



R I V U X G

**FIGURE 8-42 A Frozen Lake on Triton** Scientists think that the feature in the center of this image is a basin filled with water ice. The flooded basin is about 200 km across. (NASA)

*Voyager* instruments measured a surface temperature of 36 K ( $-395^{\circ}\text{F}$ ), making Triton the coldest world that our probes have ever visited. Nevertheless, *Voyager* cameras did glimpse two towering plumes of gas extending up to 8 km above the satellite's surface. These are apparently jets of nitrogen gas warmed by interior radioactive decay and escaping through vents or fissures.

Triton continues to create tides on Neptune. Whereas the tides on Earth cause our Moon to spiral outward, the tides on Neptune cause Triton (in its retrograde orbit) to spiral inward. Within the next quarter of a billion years, Triton will reach the Roche limit, the distance at which a planet creates tides on its moon's solid surface high enough to pull its moon apart. Pieces of Triton will then literally float into space until the entire moon is demolished! By destroying Triton, Neptune will create a new ring system that will be much more substantial than its present one (Figure 8-43).

## 8-17 Comparative planetology of the outer planets

Now that we have examined the individual outer planets, it is instructive to compare their various properties. The table, *The Outer Planets: A Comparison* summarizes much of this material.

**Size and Mass** The four giant planets, Jupiter, Saturn, Uranus, and Neptune, are all much larger (roughly 4 to 11 times Earth's diameter) and more massive (roughly 14 to 318 times Earth's mass) than Earth.

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Is our Moon inside or outside Earth's Roche limit?

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**Atmospheres and Rotations** The four outer planets have thick hydrogen and helium-rich atmospheres that are permanently and completely covered with clouds. All of the giant planets rotate rapidly compared to Earth. Their sidereal rotation rates range from about 10 to about  $17\frac{1}{4}$  h. This rapid rotation draws their clouds into parallel bands, called *belts* and *zones*. Earth's slower rotation allows the clouds and winds here to roam over much greater range of latitudes than on the giant planets.

**Interiors** All four giant planets have terrestrial bodies as their cores. That is where their internal similarities to Earth end. Jupiter and Saturn have small amounts of "ice" surrounding their cores. These ices are surrounded by thick liquid metallic hydrogen layers, which, in turn, are surrounded by layers of normal hydrogen and helium. In contrast, Uranus's and Neptune's terrestrial cores are surrounded by large amounts of water, which, in turn, are surrounded by liquid hydrogen and helium.

**Magnetic Fields and Rings** The four giant planets all have magnetic fields that store particles from the solar wind, similar to Earth's Van Allen belts. Like Earth's magnetic field, those of Jupiter, Uranus, and Neptune are tilted relative to their rotation axes. Saturn's magnetic field is along its rotation axis. The four giants all have rings. Saturn's rings are the most massive and distinctive, followed by those of Uranus, Jupiter, and Neptune.

**Moons** Among them, the giant planets have at least 163 moons. Each of the giants has between one and a few spherical moons, like our Moon. Most of the moons in the solar system are much smaller, irregularly shaped bodies. These objects are most likely captured space debris. Unlike our Moon, all of the satellites of the giants are no more than a few hundred thousand times less massive than their planets. Most moons are millions or billions of times less massive than their planets. Recall that our Moon is 81 times less massive than Earth.

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How do the numbers and types of moons found orbiting the giant planets compare to those that orbit the terrestrial planets?

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## 8-18 Frontiers yet to be discovered

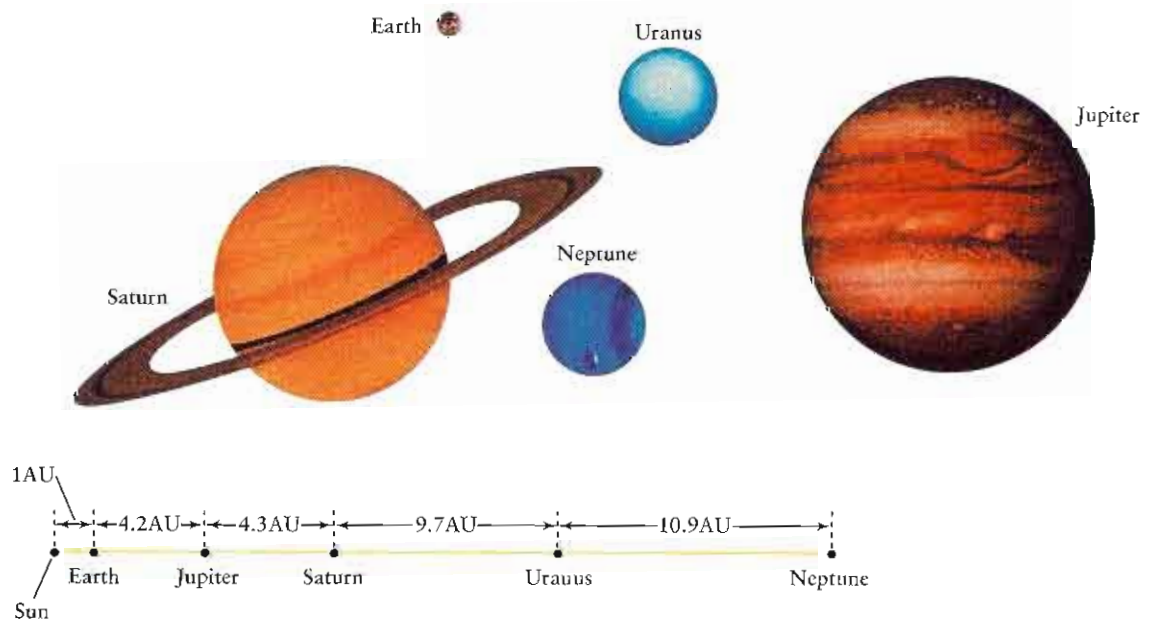
The outer planets hold countless new insights into the formation and evolution of the solar system. Considering that most of the known extrasolar planets are Jupiter-like gas giants, our outer planets all have a

## The Outer Planets: A Comparison

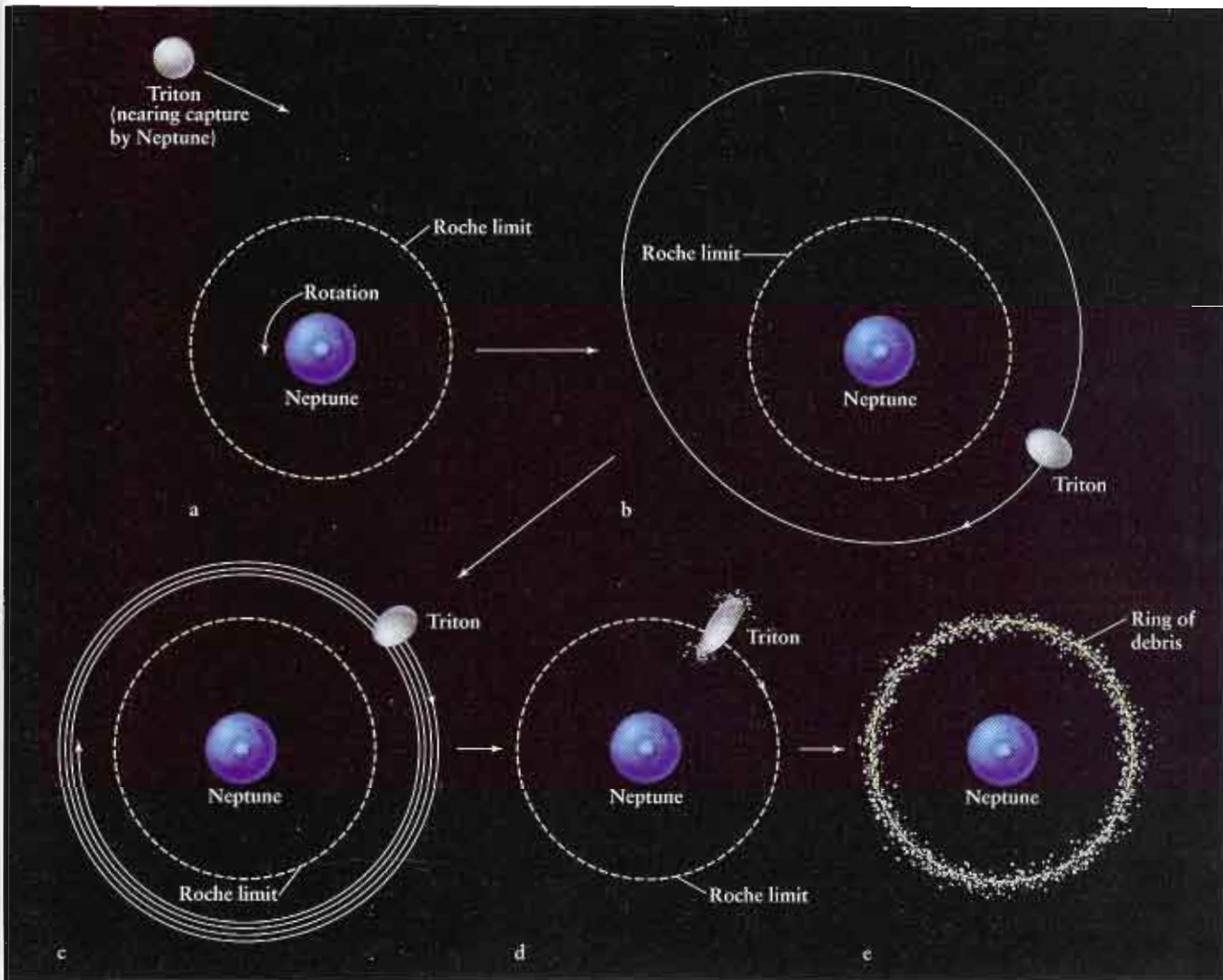
	Interior	Surface	Rings	Atmosphere	Magnetic Field
Jupiter	Terrestrial core, liquid metallic hydrogen shell, liquid hydrogen mantle	No solid surface, atmosphere gradually thickens to liquid state, belt and zone structure, hurricane-like features	Yes	Primarily H, He	$19,000 \times$ Earth's total field; at its cloud layer, $14 \times$ stronger than Earth's surface field
Saturn	Similar to Jupiter, with bigger terrestrial core and less metallic hydrogen	No solid surface, less distinct belt and zone structure than Jupiter	Yes	Primarily H, He	$570 \times$ Earth's total field; at its cloud layer, $\frac{2}{3} \times$ Earth's surface field
Uranus	Terrestrial core, liquid water shell, liquid hydrogen and helium mantle	No solid surface, weak belt and zone system, hurricane-like features, color from methane absorption of red, orange, yellow	Yes	Primarily H, He, some $\text{CH}_4$	$50 \times$ Earth's total field; at its cloud layer, $0.73 \times$ Earth's surface field
Neptune	Similar to Uranus	Like Uranus	Yes	Primarily H, He, some $\text{CH}_4$	$35 \times$ Earth's total field; at its cloud layer, $0.4 \times$ Earth's surface field

For detailed numerical comparisons between planets, see Appendix Tables E-1 and E-2.

\*To see the orientations of these magnetic fields relative to the rotation axes of the planets, see Figure 8-34.



(Stephen P. Meszaros/NASA, M. Buie, K. Horne, and D. Tholen)



**FIGURE 8-43 The Capture and Destruction of Triton** This series of drawings depicts how (a) Triton was captured by Neptune in a retrograde orbit. (b) The tides that Triton then created on the

planet caused that moon's orbit to become quite circular and (c) to spiral inward. (d) It will eventually reach Neptune's Roche limit and (e) be pulled apart to form a ring.

lot to tell us about planets throughout our Galaxy. Some specific issues include: Why did the *Galileo* probe fail to detect the atmospheric structures believed to exist on Jupiter? How has the Great Red Spot persisted for so long? Is there life in the underground oceans of the outer Galilean moons? What, exactly, do the individual ring particles around each of the planets look like? How long ago did Saturn's ring system form? How long will it last? Are the moving spokes in Saturn's rings really caused by its magnetic field, and, if so, why do the spokes appear as they do? What caused Miranda's surface to become so profoundly disturbed? These are but a few of the questions about the outer planets that are likely to be answered during this century.

## SUMMARY OF KEY IDEAS

### Jupiter and Saturn

- Jupiter is by far the largest and most massive planet in the solar system.
- Jupiter and Saturn probably have rocky cores surrounded by a thick layer of liquid metallic hydrogen and an outer layer of ordinary liquid hydrogen. Both planets have an overall chemical composition very similar to that of the Sun.
- The visible features of Jupiter exist in the outermost 100 km of its atmosphere. Saturn has similar features,

but they are much fainter. Three cloud layers exist in the upper atmospheres of both Jupiter and Saturn. Because Saturn's cloud layers extend through a greater range of altitudes, the colors of the Saturnian atmosphere appear muted.

- The colored ovals visible in the Jovian atmosphere are gigantic storms, some of which (such as the Great Red Spot) are stable and persist for years or even centuries.
- Jupiter and Saturn have strong magnetic fields created by electric currents in their metallic hydrogen layers.
- Four large satellites orbit Jupiter. The two inner Galilean moons, Io and Europa, are roughly the same size as our Moon. The two outer moons, Ganymede and Callisto, are approximately the size of Mercury.
- Io is covered with a colorful layer of sulfur compounds deposited by frequent explosive eruptions from volcanic vents. Europa is covered with a smooth layer of frozen water crisscrossed by an intricate pattern of long cracks.
- The heavily cratered surface of Ganymede is composed of frozen water with large polygons of dark, ancient crust separated by regions of heavily grooved, lighter-colored, younger terrain. Callisto has a heavily cratered ancient crust of frozen water.
- Saturn is circled by a system of thin, broad rings lying in the plane of the planet's equator. Each major ring is composed of a great many narrow ringlets that consist of numerous fragments of ice and ice-coated rock. Jupiter has a much less substantial ring system.
- Titan has a thick atmosphere of nitrogen, methane, and other gases, as well as lakes of methane and ethane.
- Enceladus has areas with very different surface features: an older, heavily cratered region and a newer, nearly crater-free surface created by tectonic activity.

### Uranus and Neptune

- Uranus and Neptune are quite similar in appearance, mass, size, and chemical composition. Each has a rocky core surrounded by a thick, watery mantle; the axes of their magnetic fields are steeply inclined to their axes of rotation; and both planets are surrounded by systems of thin, dark rings.
- Uranus is unique in that its axis of rotation lies near the plane of its orbit, producing greatly exaggerated seasons on the planet.
- Uranus has five moderate-sized satellites, the most bizarre of which is Miranda.
- Triton, the largest satellite of Neptune, is an icy world with a tenuous nitrogen atmosphere. Triton moves in a retrograde orbit that suggests it was captured into orbit by Neptune's gravity. It is spiraling down toward Neptune and will eventually break up and form a ring system.

## WHAT DID YOU THINK?

1. *Is Jupiter a "failed star"? Why or why not?* No. Jupiter has 75 times too little mass to shine as a star.
2. *What is Jupiter's Great Red Spot?* The Great Red Spot is a long-lived, oval cloud circulation, similar to a hurricane on Earth.
3. *Does Jupiter have continents and oceans?* No. Jupiter is surrounded by a thick atmosphere primarily of hydrogen and helium that gradually becomes liquid as you move inward. The only solid matter in Jupiter is its core.
4. *Is Saturn the only planet with rings?* No. All four outer planets (Jupiter, Saturn, Uranus, and Neptune) have rings.
5. *Are the rings of Saturn solid ribbons?* No. Saturn's rings are all composed of thin, closely spaced ringlets consisting of particles of ice and ice-coated rocks. If they were solid ribbons, Saturn's gravitational tidal force would tear them apart.

## Key Terms for Review

A ring, 232	liquid metallic hydrogen, 220
B ring, 232	occultation, 242
belt, 217	polymer, 236
Cassini division, 232	prograde orbit, 229
C ring, 232	resonance, 233
differential rotation, 218	retrograde orbit, 229
Encke division, 233	ringlet, 229
F ring, 233	Roche limit, 245
Galilean moon (satellite), 223	shepherd satellite (moon), 233
Great Dark Spot, 243	spoke, 235
Great Red Spot, 218	zone, 217
hydrocarbon, 235	

## Review Questions

1. Which is the most massive planet in the solar system? a. Earth, b. Neptune, c. Saturn, d. Jupiter, e. Mercury
2. Which of the following planets does *not* have rings? Choose only one. a. Mars, b. Uranus, c. Neptune, d. Saturn, e. Jupiter
3. Which is the least massive planet in the solar system? a. Mercury, b. Mars, c. Uranus, d. Jupiter, e. Venus
4. Which planet is presently known to have the most moons? a. Mars, b. Saturn, c. Uranus, d. Jupiter, e. Neptune