Chapter 13: Uranus, Neptune and Pluto

The Outer Worlds of the Solar System

Outline

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Summary

Although Pluto has been included in this chapter, you could just as well save it for the following chapter. **Uranus** and **Neptune** share many features with each other as well as with their jovian family members Jupiter and Saturn, but **Pluto** is quite different The attraction to discuss Pluto here is in that it is one of the three planets that were not known until science and technology had advanced enough to detect them. As technology continue to progress, we are in fact finding new Pluto-like objects, such as the recently discovered Quaoar and Sedna, which are believed to be very similar to Pluto in many respects. These types of objects will be part of the focus of Chapter 14.

The outer solar system, although so distant and remote from Earth, is truly a dynamic environment. All the outer planets have been rearranged from the orbits where they originally formed. The unimaginable number of minor, icy bodies that encountered their gravity were moved to entirely new orbits but exacted a toll on these planets by moving them too. Those bodies that, by chance, did not move outward, moved inward and possibly brought to the terrestrial planets their water. So we are connected to the outer solar system as we are the inner. In that remoteness, there are answers to questions we have yet to ask, answers to our origins.

Major Concepts

- Three "new" planets previously unknown to mankind
- Physical properties of Uranus and Neptune
  - Large, but smaller than Jupiter and Saturn
  - Massive, but not as massive as Jupiter and Saturn
  - Low Density, comparable to Jupiter, higher than Saturn
  - Similar atmospheric composition to Jupiter and Saturn, except slightly more methane
  - Distinctive blue color
  - Uranus's tilt
  - Neptune's slightly higher temperature than Uranus
  - Neptune's Great Dark Spot
- The moons of Uranus and Neptune
- The rings of Uranus and Neptune
- Pluto

- Discovery
- Pluto's orbit
- Composition
- Pluto's moon Charon
- Origin

Teaching Suggestions and Demonstrations

Section 13.1

Try to convey to the students the excitement that William Herschel must have felt upon his discovery of a new planet. Until then, the human race had only known of six. Contrast this discovery with the recent discoveries of large bodies beyond Pluto. Our neighborhood is getting bigger all the time. Also, reiterate the results of searches for Extrasolar planets, with the planet count currently higher than 120!

Section 13.2

The discovery of Neptune presents a perfect opportunity to review the **scientific process**. Discuss again the scientific method by showing Figure 1.6. Uranus's orbit veered from its predictions, which were based on Newton's laws. Ask the students what choices were available to the astronomers once this discrepancy was discovered. Was the theory thrown out the window? Were the observations rejected out of hand? No, the observations were confirmed and the theory was trusted and used to move to the next step. If Neptune had not been located, what then would be the options?

Section 13.3

Because Uranus and Neptune are so similar, it is easiest to describe them at the same time. Show Figure 13.5 or use the models prepared in Chapter 9 to compare their sizes to Jupiter and Earth.

The 98° **tilt of Uranus** is worth demonstrating because it is so unusual. ➲ **DEMO** Although earlier, in the discussion of the Earth, it was established that the direction of the tilt does not change during the orbit, the concept applied to Uranus seems harder to accept. Demonstrate this using a globe for Uranus and another for the Sun. *Voyager 2* viewed Uranus when its north pole (south, using a different convention) was almost pointing towards the Sun. Also indicate that the moons orbit equatorially. Neptune's tilt of about 30° appears rather normal in comparison.

It used to be that any deviation from the "norm" which a planet exhibits could be traced back to some massive collision during the early stages of the formation of the solar system. The retrograde spins of Venus and Uranus were explained in this way. However, it is known that spinning objects cannot easily change the tilt direction of their spin axis. The faster the rotation, the more difficult it becomes. ➲ **DEMO** Demonstrate this with a spinning bicycle wheel, a common demonstration used in most physics classes. With the wheel spinning slowly it is easy to alter the tilt, but with higher rates of spin it will not tilt but rather precess. Uranus very likely formed with the tilt that it has. The equatorial orbits of the moons is added evidence of this. Although it seems less likely that a massive collision caused the extreme tilt angle of Uranus, there is no generally accepted theory of why it should have this degree of tilt. As is true with most problems under investigation, this difficult problem may have to wait for new observational data in order to be solvable at all.

Referring to previous demonstrations as discussed in Chapters 7 through 12, have your thermometer and meter stick models handy. ➲ **DEMO** For Uranus and Neptune, set the thermometer's low **temperature** just below 60 K. It is difficult at this time to give the high temperatures. ➲ **DEMO** Using the meter stick model of Jupiter, Uranus will have a radius of 36 cm and Neptune 35 cm. Their rocky cores will extend out to about 11 cm, the "slushy" layer out to 22 cm, and from 22 cm on out is the molecular hydrogen, helium, and methane atmosphere.

Section 13.4

The difference in **rotation rates** of the planets and their **atmospheres** allows equatorial wind velocities to be calculated. For Uranus, with a circumference of 160,500 km, the true rotation rate of 17.2^h gives a velocity of 9300 km/hr and the atmospheric rotation at the equator of 16.5^h gives a velocity of 9700 km/hr. Thus the cloud velocities are on the order of 400 km/hr, as noted in the text. For Neptune the same type of calculation is made. However, note that the rotation rate of the clouds is longer than the true rate, so the cloud motion must be in the east to west direction. For a circumference of 155,700 km and rotation rates of 16.1^h and 17.3^h result in velocities of 9700 km/hr and 9000 km/hr, respectively. The difference of 700 km/hr is not as high as that given in the text, 2000 km/hr. This is because the 17.3^h is an average rate and not correct for the fastest moving clouds.

Section 13.5

The **magnetic fields** associated with Uranus and Neptune are interesting. After spending so much energy in previous chapters discussing the dynamo effect, it seems as if that theory does not apply to Uranus and Neptune...or does it? Ask the students to comment on this question. The text mentions the possibility of catching both planets' magnetic fields in the process of flipping. Is this likely? Discuss Figure 13.9 again. Ask the students to comment on the fact (coincidence?) that both Uranus and Neptune's magnetic fields are roughly the same strength and tilted the same with respect to the ecliptic plane, but flipped with respect to each other.

Again, the complexities of nature present a continual challenge to scientists. "If it were easy, then everybody would be doing it…"

Section 13.6

Uranus' rings and moons are nicely organized. ➲ **DEMO** Rings are from about 1.5 to 2.0 Uranus radii from its center, the smallest moons are from 2 to 3 radii, and the 5 medium-sized moons are from 5 to 23 radii. Using the 20 cm model of Uranus from the previous chapter, it is easy enough to lay out this model. People often compare the 5 medium-size moons of Uranus to the 6 of Saturn. But there are some differences that may be important. Uranus' moons tend to have a slightly higher density and they are darker. For the most part, the Uranian moons are also relatively farther away from their planet than are the Saturnian moons. Although we believe we know why they are darker, we really do not understand yet what these clues are telling us about Uranus, its moons, how they were formed, and how they have changed over time. It's just like a mystery where we have uncovered only some of the clues and we are uncertain whether that is enough to solve the mystery.

Miranda is undoubtedly the most unusual moon of Uranus that we know of (probably because *Voyager 2* obtained some of its best images of Miranda). It has a cliff about 5 km high. This is particularly unusual because Miranda is so small, only 485 km is diameter. A little fun can be had by examining what would happen to an object or person who falls off this cliff. The acceleration due to gravity on Miranda is 0.085 m/s^2. Using simple physics for a falling object, we can calculate the time it takes to fall down the 5,000 meter cliff.

$$t = \sqrt{\frac{2s}{g}}$$

The time will be 5^m43^s. Calculate the velocity using $v^2 = 2as$. The velocity will be 29.2 m/s or 65 mph! The acceleration due to gravity is low and it takes a long time to fall to the bottom. But there is no air friction and the final velocity is unpleasantly high for landing! Imagine what happens to rocks that fall off the top of the cliff. There should be a lot of broken rubble at the base of the cliff.

Neptune's large moon, Triton, has nitrogen geysers and an odd orbit; its orbit is tilted 20^o and is retrograde, indicating that either something cataclysmic occurred to Triton or it was captured after the formation of the planet. The presence of an atmosphere on one moon and substantial quantities of water on another are particularly intriguing to scientists interested in the possibility of life elsewhere in the solar system.

➲ **DEMO** Using the scale model of Neptune from the previous chapter, about 19.5 cm in diameter, Triton, Nereid, and their orbits can be scaled. The two moons will be small, 1 and 0.1 cm respectively. Triton is slightly smaller than the moon and Nereid is a mere dot. Triton's orbit is 136 cm from Neptune's center, tilted 20° and retrograde in direction. Nereid will vary from 54 to 370 cm in its very elliptical orbit. Also on this scale, the ring of Neptune can be shown from 17 to 20 cm from the center. The 6 small inner moons orbit between 19 and 46 cm from Neptune's center.

Triton's orbit is getting smaller and it will slowly spiral into Neptune in about 100 million years. This is caused by its retrograde motion and its tidal interaction with Neptune. Imagine the series of catastrophes that will occur when Triton approaches the small inner moons and then is finally torn apart by Neptune's gravity as it approaches the location of the outer rings. In 100 million years this will be a very different-looking system of moons and rings. In light of what we learned about the total volume present in the rings of Saturn, have the students conjecture about the resulting ring system for Neptune.

Section 13.7

Once again, show Figure 12.13 comparing the **ring systems of the four jovian planets**. Saturn's rings have been known since Galileo, while the others were discovered fairly recently, either by stellar occultations or spacecraft flybys.

➲ **DEMO** It is a straight-forward matter to demonstrate how occultation works and how it allowed for the discovery of Uranus's rings. Take a small, clear light bulb to represent a distant star. Note: this bulb must have clear glass as opposed to frosted glass so that the small filament can be seen directly. Make a ring out of a coat hanger or other stiff wire and pass it between the light bulb and the students. They will clearly see the filament appear to flicker as the light is temporarily blocked from their view. You can also use this demonstration to calculate the dimensions of the "ring" once you know the transverse speed at which the ring moves during the occultation process.

Section 13.8

There is generally no room in the scientific process for the concept of "luck," but that appears to be one factor that contributed to the discovery of Pluto. Ask the students if they are aware of any other such discoveries which were made partially by chance. Consider the discovery of x-rays or the atomic nucleus as examples.

There is a note of interest regarding the name selected for Clyde Tombaugh's discovery. He wanted to name the planet after his mentor, Percival Lowell, but also wanted to continue the tradition of naming planets after Greco-Roman mythological figures. The name Pluto was the compromise as the first two letters are the initials of Percival Lowell.

Section 13.9

➲ **DEMO** Using the scale we have for the other planets, Pluto and Charon end up too small for practical demonstrations. "Magnify" the model by a factor of 10. Pluto will now be 9 cm, Charon will be 5 cm, and their separation will be 77 cm. For comparison, you may want to show the Moon and/or Earth at this scale, possibly on the chalkboard. The Earth will be 50 cm, the Moon will be 13 cm, and their separation will be 14 m. Although this latter model may not fit in a medium sized classroom, the point is made that Pluto and Charon are small and form a close binary-type system compared to other planet-moon systems. Indeed, the entire system fits within about one-and-a-half Earth diameters!

➲ **DEMO** With the enlarged model of Pluto and Charon, the spin-orbit resonance can easily be shown. The same sides of Pluto and Charon continually point to each other. In addition, the circumstances of the eclipses can be shown. By timing the length of an eclipse of Charon (about 1.6^h), its diameter is measured. Similarly, an eclipse of Pluto by Charon (about 2.9 hours) measures the size of Pluto. Because Charon's orbit is circular, the calculations are simple. Really! The ratio of the diameter of the moon to the circumference ($2\pi \times 19{,}700$ km = 124,000 km) of the orbit is equal to the ratio of the length of the eclipse 2.9^h or 1.6^h to the orbital period (6.4 days × 24 hrs/day = 154^h). So, for Pluto, its size is given by

$$\frac{2.9}{154}\times 124{,}000 = 2{,}300\text{km}$$

For Charon, its size is given by

$$\frac{1.6}{154}\times 124{,}000 = 1{,}300\text{km}$$

Since the size and period of the orbit must be known, Kepler's third law can also be solved for the *sum* of the masses. The value of the mass given in the text, 1.5×10^{22} kg, can easily be demonstrated. It is by assuming that Charon and Pluto have similar compositions and densities that the *individual* masses are estimated. Pluto will be more massive than Charon by the ratio of their volumes. Assuming spherical shapes, Pluto will be more massive by the ratio of the cubes of their diameters; $(2300 / 1300)^3 = 5.5$, or about 6 as given in the text.

Finally, the density can be calculated. Since both objects are assumed to have the same density, we can calculate either one. Let's do Charon. If the mass ratio is 5.5, then the total mass must be equal to 6.5 Charon masses. Charon's mass is then 1.5×10^{22} kg / 6.5 = 2.3×10^{21} kg. With a radius of 650 km = 650,000 m its volume is calculated.

$$\frac{4}{3}\pi\left(650{,}000\right)^3 = 1.15\times10^{18}\ \text{m}^3$$

Dividing the mass by the volume gives the density.

$$\frac{2.3\times10^{21}}{1.15\times10^{18}} = 2000\ \text{kg/m}^3$$

Now it is evident that Charon and Pluto must be somewhat like Triton because they have similar sizes (Pluto being just a bit smaller than Triton) and densities. If Pluto had turned out to be a moon of some planet, it would have been the smallest of the large moons; Charon is a rather average medium-size moon.

These types of computational demonstrations show the significance and power of some of the basic physics in the laws of gravity and orbits, as derived by Kepler and Newton.

Section 13.10

Pluto has long been considered the "oddball" in the solar system. Compared to the other planets, it really is strange. Its orbit is more elliptical and more tilted than any other, and its path crosses the path of Neptune. It does not belong with either the terrestrial planets, which are close to the Sun, or the jovian planets, which are gaseous. Its moon, Charon, is more like a smaller twin than a satellite. However, when compared to the moons in the outer solar system or to the more recently discovered Kuiper-Belt objects, Pluto does not seem so far out of place at all! Take a vote in your class to see how many students would reclassify Pluto and how many would retain its planet status. (Singer-songwriter Christine Lavin wrote a song called "Planet X" in which she very humorously discusses the controversy. If you can get a copy, play it for your class!)

Student Writing Questions

1. Discuss how Uranus became tilted into its present position. Choose whether it happened while forming or at a later date. Which of these is more likely?

2. You are a news reporter 100 million years from now. Describe the series of events that are taking place as Triton approaches Neptune's Roche limit. What is happening to Neptune's smaller moons? How is Neptune being affected?

3. Miranda has just been purchased by the Planetary Holding of Uranus and Neptune (PHUN) Co. for development as an amusement center. What sort of unique rides, games, and sporting events could you develop on the surface of Miranda with its unusual terrain and low gravity?

4. Pluto is the only planet yet to be imaged close-up by a probe. Make some predictions about what its surface will look like when it is finally imaged. Will an atmosphere be apparent? What will Charon look like from Pluto's surface? Do you think Pluto will have a significant equatorial bulge due to the tidal effect and Charon's close proximity?

5. Look ahead to Chapter 20 and the changes the Sun will go through as it evolves and dies out. During the red giant stage, what changes would you expect to occur in the outer solar system? What will it be like during that period of time? When the Sun ejects its planetary nebula, how will these objects be affected? Will everything be destroyed or will they be little affected?

Answers to End of Chapter Exercises

Review and Discussion

1. Uranus was discovered by the British amateur astronomer William Herschel in March 1781. Herschel was engaged in charting the faint stars when he came across an odd-looking object that he described as "a curious either nebulous star or perhaps a comet." It appeared as a disk in the Herschel's telescope and moved relative to the stars, but too slowly to be a comet. Herschel had found the solar system's seventh planet.

2. As astronomers observed the position of Uranus, they realized its positions were different than predicted. Using perturbation theory, an eighth planet was predicted to be affecting the orbit of Uranus. The predictions were refined and in time Neptune was discovered close to the predicted position.

3. It may have been hit by a large, planet-sized object when young or forming but there is no direct evidence for this either.

4. The gas methane efficiently absorbs red light. Uranus and Neptune have increasing abundance of methane compared to Jupiter or Saturn. Reflected sunlight from Uranus and Neptune thus has less red light and is mostly blue. Because Uranus has less methane than Neptune, it appears more blue-green; Neptune appears quite blue.

5. Because they have lower masses than Jupiter or Saturn, Uranus and Neptune do not have liquid metallic hydrogen in their interiors. They may also have thick layers of slushy water with ammonia dissolved in it. This ionic layer could produce the magnetic fields of these planets.

6. Both Uranus and Neptune have magnetic fields that have axes that are highly tilted from their rotational axis. These tilts are 60° and 46° respectively. In addition, the magnetic fields are not centered on the planets' centers but significantly offset. Why these differences occur is not understood.

7. A typical day on Titania will depend on the orientation of Uranus and its moons to the Sun. When either pole is facing the Sun, the northern or southern hemispheres will be in continued sunlight and the other hemisphere will be in total darkness. About 21 years later, the equator of Uranus will be oriented towards the Sun. In this case, as Titania orbits around Uranus in 8.7 days, and with synchronous rotation, it also rotates with the same period. The Sun may rise and set but the planet being orbited by Titania will not move much.

8. Miranda displays a wide range of surface terrains that seems exaggerated for its small size. There are ridges, valleys, and large faults. Apparently, Miranda has been disrupted from forces within or from without.

9. The icy moons of the outer planets are mostly dark because they may be coated with a thin layer of organic matter formed from the reaction of the surface material with light and solar radiation.

10. Neptune does not have a regular moon system. Triton, the large moon of Neptune, has a very unusual orbit compared to the other large moons of the solar system. It has a retrograde orbit that is tilted 20° to Neptune's equator. This suggests that Triton may have been captured or had its orbit greatly changed by some catastrophic event. Nereid has a very

elliptical orbit. Proteus is Neptune's only medium-sized moon; there are 5 other small moons.

11. Triton's geysers are caused by the left-over heat inside Triton and the availability of subsurface nitrogen that vents after it has been frozen or trapped underground.

12. Over the next 100 million years, Triton will spiral closer and closer to Neptune. This is caused by its tidal interaction with Neptune and its retrograde orbit. As it reaches the Roche limit of Neptune it will be torn apart, forming a very large ring.

13. Uranus has 9 distinct rings. They are dark, narrow, and widely spaced. Saturn's rings are bright, wide, and close together. Both systems of rings, however, are very thin.

14. Uranus's rings are "shepherded" like some of Saturn's rings. This keeps them narrow.

15. Neptune has four dark rings, two quite narrow and two quite broad and diffuse. One of the rings is apparently "clumped" in places for unknown reasons, producing the appearance of partial ring arcs from Earth.

16. Neptune and Pluto will never collide because their orbits are synchronized in a 3 to 2 resonance. At closest approach they are still 17 A.U. apart.

17. In the 1980s, eclipses of Charon and Pluto were observed. Timing of the eclipses gives the diameters, since the size of the orbit and its circular nature is known. Kepler's third law allows the combined mass of Pluto and Charon to be determined. If their densities are assumed to be the same, then their individual masses may be determined from their volumes.

18. Pluto's size and density are more similar to the moon Triton than they are to any other object in the solar system. It is neither rocky like the terrestrial planets nor gaseous and liquid like the jovian planets. Pluto also has an icy surface like Triton.

19. No one expected nor had ever predicted that there were more planets in the solar system than those that could be seen with the naked eye. So Uranus came as quite a surprise. Perturbation theory, and observations of the planets, are now so refined that we can be certain that no new planets will be found, although numerous smaller bodies await discovery.

20. The calculated perturbation on Neptune, due to a ninth planet, was incorrect. A wide search was conducted and Pluto was discovered.

Conceptual Self-Test

1. T
2. T
3. T
4. F
5. T
6. T
7. F
8. T
9. T
10. F
11. B

12. B
13. C
14. D
15. C
16. D
17. D
18. A
19. A
20. D

Problems

1. Use the formula for synodic period from Chapter 9.
(a) For Neptune and Uranus: 1 / S = 1 / 84.01 - 1 / 164.8, S = 171.37 years.

(b) For Pluto and Neptune: 1 / S = 1 / 164.8 - 1 / 248.6, S = 488.9 years.

The first synodic period is just over one of Neptune's periods; Uranus's period is about half of that of Neptune. The second synodic period is almost exactly three times Neptune's period and almost twice Pluto's period. Because of these near coincidences there has been speculation that these planets have been trying to synchronize their orbits with each other.

2. The comparison of the gravitation forces of Neptune and the Sun on Uranus will reduce to a ratio of their masses and inversely on their distances squared.

$$\frac{F_{Neptune}}{F_{Sun}} = \frac{1.02\times10^{26}\left(19.19\right)^2}{2\times10^{30}\left(10.87\right)^2} = 0.000159$$

The Sun's gravitational force is about 6300 times stronger on Uranus than is Neptune's force.

3. The Sun will be 19.2 times smaller at Uranus when compared to how it is seen from Earth. As has been done in previous questions like this 30' / 19.2 = 1.6'. (Note: the Sun would look almost like a point of light to the naked eye, at the distance of Uranus. The human eye has a resolution of about 1 - 2'.)

To find Titania's angular diameter, θ = 3438' (1580 / 436,000) = 12.4'.
Solar eclipses could easily occur whenever Triton crosses Neptune's orbital plane.

4. Mass of the core is density times volume, m = 8,000 4/3π (2 × 6.378×10^6)^3 = 7.0×10^{25} kg. Subtracting this from the total mass gives 8.7×10^{25} - 7.0×10^{25} = 1.7×10^{25}. Dividing the core mass by the total mass gives 0.80 or 80%.

5. The A cloud moved about half the circumference of Uranus in 8 hours. The circumference is 2π × 25,600 km = 161,000 km. Take half of this and divide by 8 hours which gives 10,000 km/h. Uranus rotates in 0.72 days = 17.3^h. Half of this is 8^h, so the picture shows mostly rotation and not cloud motion.

6. Using the formula from Chapter 11, Problem 10 gives 2(1×10^{26} / 0.292×7.35×10^{22}) × (1355 / 355,000)^3 = 5.2×10^{-4}. For Jupiter and Io this ratio is 3.5×10^{-3}.

7. The total mass for the moons of known mass for Uranus, Neptune and Pluto equals only 0.44 Earth Moon masses, which is also equal to about 2.4 Pluto masses

8. (a) The light coming from the star can be considered infinitely distant, producing parallel rays. Also consider that the motion is entirely due to the Earth; the synodic period is only about 4.5 days longer than a year. The Earth's orbital velocity averages 30 km/s. It will obviously take 3 seconds to move 90 km.

   (b) The Epsilon ring is at 51,200 km and the Alpha ring is at 44,700 km. The difference is 6,500 km. Dividing by 30 km/s gives 217 s or $3^m\ 37^s$.

9. The text notes the temperature of Triton to be 37 K. From *More Precisely 8–1* the escape speed can be calculated (converting units to Earth units) to be = 11.2 $\sqrt{(0.292 / 80)}$ / $\sqrt{(2710 / 12{,}800)}$ = 1.5 km/s. The molecular speed for nitrogen at 37 K is 0.157 $\sqrt{(37 / 28)}$ = 0.18 km/s. Using the usual multiplier of a factor of 6 gives 1.08 km/s which is under the 1.47 km/s escape speed of Triton. So it should be expected to retain an atmosphere of nitrogen.

10. Determine the synodic period, 1 / P = 1 / 0.34 - 1 / 0.38. P = 3.2 days.

11. If Pluto is at perihelion, then its distance from Earth will be approximately 28.7 A.U. Use the parallax formula from *More Precisely 1–4* and use arc minutes instead of degrees. The baseline will be the motion of the Earth in one day = $2\pi \times 1$ A.U. / 365 = 0.0172 A.U. Parallax = 3438' × (0.0172 / 28.7) = 2.1'.

12. Because Pluto's mass is 0.0025 Earth masses, your weight will be reduced by this amount. However, because Pluto is smaller than Earth, 0.18 Earth radii, your weight will be increased by the square of this amount. The result is 0.077; you will weigh 1/13 your weight on Earth.

    Similarly, for Charon, its mass is 1/6 that of Pluto, so your weight will be further reduced by this factor. But its radius is smaller too, by 0.578, so your weight will increase by the square of this. The result is 0.50 your weight on Pluto or 0.0384 your Earth weight. A 150 lb person would weigh just under 6 lbs on Charon and 11.5 lbs on Pluto.

13. The Roche limit is 2.4 times the planet's radius. For Pluto this is 1150 × 2.4 = 2760 km. Charon's distance of 19,700 km is about 7 times that

14. Take Pluto's average temperature to be 50 K. Using Wien's law gives: λ_{max} = 0.29 cm / 50 = 0.0058 cm = 58 μm. This is in the infrared.

15. The round-trip distance is 2 × 40 A.U. × 150,000,000 km/A.U. = 1.2×10^{10} km. Dividing this by the speed of light, 300,000 km/s gives 40,000 s or 11 hours 7 minutes. A satellite orbiting Pluto at 0.5 km/s would travel 20,000 km, or almost 3 orbits around Pluto, in a low Pluto orbit.

Resource Information

Student CD Media

Movies/Animations

Orbits of Neptune and Pluto
Historical Observations of Pluto

Mutual Eclipses of Charon and Pluto

Interactive Student Tutorials
None

Physlet Illustrations
None

Transparencies

T-113	Figure 13.2/4	Uranus and Neptune - Closeup	p. 330/331
T-114	Figure 13.5	Jovian Planets	p. 332
T-115	Figure 13.6	Seasons of Uranus	p. 333
T-116	Figure 13.9	Jovian Magnetic Fields	p. 337
T-117	Figure 13.10	Jovian Interiors	p. 338
T-118	Figure 13.15	Occultation of Starlight	p. 344
T-119	Figure 13.16/19	Uranus's Rings and Neptune's Rings	p. 345/346
T-120	Figure 13.20	The Orbits of Neptune and Pluto	p. 348
T-121	Figure 13.22	Pluto and Charon	p. 349
T-122	Figure 13.24	The Pluto-Charon Orbit	p. 350

Suggested Readings

Cheng, A. "Pluto or Bust." *Astronomy* (May 2002). p. 47. Overview of the planned *New Horizons* Mission to Pluto. Also discusses Kuiper-Belt objects similar to Pluto.

"Creating Uranus and Neptune." *Sky & Telescope* (Apr 2000). p. 24. A short news report about recent work simulating the origin of the orbits of Uranus and Neptune.

"Diamond hail in Uranus and Neptune." *Sky & Telescope* (Apr 2000). p. 24. A short news report about a hypothesis that diamonds could form in the atmospheres of Uranus and Neptune.

Krupp, E. C. "The fountains of Neptune." *Sky & Telescope* (Sept 1996). p. 66. Discusses mythology associated with Neptune and its moons.

McEwen, A. S., Belton, M. J. S., and Breneman, H. H. "*Galileo* at Io: results from high-resolution imaging." *Science* (May 19 2000). p. 1193. Presents high resolution images of Io taken by the *Galileo* spacecraft in late 1999 and early 2000.

Moore, Patrick. "The hunt for Neptune." *Sky & Telescope* (Sept 1996). p. 42. Describes the discovery of Neptune.

Naeye, Robert. "Neptune's Triton a mere babe." *Astronomy* (Mar 2000). p. 32. A short report on a recent study of the age of Triton.

Sagan, Carl. "The first new planet: William Herschel discovers Uranus in 1781." *Astronomy* (Mar 1995). p. 34. Details the discovery of Uranus.

Showman, Adam P.; Malhotra, Renu. "The Galilean satellites." *Science* (Oct 1 1999). p. 77. Provides a detailed summary of our understanding of each of the Galilean moons.

Ward, William R.; Hahn, Joseph M. "Neptune's eccentricity and the nature of the Kuiper belt." *Science* (June 26 1998). p. 2104. Discusses the relations between the orbit of Neptune and the structure of the Kuiper belt.

Notes and Ideas

*Class time spent on material: Estimated:*_______ *Actual:*______________

Demonstration and activity materials:

Notes for next time: