Chapter 12: Saturn
Spectacular Rings and Mysterious Moons

Outline

12.1 Orbital and Physical Properties
12.2 Saturn's Atmosphere
12.3 Saturn's Interior and Magnetosphere
12.4 Saturn's Spectacular Ring System
12.5 The Moons of Saturn

Summary

Saturn is perhaps more recognizable to people than virtually any other astronomical body. It is also commonly referred to as the most beautiful of objects to see. However, take its ring away and you have one of the blandest looking planets, second only to Uranus, with few features ever seen in its clouds. When questions are asked about Saturn they are usually about the rings and not Saturn itself.

At the beginning of the chapter, review with students the list of comparisons between the terrestrial and the jovian planets that was generated in Chapter 6. Again, use Jupiter as the prototype jovian planet, and compare the others to it. Remember to compare them to Earth as well. Continue to emphasize a special characteristic of each planet. Jupiter and Saturn are easy; Jupiter is the largest and the home of the Great Red Spot, and Saturn has the most spectacular ring system.

Since Saturn is, in some ways, just a smaller version of Jupiter, more time can be spent understanding the rings and the processes that likely produced them. And while you are at it, focus on the spectacular system of moons around Saturn, now totaling 30. Its one large moon, Titan, is unique in the solar system and will be the focus of attention for the Cassini mission to Saturn.

Major Concepts

- Overall characteristics
  - Rapid Rotation Rate
  - Low Density
  - 2nd most Massive in the Solar System
- Magnetosphere
- Rings
  - Cassini Division
  - Encke Gap
  - A-G Rings
  - The Roche Limit
  - Shepherd Satellites
- Moons
  - Titan's Atmosphere
  - Co-orbital Satellites
  - Tidally Locked Orbits

Teaching Suggestions and Demonstrations

Section 12.1

Continue your discussion of the **bulk properties** and **characteristics of the jovian planets** by reminding students of the sizes of these planets compared to each other and to Earth and the Sun. In the spirit of comparative planetology, try not to tire of showing Table 6.1 and Figure 6.7. While discussing each planet, have ready at hand figures and images of the individual planets as well, and ask students how they differ. The colored bands and spots on Jupiter are even more remarkable when compared to the duller Saturn and the nearly nondescript Uranus. Ask students to keep these differences in mind and see how they can be explained as you discuss the planets further. Table 6.1 compares less-obvious characteristics as well. Using the surface-gravity values, students can calculate how much they would weigh "on" each of the jovian planets. As students examine the table, ask them what stands out. Jupiter has a very large magnetic field, unlike the other jovian or terrestrial planets, and Saturn's density is lower than the density of water.

Saturn is the most oblate of the planets. Its **rapid rotation rate** has the effect of "pulling" the equator away from the planet. ➲ **DEMO** Demonstrate this by taking a simple spring (typical spring constant of 20 N/m) with closed loops on both ends. Attach a small mass (e.g., 100 g) to one end and insert a small rod through the other loop. Twirl the mass and spring, showing that as the period of rotation increases, the mass moves outward.

➲ **DEMO** Make a scale model of Saturn and Titan with Saturn having a diameter of 25 cm or so. Titan will be about 1 cm in diameter and will be located 2.5 m away from Saturn.

Section 12.2

Figures 11.6 and 12.4 can be used to compare the **atmospheres** of Jupiter and Saturn, respectively. They are very similar in structure but different in size. Saturn is smaller than Jupiter, but has a cloud layer about three times as thick. See if students can figure out that the reason for this is Saturn's smaller gravity. The thickness of the clouds results in a less-colorful appearance, because the higher clouds block our view of the lower layers. Spend some time looking in detail at Jupiter's beautifully colored belts, zones, and spots.

To discuss the **temperatures** associated with Saturn, display your thermometer again. Similar to Jupiter, the low temperature is measured at the top cloud layer and is about 97 K. The high temperature would be set depending on the depth to be discussed.

A good exam question concerning Saturn as well as the other jovians is: "What would the weather be like for an observer standing on the surface of Saturn?" Of course, there is no real surface, so the question is meaningless (which, by the way, should be one of the choices). However, Saturn has an atmosphere and, therefore, **weather**. Once again, the equatorial velocity of the clouds may be determined by comparing the two velocities calculated from the cloud rotation rate and the planetary rotation rate. Using a radius of 60,000 km and calculating a circumference of 377,000 km, for a period of 10^h14^m for clouds at the equator gives a velocity of 36,800 km/hr. The true rotation rate of 10^h40^m gives 35,300 km/hr. The difference is a wind and cloud velocity of 1,500 km/hr towards the east. This is exactly the velocity given later in the section on weather. Note that the winds must be again in the eastward direction.

Section 12.3

Continuing the meter stick model of the interior of Jupiter as discussed in Chapter 11, model

Saturn in a similar way. However, continue to let Jupiter's radius be one meter. This will help show Saturn in proportion and the real differences in the thickness of some of the layers.

84 cm	Top of cloud layer
83.7 - 84.0 cm	Cloud layers in the upper atmosphere
32 - 83.7 cm	Hydrogen is liquid
14 - 32 cm	Hydrogen is liquid metal
0 - 14 cm	Rocky, high density planetary core

Notice that although the rocky cores are the same in the size, the layer of liquid metallic hydrogen is over 3 times thinner in Saturn than in Jupiter.

Also, use Figures 11.10 and 12.8 to compare the **interiors** of Jupiter and Saturn. If you did not **discuss liquid hydrogen** in Chapter 11, then here is your chance to do so. It is a difficult concept for students as they are familiar with hydrogen only as a gas. Please refer to the previous chapter for discussion recommendations concerning liquid metal.

Jupiter's **magnetic field** is strikingly large compared to all other planets in the solar system. As discussed previously, a rapid rotation and metallic interior are necessary for a strong magnetic field. Recall that Jupiter has both of these features. Saturn, while possessing a rapid rotation rate, has only about one-twentieth the volume of liquid metallic hydrogen compared to Jupiter. Therefore, Saturn's **magnetosphere** extends into space only a fraction of the distance compared to that of Jupiter's. Uranus and Neptune are missing the metallic hydrogen and so have weak magnetic fields. Figure 13.9 summarizes the magnetic and rotational properties of the four jovian planets.

Section 12.4

This is the obvious chapter in which to delve more deeply into the physics behind the jovian ring systems. Figure 12.13 compares the ring systems of the four jovian planets. Saturn's rings were first noted by Galileo, though he didn't know what they were and reported that the planet looked like it had "ears." The others were discovered fairly recently, either by stellar occultations or spacecraft flybys.

Extend the scale model of Saturn discussed in Section 12.1 above to include **Saturn's ring system**. The rings will extend from 14 cm to 1 m from the center of Saturn. You could use a thin sheet of poster board to represent the ring system, but, in reality, the thinness of the rings cannot be represented on this scale or any other scale suitable for the classroom. They are less than 100 m thick but about 70,000 km wide. If the ring system were as wide as a football field, the thickness would be that of a hair!

Discuss the **Roche limit** and the critical role of gravity in the formation and evolution of ring systems. In Chapter 7 we determined the form for the tidal force to be

$$\frac{\Delta F}{F} = \frac{4\Delta r}{r}$$

where ΔF is the tidal force across an object whose radius is Δr and F is the gravitational force between this object and another body at a distance r. A simple approach to the Roche limit is to think of the two halves of a moon being pulled apart by this tidal force, produced by a planet of mass M and radius R. What tries to keep the moon together is the moon's own gravitational force. Again, thinking simply as if the two halves of the moon are attracting each other, the force of attraction will be

$$= \frac{G\frac{m}{2}\frac{m}{2}}{\Delta r^2}$$

Setting this equal to the tidal force, ΔF, and using $\frac{1.35\times10^{23}/5.97\times10^{24}}{5{,}150/12{,}756^2} = 0.139$ we have

$$\frac{GMm4\Delta r}{r^3} = \frac{G\frac{m}{2}\frac{m}{2}}{\Delta r^2}$$

Rearranging terms and multiplying the left side by R^3/R^3 gives

$$\frac{16MR^3}{r^3R^3} = \frac{m}{\Delta r^3}$$

But mass divided by radius cubed is just the density of the object (both sides can be divided by the factor of 4/3π to make the denominator look more like the volume of a sphere) and here we will assume that the density of the moon and planet are the same. Taking the cube root, this reduces to

$$r = 2.5R$$

Because of our simplifying assumptions we get 2.5 instead of 2.4 for the constant. The Roche limit simply asks the question "At what distance does the tidal force tear an object apart?" and only a small amount of algebra is needed to demonstrate the principle. Have the students calculate the Roche limit for the Earth and the Sun as well.

Some of the information provided in the text allows a model of the ring environment to be calculated. The volume of the rings needs to be known first. This is easy, since the volume of a disc is just the area of a circle times its thickness. The volume of the inner part of the ring must be subtracted to obtain the ring volume. If R is the outer radius, r is the inner radius of the ring, and t is the thickness, then

$$\text{Vol. of Ring} = \pi(R^2 - r^2)t$$

which gives about 2×10^{18} m^3. Since the average ring particle size is estimated to be like a large snowball, let the radius of each ring particle be 5 cm. The particles are made of water ice, so the density is 1 gm/cm^3 and the mass is calculated to be about 0.5 kg. (Use the formula for density = mass divided by the volume of a sphere.)

The only question that remains is the spacing of the "snowballs" in the ring. This and the total mass of the ring material are the unknowns. Let us make a guess that each ring particle occupies a volume 1 meter in radius. The density of this volume is the mass of the particle, 0.5 kg, divided by the volume of a sphere 1 meter in radius. This will also equal mean density of the ring; the total mass of the ring divided by its volume. The result is a total mass of 2.4×10^{17} kg, or 3×10^{14} tons; very close to the 10^{15} tons noted in the text. So the ring environment is like having a lot of snowballs about two meters apart, swarming in their individual orbits around Saturn, moving at speeds from 59,000 km/hr to 81,000 km/hr. Little wonder that the *Voyager* space probe had to avoid the rings!

Section 12.5

Show Figures 12.22 and 12.23 while discussing Titan. The thick, chemically complex atmosphere is highly intriguing and important for the study of the primitive atmosphere of Earth. The *Cassini* mission to Saturn will lay special emphasis on this the largest Saturnian moon. There is an excellent opportunity to show the students how alive the science of astronomy is. Take every opportunity to visit the website for the *Cassini* and *Huygens* Probes (the probe that will descend to the surface of Titan). See http://saturn.jpl.nasa.gov for details and status of the mission. It is highly recommended that this website, and others, be visited *during* class.

Student Writing Questions

1. You have been assigned the job of designing a mission to sample the ring material of Saturn by capturing some of it and returning to Earth. You know that it is normally very dangerous for a spacecraft to get near the rings because of all the fast moving particles that make it up. How would you go about making a probe to do this job? Include its path around Saturn and the rings.

2. A research colony is set up on Dione. What could you use to provide for the basic necessities such as an atmosphere (in an enclosure), energy source, water, building material, food production. Think in terms of the resources available on the surface of Dione.

3. Repeat the situation in question 2 but for Titan instead of Dione. What would be the advantages and disadvantages of being on the surface of Titan?

4. Far into the future it is decided to try to make Venus habitable. Its water has to be replaced. There is plenty of water making up the moons of Saturn. How would you go about getting the water from one of the medium sized moons of Saturn all the way to Venus? You have to keep the costs to a minimum and it is not possible to "tow" the entire moon to Venus.

5. When the Sun starts to die out, it will become much brighter and larger (see Ch. 20). Titan will have a temperature similar to Earth. This will take place slowly over tens of millions of years. What might Titan become like when it warms up? Like the Earth or someplace else? Could life begin to develop or could life from Earth find Titan a good place to live while the Sun destroys the inner solar system?

Answers to End of Chapter Exercises

Review and Discussion

1. Saturn has a tilt of 27°. Because its rings are equatorial, we sometimes see them tilted by this amount; at other times we see them edge-on. During Saturn's 30-year orbit around the Sun, this orientation changes about every 7-8 years. First we see the rings from the north, then edge-on, then from the south, then edge-on again, and finally back to a north view.

2. A ring-crossing is when Saturn is viewed edge-on. The next one will occur in 2010.

3. Because Saturn has weaker gravity than Jupiter, due to its lower mass, its cloud layers are thicker, not as compressed as on Jupiter. Saturn is farther from the Sun and has a cooler temperature than Jupiter. This produces a thicker layer of ammonia clouds on top, which hides the more colorful cloud layers that occur deeper in the atmosphere.

4. Saturn's equatorial bulge is due to its rapid rotation and lower mass than Jupiter. But it is not as flattened as these factors would indicate. To account for this, Saturn must have a larger core made of dense material.

5. Saturn's atmosphere is cooler than Jupiter's because of its greater distance from the Sun. Because of Saturn's weaker gravity, its atmosphere is 2.5 times thicker than Jupiter's. The cloud layers are similar to Jupiter's but thicker; the top layer of ammonia ice hides many of the cloud features below it. Saturn's atmosphere is under-abundant in helium because it has precipitated out.

6. Saturn has a cloud layer 2.5 times thicker than Jupiter, due to its lower gravity. Its layer of molecular hydrogen is 30,000 km thick compared to Jupiter's 20,000 km thick molecular hydrogen layer. The metallic hydrogen layer of Saturn is only 15,000 km thick compared to 40,000 km for Jupiter. Saturn's core is 15,000 km thick compared to a 10,000 km thick core for Jupiter. All these differences can be explained through Saturn's weaker gravity.

7. Helium has precipitated out of the atmosphere of Saturn, after it initially cooled off. This mechanism accounts for both the extra energy coming from Saturn and the depletion of helium in the atmosphere.

8. Saturn's helium has sunk below the atmosphere where it cannot be easily detected. It should have as much helium, proportionally, as Jupiter.

9. Although Galileo saw the rings, he could not tell they were separate from the planet; Saturn looked oblong to him. Huygens in 1659 was the first person to actually see the rings for what they are.

10. The Roche limit is the distance from a body at which that body's tidal forces can pull apart a second body, assuming the second body is held together by its own gravity. Within the distance of the Roche limit, a single object is pulled apart or many small objects are prevented from gravitationally attracting each other into a larger object. If a satellite came too close to Saturn, within its Roche limit, the moon would be broken apart and eventually become a ring.

11. Collisions between ring particles are predicted to destroy the ring system in a time relatively short compared to the age of the solar system. If this is the case, then either the rings were recently formed or they are replenished by new material.

12. Mimas is the cause of the Cassini Division. Ring particles in the Division have an orbital period twice that of Mimas. They feel a gravitational pull from Mimas at the same place in their orbit every time they are the closest to Mimas. These particles are therefore pulled out of the orbit of the Division.

13. Shepherd satellites are very small moons that "shepherd" ring particles into narrow orbits, forming thin rings. Prometheus and Pandora are two shepherd satellites around the F ring.

14. Voyager could not see the surface of Titan because it has a thick layer of haze in its upper atmosphere. The primary layer is from 100 to 200 km above the surface, with two thinner layers at 300 and 400 km elevation.

15. Titan is just a little smaller than Ganymede and has a mass between that of Ganymede and Callisto. Its density is the same as these two moons. Its albedo is the same as Callisto; darker than Ganymede. Its orbit is a little larger than Ganymede's orbit. So in many ways, Titan is a moon intermediate to Ganymede and Callisto, and actually rather similar to both. It differs by having a significant atmosphere, which neither Ganymede nor Callisto possess. It is also certainly colder, being much farther away from the Sun than the Galilean moons.

16. The key to Titan having an atmosphere and Ganymede and Callisto not is in its low temperature, about 94 K. The low temperature makes it difficult for an atmosphere to escape. The low temperature would also allow Titan to have formed out of material rich in methane and ammonia, which condense or freeze at this temperature. Methane and ammonia may have formed its original atmosphere when radioactivity heated Titan's interior and released them as a gas.

17. Part of the surface of Enceladus has been erased by water that is now frozen. It may have had water volcanoes or geysers that spewed out water, which then coated the surface. The nearby E ring contains material that may have been released by such eruptions.

18. Iapetus has a rather eccentric and inclined orbit. It has a large circular dark region, called Cassini Regio, which resembles methane ice that has been altered by sunlight. Its origin is completely unknown.

19. The co-orbital satellites have circular orbits that are so similar, they differ in size by only 50 km, which is less than the size of the satellites. As the inner moon overtakes the outer moon, they gravitationally interact and exchange orbits. This occurs about every 4 years.

20. The rising and setting of any, and all, objects would be hard to predict on Hyperion because of its chaotic rotation. Objects would not appear to move across the sky at a constant rate nor would they appear to follow the same path each time. Because of this chaotic rotation the positions and times of appearance of all astronomical bodies, viewed from Hyperion, would be unpredictable.

Conceptual Self-Test

1. F
2. F
3. T
4. F
5. T
6. T
7. T
8. F
9. F
10. F
11. B
12. C
13. D
14. C
15. D

16. D
17. B
18. C
19. A
20. C

Problems

1. Saturn's perihelion distance is 9 A.U., so at closest approach, Saturn will be 9.0 - 1 = 8.0 A.U. from Earth. This is 1.2×10^9 km. The A ring has a diameter of 273,600 km.

$$\text{angular diameter} = \frac{\text{true diameter}\times 57.3^\circ}{\text{distance}} = \frac{2.74\times10^5\ \text{km}\times 57.3^\circ}{1.2\times10^9\ \text{km}} = .013^\circ = 47''$$

2. At closest approach, Saturn is about 8 A.U. from Earth, or 1200 million km. size = 1.2×10^9 km (0.05 / 206,000) = 290 km

3. Mass = density × volume. Mass = 0.08 × 4/3π(6.03×10^7 m)^3. Mass = 7.3×10^{22} kg. This is 1.3×10^{-4} its actual mass. This is equal to the Moon's mass or 1/80 the mass of Earth (1.2%).

4. Saturn's equatorial radius is 60,000 km. Its circumference is $2\pi R$ or 377,000 km. At 1,500 km/h, it should take 377,000 / 1,500 = 251 hours (10.5 days) for the flow to encircle the planet.

5. Using Stefan's law, $(97)^4 / 3 = T^4$. T = 74 K.

6. The core of Saturn is 15,000 km in radius. Its volume is $4/3\pi r^3 = 1.41\times10^{22}$ m^3. Since the text states the central pressure is about the same as for the Earth, assume this is also true of the central density. The central density of Earth is about 12,000 km/m^3. Density times volume gives mass, so the mass of Saturn's core is 1.7×10^{26} kg. The mass of the Earth is 6×10^{24} kg so the core mass is about 28 Earth masses.

7. Each particle has a mass, m, where $m = \rho V = \rho \frac{4}{3}\pi r^3 = \left(1000\ \text{kg/m}^3\right)\times\frac{4}{3}\times\pi\times\left(0.06\ \text{m}\right)^3 = 0.9\ \text{kg}$. Therefore, there would have to be $\frac{10^{18}\ \text{kg}}{0.9\ \text{kg}} = 1.1\times10^{18}$ particles.

8. From Kepler's third law, $P^2 \propto a^3$. The orbital radius for the inner part of the B ring is 92,000 km. Compare this to any given moon and its orbit. Use Pan as an example. Its orbital radius is 134,000 km and its period is 0.58 days. $(P / 0.58)^2 = (92{,}000 / 134{,}000)^3$. P = 0.33 days = 7.9 hours = 28,500 s. The circumference of the inner B ring is 2π × 92,000 = 578,000 km. Dividing this distance by the period gives a velocity of 20 km/s.

   Chapter 2 gave the velocity of a satellite in a low Earth orbit as 7.9 km/s. Why is a low Saturn orbit so much higher? Notice that Chapter 2 also gave a method for calculating orbital velocity. It depends on the square root of the ratio of mass to orbital radius. Although the large B ring orbit is almost 15 times bigger than the Earth's orbit, and the square root of that should reduce the speed by a factor of 3.8, the mass of Saturn is 95 times that of Earth, which will increase the speed by 9.7. 9.7 / 3.8 = 2.56, so the orbital velocity should be 2.56 times that of a low Earth orbit. To check our result, 2.56 × 7.9 = 20 km/s. So it's the mass of Saturn that makes a big difference in the orbital speed.

9. Titan has a mass of 1.35×10^{23} kg and a radius of $2.6\text{x}10^{3}$ km. The surface gravity is

$$g=\frac{GM}{r^2}=\frac{6.673\times10^{-11}\ \text{Nm}^2/\text{kg}^2\times1.35\times10^{23}\ \text{kg}}{\left(2.6\times10^6\ \text{m}\right)^2}=1.3\ \text{m/s}^2\ ,$$

which is 1/7th that of the Earth's.

The escape speed is

$$v_{escape}=\sqrt{\frac{2GM}{r}}=\sqrt{\frac{2\times6.673\times10^{-11}\times1.35\times10^{23}}{2.6\times10^6}}=2.6\ \text{km/s}\,.$$

10. The escape velocity is $v^2 = 2GM/R$ and the mass is given by $\rho 4/3\pi R^3$, where ρ is the density and R is the desired radius. Eliminating M in both equations and solving for R^2 gives $R^2 = 3v^2/8\pi G\rho$. Substituting in all values gives R = 38,000 m = 38 km.

11. Set up Kepler's third law for moons orbiting Saturn. Use units of days for the period and planet radii for the orbital radii. $P^2 = ka^3$. The constant k will adjust for these units.

Using Mimas to establish the constant k, $(0.94)^2 = k(3.10)^3$. k = 0.0297.

(a) For one third of Tethys' orbit, P = 0.63. $(0.63)^2 = 0.0297a^3$, a = 2.37 = 143,000 km. This is about at the F ring.

(b) For half the period of Mimas, calculate a. $(0.47)^2 = 0.0297a^3$, a = 1.95 = 117,500 km. This is Cassini's division.

(c) For 3:2 the period will be 0.62667. $(0.\ 62667)^2 = 0.0297a^3$, a = 2.365 = 142,500 km. This is just outside the F ring.

(d) 2:1 for Dione the period will be 1.37. $(1.37)^2 = 0.0297a^3$, a = 3.98 = 240,000 km. This is near Enceladus.

12. Use the tidal force given in Chapter 7 and the gravitational force from Chapter 2. Calculate the tidal force, not across the diameter, but from the center to the surface. Comparing the two for Mimas (Saturn's tidal force to Mimas's surface gravity) gives:

$$\frac{2M_{Saturn}\times(\text{Mimas's Radius})^3}{M_{Mimas}\times(\text{Mimas's Orbit})^3}$$

$$\frac{2\times5.69\times10^{26}\times(1.97\times10^5)^3}{4.0\times10^{19}\times(1.87\times10^8)^3}$$

$$=0.033$$

Mimas's surface gravity is about 30 times stronger than Saturn's tidal pull.

13. Use the formula derived in the last chapter for Problem 10.

$$2\frac{M_{Sat.}}{M_{Moon}}\left(\frac{R}{D}\right)^3$$

The result is 7.9×10^{-5}. This is the same as for Callisto but much less than the other Galilean moons.

14. Use the Doppler equation $(\Delta\lambda / \lambda)c = v$. Solving for the wavelength shift, $\Delta\lambda = (v / c)\lambda$. Also, $\Delta\lambda = \lambda_{new} - \lambda = \pm(v / c)\lambda$. So, finally, $\lambda_{new} = (v / c)\lambda + \lambda$, or $\lambda_{new} = [\pm(v / c) + 1]\lambda$.

    Circular orbital speed is inversely proportional to the square root of the radius of the orbit. To find the constant for the Saturn system, try this for one of the moons, Pan. Its orbital radius is 134,000 km and its period is 0.58 days. The circumference of its orbit is $2\pi \times 134{,}000 = 842{,}000$ km. Dividing this distance by the period of 50,112 s gives a velocity of 16.8 km/s. The orbital radius for Pan is also 2.23 planet radii, which is more convenient to use here, so, $v = k\sqrt{1/r}$, $16.8 = k/\sqrt{2.23}$ and $k = 25.1$

    (a) Inner radius of the B ring, 1.53 radii. $v = 20.3$. $\lambda_{new} = [-(40.6 / c) + 1]\ 650$. $\lambda_{new} = 649.912$. (The minus sign was used because of motion towards Earth.)
    (b) $v = 20.3$. $\lambda_{new} = [(40.6 / c) + 1]650$. $\lambda_{new} = 650.088$.
    (c) $v = 16.6$. $\lambda_{new} = [-(33.2 / c) + 1]\ 650$. $\lambda_{new} = 649.928$.
    (d) $v = 16.6$. $\lambda_{new} = [(33.2 / c) + 1]\ 650$. $\lambda_{new} = 650.072$.

15. Assume one moon has a period of exactly 0.69 days and the lapping (synodic) time is 4 years. 0.69 days = 0.001889168 years. Find the period of the second moon, using the synodic period of 4 years; $P = 0.002890061$. Convert this back to days = 0.690325879. Calculate the semi-major axis for both of these periods using the formula from Problem 10 and $k = 0.0297$ exactly. $a = 151{,}962$ km and 152,009 km. This is approximately 47 km.

Resource Information

Student CD Media

Movies/Animations
Saturn Storm

Interactive Student Tutorials
None

Physlet Illustrations
Tidal Forces vs. Self Gravity

Transparencies

T-104	Figure 12.1	Ring Orientation	p. 304
T-105	Figure 12.4	Saturn's Atmosphere	p. 307
T-106	Figure 12.5	Saturn's Cloud Structure	p. 307
T-107	Figure 12.8	Saturn's Interior	p. 309
T-108	Table 12.1/Fig 12.11	The Rings of Saturn and Saturn Up-Close	p. 311

T-109	Figure 12.13	Jovian Ring Systems	p. 313
T-110	Figure 12.18/19	Shepherd Moon and the Moon-Ring Interaction	p. 316
T-111	Figure 12.22/23	Titan's Atmosphere and Haze Layers on Titan	p. 321
T-112	Figure 12.27	Synchronous Orbits	p. 324

Materials

Slide sets of NASA images of the jovian planets obtained by spacecraft flybys are available from the Public Information Office, Jet Propulsion Laboratory, California Institute of Technology. Order online at www.finley-holiday.com.

Items useful for demonstrations in this chapter include a mass on a spring and a sample of mercury.

Suggested Readings

Alper, J. "It Came from Outer Space." *Astronomy* (November 2002). p. 36. Fairly detailed discussion of the chemistry associated with the formation of life and the possible source of ingredients as being carried by comets. This is relevant to the chemistry of Titan's atmosphere, which will be the subject of scrutiny for the Huygens Probe.

Dobbins, Thomas; Sheehan, William. "Beyond the Dawes Limit: Observing Saturn's ring Divisions." *Sky & Telescope* (Nov 2000). p. 117. Discusses the history of observations of Saturn's rings.

Dobbins, Thomas; Sheehan, William. "Saturn's enigmatic crepe ring." *Sky & Telescope* (Sept 1998). p. 116. Describes the discovery of Saturn's C ring.

Gould, Stephen Jay. "The sharp-eyed lynx, outfoxed by nature. Part one: Galileo Galilei and the three globes of Saturn." *Natural History* (May 1998). p. 16. Discusses Galileo's and other historic observations of Saturn.

Oberg, James. "The spacecraft's got swing: the *Cassini* probe's gravity assist from Earth." *Astronomy* (Aug 1999). p. 48. Discusses the gravity assist maneuver used by the *Cassini* spacecraft to direct it towards Saturn.

Rogan, Josh. "Bound for the ringed planet: *Cassini* mission to Saturn." *Astronomy* (Nov 1997). p. 36. An overview of Saturn, its moons and rings, and the *Cassini* mission.

Ruben, Al. "Exposing Saturn's Secrets." *Astronomy* (December 2002). p. 49. Historical overview and detailed discussion of Saturn's ring system. Several high-resolution images of Saturn's rings.

Sanches-Lavega, A.; Perez-Hoyos, S.; Rojas, J.; Hueso, R.; French, R. "A strong decrease in Saturn's equatorial jet at cloud level." *Nature* (05 June 2003). p. 623. A good demonstration of the state of research into weather patterns on Jupiter and Saturn.

Notes and Ideas

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

Demonstration and activity materials:

Notes for next time: