Why are the Jovian planets so much larger than the terrestrial planets? According to the nebular hypothesis, the planets formed from a rotating disk of dust and gases that surrounded the sun. The growth of planets began as solid bits of matter began to collide and clump together. In the inner solar system, the temperatures were so high that only the metals and silicate materials could form solid grains. It was too hot for ices of water, carbon dioxide, and methane to form. Thus, the innermost (terrestrial) planets grew mainly from the high melting point substances found in the solar nebula. By contrast, in the frigid out reaches of the solar system, it was cold enough for ices of water and other substances to form. Consequently, the outer planets are thought to have grown not only from accumulations of solid bits of metals and silicate minerals but also from large quantities of ices. Eventually, the outer planets became large enough to gravitationally capture the lightest gases (hydrogen and helium), and thus grow to become "giant" planets.

In contrast, the Jovian planets have much greater surface gravities. This gives them escape velocities of 21 to 60 kilometers per second—much higher than the terrestrial planets. Consequently, it is more difficult for gases to escape from their gravitational pulls. Also, because the molecular motion of a gas depends upon temperature, at the low temperatures of the Jovian planets even the lightest gases are unlikely to acquire the speed needed to escape.

Formation of the Solar System

Between stars is "the vacuum of space." However, it is not a pure vacuum because it is populated with regions of dispersed dust and gases. A cloud of dust and gas in space is called a **nebula** (*nebula* = cloud; plural: *nebulae*). A nebula, shown in Figure 3A, often consists of 92 percent hydrogen, 7 percent helium, and less than 1 percent of the remaining heavier elements. For some reason not yet fully understood, these thin gaseous clouds begin to rotate slowly and contract gravitationally. As the clouds contract, they spin faster. For an analogy, think of ice skaters—their speed increases as they bring their arms near their bodies.

Nebular Theory Scientific studies of nebulae have led to a theory concerning the origin of our solar system. **According to the nebular theory, the sun and planets formed from a rotating disk of dust and gases.** As the speed of rotation increased, the center of the disk began to flatten out, as shown in Figure 3B. Matter became more concentrated in this center, where the sun eventually formed.

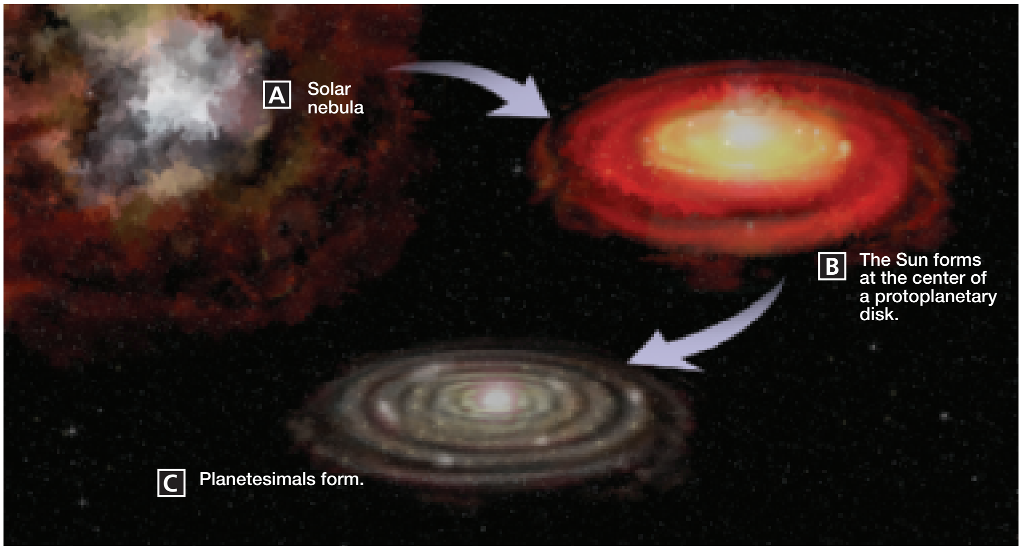


Figure 3 Formation of the Solar System A According to the nebular theory, the solar system formed from a rotating cloud of dust and gas. **B** The sun formed at the center of the rotating disk. **C** Planetesimals collided, eventually gaining enough mass to be planets.

Formation of the Solar System

Teacher Demo

Speeding Up a Spinning Nebula L2

Purpose Students will see how rotational speed would have increased as the nebula contracted early in the formation of our solar system.

Materials a chair that can be spun in place

Procedure One person sits in the chair, and the chair is spun. The seated person extends his or her arms out to the sides, which will cause the spinning to slow. Then the seated person pulls his or her arms in, causing the spinning rate to increase. This activity can be repeated with multiple students.

Safety A lighter student will be easier to spin, however, you may prefer to be the person in the chair. The person in the chair should not move in any way other than to put his or her arms in and out.

Expected Outcomes Students will see that extended arms (representing the early, wider nebula) result in a slower spin. Pulling in the arms (representing the contracting nebula) causes an increase in spinning rate.
Visual, Kinesthetic

Answer to . . .

Figure 2 *The terrestrial planets are much smaller than the Jovian planets.*

Section 23.1 (continued)

3 ASSESS

Evaluate Understanding L2

Have students create quiz questions from this section and put them on flashcards. Then put the students in small groups where they will compete to see who can answer the most questions correctly. Put the cards in the center of the table, and have students take turns selecting a card and trying to answer it. If a student cannot answer the question on the card he or she selects, it is returned to the bottom of the pile. Students earn the card of each question they answer correctly. The winner is the one with the most cards at the end of the game.

Reteach L1

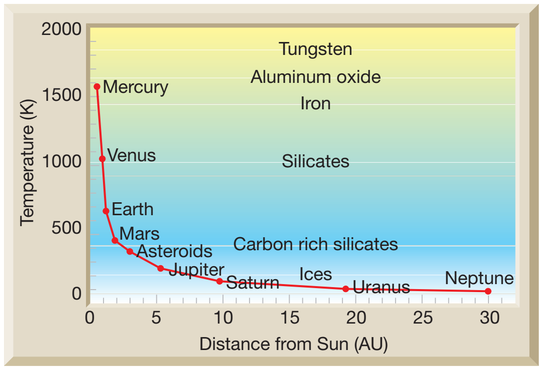
Have students summarize the differences between the terrestrial and Jovian planets by using the figures and tables in this section.

Math Practice

8. Show students how to use the equation: distance = rate / time to answer these questions. Since they are asked to find time, the equation can be rearranged as time = distance / rate.

Solutions
(1) 6.3×10^8 km ÷ 100 km/h = 6,300,000 h ÷ 24 h/day = 262,500 days ÷ 365 days/yr = 719 yrs
(2) 6.3×10^8 km ÷ 1000 km/h = 630,000 h ÷ 24 h/day = 26,250 days ÷ 365 days/yr = 72 yrs
(3) 6.3×10^8 km ÷ 40,000 km/h = 15,750 h ÷ 24 h/day = 656 days ÷ 365 days/yr = 1.8 yrs
(4) 6.3×10^8 km ÷ 300,000 km/s = 2100 s ÷ 60 s/ 1 min = 35 minutes

Figure 4 The terrestrial planets formed mainly from silicate minerals and metallic iron that have high melting points. The Jovian planets formed from large quantities of gases and ices.



Planetesimals The growth of planets began as solid bits of matter began to collide and clump together through a process known as accretion. The colliding matter formed small, irregularly shaped bodies called **planetesimals.** As the collisions continued, the planetesimals grew larger, as shown in Figure 3C on page 647. They acquired enough mass to exert a gravitational pull on surrounding objects. In this way, they added still more mass and grew into true planets.

In the inner solar system, close to the sun, temperatures were so high that only metals and silicate minerals could form solid grains. It was too hot for ices of water, carbon dioxide, and methane to form. As shown in Figure 4, the inner planets grew mainly from substances with high melting points.

In the frigid outer reaches of the solar system, on the other hand, it was cold enough for ices of water and other substances to form. Consequently, the Jovian planets grew not only from accumulations of solid bits of material but also from large quantities of ices. Eventually, the Jovian planets became large enough to gravitationally capture even the lightest gases, such as hydrogen and helium. This enabled them to grow into giants.

Section 23.1 Assessment

Reviewing Concepts

1. Which planets are classified as terrestrial? Which planets are classified as Jovian?
2. List the planets in order, beginning with the planet closest to the sun.
3. How do the terrestrial planets differ from the Jovian planets?
4. What is a nebula?
5. How did distance from the sun affect the size and composition of the planets?

Critical Thinking

6. **Summarizing** Summarize the nebular theory of the formation of the solar system.
7. **Inferring** Among the planets in our solar system, Earth is unique because water exists in all three states—solid, liquid, and gas—on its surface. How would Earth's water cycle be different if its orbit was outside the orbit of Mars?

Math Practice

8. Jupiter is 6.3×10^8 (630 million kilometers) from Earth. Calculate how long it would take to reach Jupiter if you traveled at
1) 100 km/h (freeway speed);
2) 1,000 km/h (jetliner speed);
3) 40,000 km/h (rocket speed); and
4) 3.0×10^8 km/s (speed of light).

Section 23.1 Assessment

1. Terrestrial: Mercury, Venus, Earth, and Mars; Jovian: Jupiter, Saturn, and Neptune
2. Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune.
3. The terrestrial planets are small and rocky. The Jovian planets are gas giants.
4. A nebula is a cloud of dust and gas in space.
5. In the inner solar system, close to the sun, temperatures were so high that only metals and silicate minerals could form solid grains. Thus, the inner planets grew mainly from substances with high melting points. In the outer reaches of the solar system, it was cold enough for ices of water and other substances to form. Consequently, the Jovian planets grew not only from accumulations of solid bits of material but also from large quantities of gases and ices.
6. According to the nebular theory, the sun and planets formed from a rotating disk of dust and gases. As the speed of rotation increased, the center of the disk began to flatten out. Matter became more concentrated in this center, where the sun eventually formed.
7. Sample answer: If Earth's orbit were outside the orbit of Mars, the extreme cold would freeze all water and only ice would exist. With only frozen water, there would be no precipitation, runoff, or infiltration—the water cycle and life itself would not exist.