CHAPTER 5: Circular Motion; Gravitation

Questions

1. Sometimes people say that water is removed from clothes in a spin dryer by centrifugal force throwing the water outward. What is wrong with this statement?

2. Will the acceleration of a car be the same when the car travels around a sharp curve at a constant $60\,\mathrm{km/h}$ as when it travels around a gentle curve at the same speed? Explain.

3. Suppose a car moves at constant speed along a hilly road. Where does the car exert the greatest and least forces on the road: (*a*) at the top of a hill, (*b*) at a dip between two hills, (*c*) on a level stretch near the bottom of a hill?

4. Describe all the forces acting on a child riding a horse on a merry-go-round. Which of these forces provides the centripetal acceleration of the child?

5. A bucket of water can be whirled in a vertical circle without the water spilling out, even at the top of the circle when the bucket is upside down. Explain.

6. How many "accelerators" do you have in your car? There are at least three controls in the car which can be used to cause the car to accelerate. What are they? What accelerations do they produce?

7. A child on a sled comes flying over the crest of a small hill, as shown in Fig. 5–31. His sled does not leave the ground (he does not achieve "air"), but he feels the normal force between his chest and the sled decrease as he goes over the hill. Explain this decrease using Newton's second law.

8. Why do bicycle riders lean inward when rounding a curve at high speed?

9. Why do airplanes bank when they turn? How would you compute the banking angle given its speed and radius of the turn?

10. A girl is whirling a ball on a string around her head in a horizontal plane. She wants to let go at precisely the right time so that the ball will hit a target on the other side of the yard. When should she let go of the string?

11. Does an apple exert a gravitational force on the Earth? If so, how large a force? Consider an apple (*a*) attached to a tree, and (*b*) falling.

12. If the Earth's mass were double what it is, in what ways would the Moon's orbit be different?

13. Which pulls harder gravitationally, the Earth on the Moon, or the Moon on the Earth? Which accelerates more?

14. The Sun's gravitational pull on the Earth is much larger than the Moon's. Yet the Moon's is mainly responsible for the tides. Explain. [*Hint*: Consider the difference in gravitational pull from one side of the Earth to the other.]

15. Will an object weigh more at the equator or at the poles? What two effects are at work? Do they oppose each other?

16. The gravitational force on the Moon due to the Earth is only about half the force on the Moon due to the Sun. Why isn't the Moon pulled away from the Earth?

17. Is the centripetal acceleration of Mars in its orbit around the Sun larger or smaller than the centripetal acceleration of the Earth?

18. Would it require less speed to launch a satellite (*a*) toward the east or (*b*) toward the west? Consider the Earth's rotation direction.

19. When will your apparent weight be the greatest, as measured by a scale in a moving elevator: when the elevator (*a*) accelerates downward, (*b*) accelerates upward, (*c*) is in free fall, (*d*) moves upward at constant speed? In which case would your weight be the least? When would it be the same as when you are on the ground?

20. What keeps a satellite up in its orbit around the Earth?

21. Astronauts who spend long periods in outer space could be adversely affected by weightlessness. One way to simulate gravity is to shape the spaceship like a cylindrical shell that rotates, with the astronauts walking on the inside surface (Fig. 5–32). Explain how this simulates gravity. Consider (*a*) how objects fall, (*b*) the force we feel on our feet, and (*c*) any other aspects of gravity you can think of.

22. Explain how a runner experiences "free fall" or "apparent weightlessness" between steps.

***23.** The Earth moves faster in its orbit around the Sun in January than in July. Is the Earth closer to the Sun in January, or in July? Explain. [*Note*: This is not much of a factor in producing the seasons — the main factor is the tilt of the Earth's axis relative to the plane of its orbit.]

***24.** The mass of Pluto was not known until it was discovered to have a moon. Explain how this discovery enabled an estimate of Pluto's mass.

Problems

5–1 to 5–3 Uniform Circular Motion; Highway Curves

1. (I) A child sitting 1.10 m from the center of a merry-go-round moves with a speed of $1.25\ \mathrm{m/s}$. Calculate (*a*) the centripetal acceleration of the child, and (*b*) the net horizontal force exerted on the child $(\text{mass} = 25.0\ \text{kg})$.

2. (I) A jet plane traveling $1980\ \mathrm{km/h}\ (525\ \mathrm{m/s})$ pulls out of a dive by moving in an arc of radius 6.00 km. What is the plane's acceleration in *g*'s?

3. (I) Calculate the centripetal acceleration of the Earth in its orbit around the Sun, and the net force exerted on the Earth. What exerts this force on the Earth? Assume that the Earth's orbit is a circle of radius $1.50 \times 10^{11}\ \mathrm{m}$. [*Hint*: see the Tables inside the front cover of this book.]

4. (I) A horizontal force of 210 N is exerted on a 2.0-kg discus as it rotates uniformly in a horizontal circle (at arm's length) of radius 0.90 m. Calculate the speed of the discus.

5. (II) Suppose the space shuttle is in orbit 400 km from the Earth's surface, and circles the Earth about once every 90 minutes. Find the centripetal acceleration of the space shuttle in its orbit. Express your answer in terms of *g*, the gravitational acceleration at the Earth's surface.

6. (II) What is the magnitude of the acceleration of a speck of clay on the edge of a potter's wheel turning at 45 rpm (revolutions per minute) if the wheel's diameter is 32 cm?

7. (II) A ball on the end of a string is revolved at a uniform rate in a vertical circle of radius 72.0 cm, as shown in Fig. 5–33. If its speed is $4.00\ \mathrm{m/s}$ and its mass is 0.300 kg, calculate the tension in the string when the ball is (*a*) at the top of its path, and (*b*) at the bottom of its path.

8. (II) A 0.45-kg ball, attached to the end of a horizontal cord, is rotated in a circle of radius 1.3 m on a frictionless horizontal surface. If the cord will break when the tension in it exceeds 75 N, what is the maximum speed the ball can have?

9. (II) What is the maximum speed with which a 1050-kg car can round a turn of radius 77 m on a flat road if the coefficient of static friction between tires and road is 0.80? Is this result independent of the mass of the car?

10. (II) How large must the coefficient of static friction be between the tires and the road if a car is to round a level curve of radius 85 m at a speed of $95\ \text{km/h}$?

11. (II) A device for training astronauts and jet fighter pilots is designed to rotate a trainee in a horizontal circle of radius 12.0 m. If the force felt by the trainee on her back is 7.85 times her own weight, how fast is she rotating? Express your answer in both m/s and rev/s.

12. (II) A coin is placed 11.0 cm from the axis of a rotating turntable of variable speed. When the speed of the turntable is slowly increased, the coin remains fixed on the turntable until a rate of 36 rpm is reached and the coin slides off. What is the coefficient of static friction between the coin and the turntable?

13. (II) At what minimum speed must a roller coaster be traveling when upside down at the top of a circle (Fig. 5–34) so that the passengers will not fall out? Assume a radius of curvature of 7.4 m.

14. (II) A sports car of mass 950 kg (including the driver) crosses the rounded top of a hill $(\text{radius} = 95\ \text{m})$ at $22\ \text{m/s}$. Determine (*a*) the normal force exerted by the road on the car, (*b*) the normal force exerted by the car on the 72-kg driver, and (*c*) the car speed at which the normal force on the driver equals zero.

15. (II) How many revolutions per minute would a 15-m-diameter Ferris wheel need to make for the passengers to feel "weightless" at the topmost point?

16. (II) A bucket of mass 2.00 kg is whirled in a vertical circle of radius 1.10 m. At the lowest point of its motion the tension in the rope supporting the bucket is 25.0 N. (*a*) Find the speed of the bucket. (*b*) How fast must the bucket move at the top of the circle so that the rope does not go slack?

17. (II) How fast (in rpm) must a centrifuge rotate if a particle 9.00 cm from the axis of rotation is to experience an acceleration of 115,000 g's?

18. (II) In a "Rotor-ride" at a carnival, people are rotated in a cylindrically walled "room." (See Fig. 5–35.) The room radius is 4.6 m, and the rotation frequency is 0.50 revolutions per second when the floor drops out. What is the minimum coefficient of static friction so that the people will not slip down? People on this ride say they were "pressed against the wall." Is there really an outward force pressing them against the wall? If so, what is its source? If not, what is the proper description of their situation (besides "scary")? [*Hint*: First draw the free-body diagram for a person.]

19. (II) A flat puck (mass M) is rotated in a circle on a frictionless air-hockey tabletop, and is held in this orbit by a light cord connected to a dangling block (mass m) through a central hole as shown in Fig. 5–36. Show that the speed of the puck is given by

$$v = \sqrt{\frac{mgR}{M}}.$$

20. (II) Redo Example 5–3, precisely this time, by not ignoring the weight of the ball which revolves on a string 0.600 m long. In particular, find the magnitude of $\vec{\mathbf{F}}_{\mathrm{T}}$, and the angle it makes with the horizontal. [*Hint*: Set the horizontal component of $\vec{\mathrm{F}}_{\mathrm{T}}$ equal to ma_{R}; also, since there is no vertical motion, what can you say about the vertical component of $\vec{\mathbf{F}}_{\mathrm{T}}$?]

21. (III) If a curve with a radius of 88 m is perfectly banked for a car traveling $75\ \mathrm{km/h}$, what must be the coefficient of static friction for a car not to skid when traveling at $95\ \mathrm{km/h}$?

22. (III) A 1200-kg car rounds a curve of radius 67 m banked at an angle of 12º. If the car is traveling at $95\ \mathrm{km/h}$, will a friction force be required? If so, how much and in what direction?

23. (III) Two blocks, of masses m_1 and m_2, are connected to each other and to a central post by cords as shown in Fig. 5–37. They rotate about the post at a frequency f (revolutions per second) on a frictionless horizontal surface at distances r_1 and r_2 from the post. Derive an algebraic expression for the tension in each segment of the cord.

24. (III) A pilot performs an evasive maneuver by diving vertically at $310\ \mathrm{m/s}$. If he can withstand an acceleration of 9.0 g's without blacking out, at what altitude must he begin to pull out of the dive to avoid crashing into the sea?

*5–4 Nonuniform Circular Motion

***25.** (I) Determine the tangential and centripetal components of the net force exerted on the car (by the ground) in Example 5–8 when its speed is $15\ \text{m/s}$. The car's mass is 1100 kg.

***26.** (II) A car at the Indianapolis 500 accelerates uniformly from the pit area, going from rest to $320\ \text{km/h}$ in a semicircular arc with a radius of 220 m. Determine the tangential and radial acceleration of the car when it is halfway through the turn, assuming constant tangential acceleration. If the curve were flat, what would the coefficient of static friction have to be between the tires and the road to provide this acceleration with no slipping or skidding?

***27.** (III) A particle revolves in a horizontal circle of radius 2.90 m. At a particular instant, its acceleration is $1.05\ \text{m/s}^2$, in a direction that makes an angle of 32.0º to its direction of motion. Determine its speed (*a*) at this moment, and (*b*) 2.00 s later, assuming constant tangential acceleration.

5–6 and 5–7 Law of Universal Gravitation

28. (I) Calculate the force of Earth's gravity on a spacecraft 12,800 km (2 Earth radii) above the Earth's surface if its mass is 1350 kg.

29. (I) At the surface of a certain planet, the gravitational acceleration *g* has a magnitude of $12.0\ \text{m/s}^2$. A 21.0-kg brass ball is transported to this planet. What is (*a*) the mass of the brass ball on the Earth and on the planet, and (*b*) the weight of the brass ball on the Earth and on the planet?

30. (II) Calculate the acceleration due to gravity on the Moon. The Moon's radius is $1.74\times10^{6}\ \text{m}$ and its mass is 7.35×10^{22} kg.

31. (II) A hypothetical planet has a radius 1.5 times that of Earth, but has the same mass. What is the acceleration due to gravity near its surface?

32. (II) A hypothetical planet has a mass 1.66 times that of Earth, but the same radius. What is *g* near its surface?

33. (II) Two objects attract each other gravitationally with a force of 2.5×10^{-10} N when they are 0.25 m apart. Their total mass is 4.0 kg. Find their individual masses.

34. (II) Calculate the effective value of *g*, the acceleration of gravity, at (*a*) 3200 m, and (*b*) 3200 km, above the Earth's surface.

35. (II) What is the distance from the Earth's center to a point outside the Earth where the gravitational acceleration due to the Earth is $\frac{1}{10}$ of its value at the Earth's surface?

36. (II) A certain neutron star has five times the mass of our Sun packed into a sphere about 10 km in radius. Estimate the surface gravity on this monster.

37. (II) A typical white-dwarf star, which once was an average star like our Sun but is now in the last stage of its evolution, is the size of our Moon but has the mass of our Sun. What is the surface gravity on this star?

38. (II) You are explaining why astronauts feel weightless while orbiting in the space shuttle. Your friends respond that they thought gravity was just a lot weaker up there. Convince them and yourself that it isn't so by calculating the acceleration of gravity 250 km above the Earth's surface in terms of *g*.

39. (II) Four 9.5-kg spheres are located at the corners of a square of side 0.60 m. Calculate the magnitude and direction of the total gravitational force exerted on one sphere by the other three.

40. (II) Every few hundred years most of the planets line up on the same side of the Sun. Calculate the total force on the Earth due to Venus, Jupiter, and Saturn, assuming all four planets are in a line (Fig. 5–38). The masses are $M_{\rm V} = 0.815M_{\rm E}$, $M_{\rm J} = 318M_{\rm E}$, $M_{\rm S} = 95.1M_{\rm E}$, and their mean distances from the Sun are 108, 150, 778, and 1430 million km, respectively. What fraction of the Sun's force on the Earth is this?

41. (II) Given that the acceleration of gravity at the surface of Mars is 0.38 of what it is on Earth, and that Mars' radius is 3400 km, determine the mass of Mars.

42. (III) Determine the mass of the Sun using the known value for the period of the Earth and its distance from the Sun. [*Note*: Compare your answer to that obtained using Kepler's laws, Example 5–16.]

5–8 Satellites; Weightlessness

43. (I) Calculate the speed of a satellite moving in a stable circular orbit about the Earth at a height of 3600 km.

44. (I) The space shuttle releases a satellite into a circular orbit 650 km above the Earth. How fast must the shuttle be moving (relative to Earth) when the release occurs?

45. (II) At what rate must a cylindrical spaceship rotate if occupants are to experience simulated gravity of 0.60 *g*? Assume the spaceship's diameter is 32 m, and give your answer as the time needed for one revolution. (See Question 21, Fig 5–32.)

46. (II) Determine the time it takes for a satellite to orbit the Earth in a circular "near-Earth" orbit. A "near-Earth" orbit is one at a height above the surface of the Earth which is very small compared to the radius of the Earth. Does your result depend on the mass of the satellite?

47. (II) At what horizontal velocity would a satellite have to be launched from the top of Mt. Everest to be placed in a circular orbit around the Earth?

48. (II) During an *Apollo* lunar landing mission, the command module continued to orbit the Moon at an altitude of about 100 km. How long did it take to go around the Moon once?

49. (II) The rings of Saturn are composed of chunks of ice that orbit the planet. The inner radius of the rings is 73,000 km, while the outer radius is 170,000 km. Find the period of an orbiting chunk of ice at the inner radius and the period of a chunk at the outer radius. Compare your numbers with Saturn's mean rotation period of 10 hours and 39 minutes. The mass of Saturn is 5.7×10^{26} kg.

50. (II) A Ferris wheel 24.0 m in diameter rotates once every 15.5 s (see Fig. 5–9). What is the ratio of a person's apparent weight to her real weight (*a*) at the top, and (*b*) at the bottom?

51. (II) What is the apparent weight of a 75-kg astronaut 4200 km from the center of the Earth's Moon in a space vehicle (*a*) moving at constant velocity, and (*b*) accelerating toward the Moon at $2.9\,\mathrm{m/s^2}$? State the "direction" in each case.

52. (II) Suppose that a binary-star system consists of two stars of equal mass. They are observed to be separated by 360 million km and take 5.7 Earth years to orbit about a point midway between them. What is the mass of each?

53. (II) What will a spring scale read for the weight of a 55-kg woman in an elevator that moves (*a*) upward with constant speed of $6.0\,\mathrm{m/s}$, (*b*) downward with constant speed of $6.0\,\mathrm{m/s}$, (*c*) upward with acceleration of 0.33 *g*, (*d*) downward with acceleration 0.33 *g*, and (*e*) in free fall?

54. (II) A 17.0-kg monkey hangs from a cord suspended from the ceiling of an elevator. The cord can withstand a tension of 220 N and breaks as the elevator accelerates. What was the elevator's minimum acceleration (magnitude and direction)?

55. (III) (*a*) Show that if a satellite orbits very near the surface of a planet with period *T*, the density $(\mathrm{mass/volume})$ of the planet is $\rho = m/V = 3\pi/GT^2$. (*b*) Estimate the density of the Earth, given that a satellite near the surface orbits with a period of about 85 min.

*5–9 Kepler's Laws

***56.** (I) Use Kepler's laws and the period of the Moon (27.4 d) to determine the period of an artificial satellite orbiting very near the Earth's surface.

***57.** (I) The asteroid Icarus, though only a few hundred meters across, orbits the Sun like the planets. Its period is 410 d. What is its mean distance from the Sun?

***58.** (I) Neptune is an average distance of $4.5\times10^9\ \mathrm{km}$ from the Sun. Estimate the length of the Neptunian year given that the Earth is $1.50\times10^8\ \mathrm{km}$ from the Sun on the average.

***59.** (II) Halley's comet orbits the Sun roughly once every 76 years. It comes very close to the surface of the Sun on its closest approach (Fig. 5–39). Estimate the greatest distance of the comet from the Sun. Is it still "in" the Solar System? What planet's orbit is nearest when it is out there? [*Hint*: The mean distance *s* in Kepler's third law is half the sum of the nearest and farthest distance from the Sun.]

***60.** (II) Our Sun rotates about the center of the Galaxy $\left(M_G \approx 4\times10^{41}\ \mathrm{kg}\right)$ at a distance of about 3×10^4 light-years $\left(1\,\mathrm{ly} = 3\times10^8\ \mathrm{m/s}\times3.16\times10^7\ \mathrm{s/y}\times1\,y\right)$. What is the period of our orbital motion about the center of the Galaxy?

***61.** (II) Table 5–3 gives the mass, period, and mean distance for the four largest moons of Jupiter (those discovered by Galileo in 1609). (*a*) Determine the mass of Jupiter using the data for Io. (*b*) Determine the mass of Jupiter using data for each of the other three moons. Are the results consistent?

***62.** (II) Determine the mass of the Earth from the known period and distance of the Moon.

***63.** (II) Determine the mean distance from Jupiter for each of Jupiter's moons, using Kepler's third law. Use the distance of Io and the periods given in Table 5–3. Compare to the values in the Table.

***64.** (II) The asteroid belt between Mars and Jupiter consists of many fragments (which some space scientists think came from a planet that once orbited the Sun but was destroyed). (*a*) If the center of mass of the asteroid belt (where the planet would have been) is about three times farther from the Sun than the Earth is, how long would it have taken this hypothetical planet to orbit the Sun? (*b*) Can we use these data to deduce the mass of this planet?

***65.** (III) A science-fiction tale describes an artificial "planet" in the form of a band completely encircling a sun (Fig. 5–40). The inhabitants live on the inside surface (where it is always noon). Imagine that this sun is exactly like our own, that the distance to the band is the same as the Earth–Sun distance (to make the climate temperate), and that the ring rotates quickly enough to produce an apparent gravity of g as on Earth. What will be the period of revolution, this planet's year, in Earth days?

General Problems

66. Tarzan plans to cross a gorge by swinging in an arc from a hanging vine (Fig. 5–41). If his arms are capable of exerting a force of 1400 N on the vine, what is the maximum speed he can tolerate at the lowest point of his swing? His mass is 80 kg, and the vine is 5.5 m long.

67. How far above the Earth's surface will the acceleration of gravity be half what it is on the surface?

68. On an ice rink, two skaters of equal mass grab hands and spin in a mutual circle once every 2.5 s. If we assume their arms are each 0.80 m long and their individual masses are 60.0 kg, how hard are they pulling on one another?

69. Because the Earth rotates once per day, the apparent acceleration of gravity at the equator is slightly less than it would be if the Earth didn't rotate. Estimate the magnitude of this effect. What fraction of g is this?

70. At what distance from the Earth will a spacecraft traveling directly from the Earth to the Moon experience zero net force because the Earth and Moon pull with equal and opposite forces?

71. You know your mass is 65 kg, but when you stand on a bathroom scale in an elevator, it says your mass is 82 kg. What is the acceleration of the elevator, and in which direction?

72. A projected space station consists of a circular tube that will rotate about its center (like a tubular bicycle tire) (Fig. 5–42). The circle formed by the tube has a diameter of about 1.1 km. What must be the rotation speed (revolutions per day) if an effect equal to gravity at the surface of the Earth (1.0 *g*) is to be felt?

73. A jet pilot takes his aircraft in a vertical loop (Fig. 5–43). (*a*) If the jet is moving at a speed of $1300\ \text{km/h}$ at the lowest point of the loop, determine the minimum radius of the circle so that the centripetal acceleration at the lowest point does not exceed 6.0 *g*'s. (*b*) Calculate the 78-kg pilot's effective weight (the force with which the seat pushes up on him) at the bottom of the circle, and (*c*) at the top of the circle (assume the same speed).

74. Derive a formula for the mass of a planet in terms of its radius *r*, the acceleration due to gravity at its surface g_{P}, and the gravitational constant *G*.

75. A plumb bob (a mass *m* hanging on a string) is deflected from the vertical by an angle θ due to a massive mountain nearby (Fig. 5–44). (*a*) Find an approximate formula for θ in terms of the mass of the mountain, m_{M}, the distance to its center, D_{M}, and the radius and mass of the Earth. (*b*) Make a rough estimate of the mass of Mt. Everest, assuming it has the shape of a cone 4000 m high and base of diameter 4000 m. Assume its mass per unit volume is 3000 kg per m^3. (*c*) Estimate the angle θ of the plumb bob if it is 5 km from the center of Mt. Everest.

76. A curve of radius 67 m is banked for a design speed of $95\ \text{km/h}$. If the coefficient of static friction is 0.30 (wet pavement), at what range of speeds can a car safely handle the curve?

77. How long would a day be if the Earth were rotating so fast that objects at the equator were apparently weightless?

78. Two equal-mass stars maintain a constant distance apart of $8.0\times10^{10}\ \text{m}$ and rotate about a point midway between them at a rate of one revolution every 12.6 yr. (*a*) Why don't the two stars crash into one another due to the gravitational force between them? (*b*) What must be the mass of each star?

79. A train traveling at a constant speed rounds a curve of radius 235 m. A lamp suspended from the ceiling swings out to an angle of 17.5º throughout the curve. What is the speed of the train?

80. Jupiter is about 320 times as massive as the Earth. Thus, it has been claimed that a person would be crushed by the force of gravity on a planet the size of Jupiter since people can't survive more than a few *g*'s. Calculate the number of *g*'s a person would experience at the equator of such a planet. Use the following data for Jupiter: $\text{mass} = 1.9 \times 10^{27}\ \text{kg}$, equatorial $\text{radius} = 7.1 \times 10^{4}\ \text{km}$, rotation $\text{period} = 9\ \text{hr}\ 55\ \text{min}$. Take the centripetal acceleration into account.

81. Astronomers using the Hubble Space Telescope deduced the presence of an extremely massive core in the distant galaxy M87, so dense that it could be a black hole (from which no light escapes). They did this by measuring the speed of gas clouds orbiting the core to be $780\ \text{km/s}$ at a distance of 60 light-years $\left(5.7 \times 10^{17}\ \text{m}\right)$ from the core. Deduce the mass of the core, and compare it to the mass of our Sun.

82. A car maintains a constant speed v as it traverses the hill and valley shown in Fig. 5–45. Both the hill and valley have a radius of curvature *R*. (*a*) How do the normal forces acting on the car at A, B, and C compare? (Which is largest? Smallest?) Explain. (*b*) Where would the driver feel heaviest? Lightest? Explain. (*c*) How fast can the car go without losing contact with the road at A?

83. The Navstar Global Positioning System (GPS) utilizes a group of 24 satellites orbiting the Earth. Using "triangulation" and signals transmitted by these satellites, the position of a receiver on the Earth can be determined to within an accuracy of a few centimeters. The satellite orbits are distributed evenly around the Earth, with four satellites in each of six orbits, allowing continuous navigational "fixes." The satellites orbit at an altitude of approximately 11,000 nautical miles [1 nautical $\text{mile} = 1.852\ \text{km} = 6076\ \text{ft}$]. (*a*) Determine the speed of each satellite. (*b*) Determine the period of each satellite.

84. The *Near Earth Asteroid Rendezvous* (*NEAR*), after traveling 2.1 billion km, is meant to orbit the asteroid Eros at a height of about 15 km. Eros is roughly $40\ \text{km} \times 6\ \text{km} \times 6\ \text{km}$. Assume Eros has a density (mass/volume) of about $2.3 \times 10^3\ \text{kg/m}^3$. (*a*) What will be the period of *NEAR* as it orbits Eros? (*b*) If Eros were a sphere with the same mass and density, what would its radius be? (*c*) What would *g* be at the surface of this spherical Eros?

85. You are an astronaut in the space shuttle pursuing a satellite in need of repair. You are in a circular orbit of the same radius as the satellite (400 km above the Earth), but 25 km behind it. (*a*) How long will it take to overtake the satellite if you reduce your orbital radius by 1.0 km? (*b*) By how much must you reduce your orbital radius to catch up in 7.0 hours?

***86.** The comet Hale-Bopp has a period of 3000 years. (*a*) What is its mean distance from the Sun? (*b*) At its closest approach, the comet is about 1 A.U. from the Sun ($1\,\text{A.U.} = \text{distance from Earth to the Sun}$). What is the farthest distance? (*c*) What is the ratio of the speed at the closest point to the speed at the farthest point? [*Hint*: Use Kepler's second law and estimate areas by a triangle (as in Fig. 5–29, but smaller distance travelled; see also Hint for Problem 59.]

87. Estimate what the value of *G* would need to be if you could actually "feel" yourself gravitationally attracted to someone near you. Make reasonable assumptions, like $F \approx 1\,\text{N}$.

***88.** The Sun rotates around the center of the Milky Way Galaxy (Fig. 5–46) at a distance of about 30,000 light-years from the center $\left(1\ \text{ly} = 9.5 \times 10^{15}\ \text{m}\right)$. If it takes about 200 million years to make one rotation, estimate the mass of our Galaxy. Assume that the mass distribution of our Galaxy is concentrated mostly in a central uniform sphere. If all the stars had about the mass of our Sun $\left(2 \times 10^{30}\ \text{kg}\right)$, how many stars would there be in our Galaxy?

89. Four 1.0-kg masses are located at the corners of a square 0.50 m on each side. Find the magnitude and direction of the gravitational force on a fifth 1.0-kg mass placed at the midpoint of the bottom side of the square.

90. A satellite of mass 5500 kg orbits the Earth $\left(\text{mass} = 6.0 \times 10^{24}\ \text{kg}\right)$ and has a period of 6200 s. Find (*a*) the magnitude of the Earth's gravitational force on the satellite, (*b*) the altitude of the satellite.

91. What is the acceleration experienced by the tip of the 1.5-cm-long sweep second hand on your wrist watch?

92. While fishing, you get bored and start to swing a sinker weight around in a circle below you on a 0.25-m piece of fishing line. The weight makes a complete circle every 0.50 s. What is the angle that the fishing line makes with the vertical? [*Hint*: See Fig. 5–10.]

93. A circular curve of radius *R* in a new highway is designed so that a car traveling at speed v_0 can negotiate the turn safely on glare ice (zero friction). If a car travels too slowly, then it will slip toward the center of the circle. If it travels too fast, then it will slip away from the center of the circle. If the coefficient of static friction increases, a car can stay on the road while traveling at any speed within a range from v_{min} to v_{max}. Derive formulas for v_{min} and v_{max} as functions of $\mu_s, v_0,$ and *R*.

94. Amtrak's high speed train, the *Acela*, utilizes tilt of the cars when negotiating curves. The angle of tilt is adjusted so that the main force exerted on the passengers, to provide the centripetal acceleration, is the normal force. The passengers experience less friction force against the seat, thus feeling more comfortable. Consider an *Acela* train that rounds a curve with a radius of 620 m at a speed of $160\ \text{km/h}$ (approximately $100\ \text{mi/h}$). (*a*) Calculate the friction force needed on a train passenger of mass 75 kg if the track is not banked and the train does not tilt. (*b*) Calculate the friction force on the passenger if the train tilts to its maximum tilt of 8.0° toward the center of the curve.