4. [I] What does 30.0° equal in radians?

SOLUTION: $30.0°/180° = x/(\pi \text{ rad})$; $x = \frac{\pi}{6}$ rad $= 0.524$ rad, which agrees with the fact that $90° = \frac{\pi}{2}$ rad.

5. [I] (a) What is the equivalent of 45.0° in radians? (b) Express your answer as a fraction in terms of π.

6. [I] (a) What is the equivalent of 240° in radians? (b) Express your answer as a fraction in terms of π.

7. [I] What is the equivalent of $3\pi/2$ rad in degrees?

8. [I] What is the equivalent of $13\pi/6$ rad in degrees?

9. [I] If a point on the circumference of a rotating wheel passes through 200 rad, how many times has it revolved? [*Hint: Once around is* 2π *rad.*]

10. [I] A race car on a circular track goes 2.88 times around in 15 minutes. Through how many radians did it pass in that time, as measured by an observer at the center of the track?

11. [I] A model plane at the end of a control line circles at a constant speed 10.6 times around in 50.0 s. Through how many radians does it fly in 25.0 s?

12. [I] A 25-cent coin is roughly 2.5 cm in diameter. How far away should it be held if it is to subtend the same angle as does the Moon?

13. [I] A well-adjusted laserbeam is emitted as an exceedingly narrow diverging cone of light with a typical spread angle of about 8×10^{-4} rad. How large a circle will be illuminated on the surface of the Moon by such a device ($r_{\oplus\leftmoon} = 3.8 \times 10^8$ m)?

14. [I] The 10-point center-circle bull's eye on the official slow fire pistol target is $\frac{7}{8}$ in. in diameter. What angle does it subtend as seen by a shooter 50 ft away? How does this compare with the apparent size of the Moon?

15. [II] THIS PROBLEM EXAMINES THE RELATIONSHIP BETWEEN ANGULAR DISPLACEMENT AND ARC-LENGTH. A carousel has a diameter of 10.0 m and is revolving clockwise. In a certain time interval a youngster sitting at the very edge is carried through an angular displacement of $-160°$. (a) What is the radius of the circular arc along which she moves though space? (b) Show that during that interval the carousel whirls her along an arc-length of -14.0 m.

16. [II] THIS PROBLEM EXAMINES THE RELATIONSHIP BETWEEN ANGULAR DISPLACEMENT AND ARC-LENGTH. A passenger in a fixed car on a Ferris Wheel is 12.0 m from the center of rotation. At that moment his girlfriend on the ground, looking at the Wheel as if it were the face of a clock, sees him to be at the 2 o'clock position. And he's moving counterclockwise on the last turn of the ride. (a) How many degrees does each "hour" correspond to? (b) Verify that that's equivalent to $\frac{\pi}{6}$ rad. (c) Through how many radians must he travel to get to the ground? (d) What is the distance (arc-length) he must traverse before the ride ends?

17. [II] Assume the human eye can resolve details separated by about 1.0 minute of arc (where there are 60 minutes per degree). How far away must you sit from a TV set (whose picture is 30-cm high) in order to no longer distinguish the horizontal scan lines? (Typically, 525 horizontal lines make up a modest TV picture.)

18. [II] An ant positioned on the very edge of a Beatles record that is 26 cm in diameter revolves through an angle of 100° as the disk turns. How far does he travel?

19. [II] If a disc 30 cm in diameter rolls 65 m along a straight line without slipping, (a) How many revolutions would it make in the process? (b) Through what angular displacement would a speck of gum on its rim be carried?

SOLUTION: (a) $N = L/2\pi r = (65 \text{ m})/2\pi(0.15 \text{ m}) = 69$ turns. (b) For each complete turn, the wheel revolves through 2π rad; therefore $\theta = 4.3 \times 10^2$ rad.

20. [II] The bob at the end of a pendulum 100-cm long swings out an arc 15.0 cm in length. Find the angle in radians and degrees through which it moves. Check your answer by determining the fraction of the complete circle to which this corresponds and then taking that fraction of 2π.

21. [II] Determine, via geometry, the angle in radians subtended by a 2.00-m-wide car seen head-on from a distance of 1.00 m away. What would that angle be as seen standing 100 m? Compute this last part exactly (using geometry and the straight-line width) and approximately (taking the width as an arc-length). Now, go back to the first part and do it with the same approximation. Compare your results.

SECTION 8.2: ANGULAR VELOCITY

SECTION 8.3: ANGULAR ACCELERATION

22. [I] What is the equivalent of 1.00 rev/min in rad/s?

23. [I] If a point on a wheel turns through 45.0° in 0.050 s, what is its angular speed? [*Hint: How many radians does it turn through per second?*]

24. [I] A radial line is drawn on a disc that is subsequently set revolving about its center. If the line sweeps through 480° in 0.25 s, how fast is the disc spinning in rad/s?

25. [I] The angular speed of a wheel is to be determined by affixing a tiny mirror to the circumference and recording the returning light bounced off it as it spins past a laserbeam. If 100 return pulses are detected in 0.020 0 s, what is the angular speed of the wheel?

26. [I] What is the average angular speed of the Earth in its orbit? Take a year to be 365.24 days. Give your answer to three significant figures.

27. [I] Take the Earth to be moving in a circular orbit ($r_{\oplus\odot} = 1.495 \times 10^{11}$ m) about the Sun. Compute its average linear speed.

28. [I] When hit with a driver (having a head sloped at 10°), a golf ball sails off rotating at about 50 rev/s. Since the ball has a diameter of 4 cm, how fast is a point on its surface moving just as a result of the spin?

29. [I] A well-trained runner can swing a leg forward in the vertical plane around a horizontal axis through the knee at a rate of about 700° per second. How much is that in rad/s?

30. [I] What is the angular speed of the 10-cm-long second hand of a clock? What is ω for the same-length minute hand?

31. [I] THIS PROBLEM DEALS WITH AVERAGE ANGULAR ACCELERATION. A large horizontal disc, which can revolve about a vertical axis, begins at rest and attains an angular speed of 25.0 rad/s. It does this in a time of 2.00 s. (a) What is the disc's initial angular speed? (b) What is its average angular acceleration?

32. [I] THIS PROBLEM DEALS WITH AVERAGE ANGULAR ACCELERATION. The propeller on an old airplane starts from rest and accelerates at an average rate of 4.0 rad/s^2 for 1 minute and 20 seconds. (a) What is the propeller's initial speed? (b) How long, in seconds, was it

accelerating? (c) How fast will it be turning after 1 minute and 20 seconds?

33. [I] Thirty seconds after the start button is pressed on a big electric motor, its shaft is whirling around at 500 rev/s. Determine its average acceleration.

34. [I] A golf ball hit by the tilted face of a number 7 iron flies off spinning at 130 rev/s. If the impact lasts 1.0 ms, what is the average angular acceleration?

SOLUTION: $\alpha_{av} = \Delta\omega/\Delta t$

$$\alpha_{av} = \frac{(130 \text{ rev/s})(2\pi \text{ rad/rev})}{1.0 \times 10^{-3} \text{ s}} = 8.2 \times 10^5 \text{ rad/s}^2$$

35. [I] A steam engine is running at 200 rpm when the engineer shuts it off. The friction of its various parts produces torques that combine to decelerate the machine at 5.0 rad/s/s. How long will it take to come to rest?

36. [I] What average angular acceleration is required to stop a turbine blade spinning at 20 000 rpm in 50.0 s?

37. [II] When vinyl records were in their prime, most good players were fitted with a band of equal-spaced radial lines on the edge of the rotating platter on which the record sat. As the platter turned, a small lamp flickered at an exact rate. When the lines appeared to stand still, the platter was turning at the right speed. Suppose the light flashed on 60 times per second and the radial lines occurred every 3.33°. What's the proper angular speed of the platter in rpm?

38. [II] The motor in Fig. P38 is mounted with a 20-cm-diameter pulley and revolves at 100 rpm. We would like to drive the attic fan so that no point on each of its four 1.0-m-long blades exceeds a speed of 7.0 m/s. What size pulley should it have?

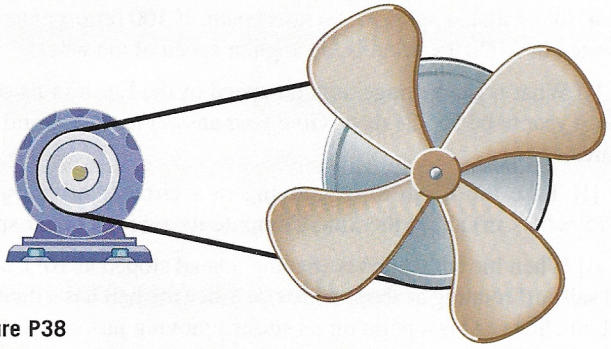

Figure P38

39. [II] A train rounds a turn 304.8 m (i.e., 1000 ft) in radius while traveling at a speed of 8.9 m/s (i.e., 20 mi/h). Determine its angular speed and centripetal acceleration. Give the answer in SI units.

40. [II] Imagine two ordinary gears of different diameters meshed together, with the larger being the driver. If the larger gear has 100 teeth around its circumference and rotates at 5.0 rad/s, the smaller gear, which has only 25 teeth, will rotate at what speed?

41. [II] The pulley on the left of Fig. P41 is 0.6 m in diameter and rotates at 1.0 rpm. It is attached by a twisted belt to the 0.2-m-diameter hub of a compound pulley whose outer diameter is 0.8 m. If the driver turns clockwise, find the velocity of the suspended body.

42. [II] Figure P42 shows the structure of a magnetic tape cassette. The tape is transported across the heads at a constant speed of $1\frac{7}{8}$ in/s. Contrary to popular belief, this is not done by driving the feed and take-up hubs. Why not? Actually, the tape is moved by being squeezed between a precisely rotating shaft—the capstan—and a soft pinch roller. If the capstan has a diameter of 3/32 in., how fast must it turn? Give the answer in SI units.

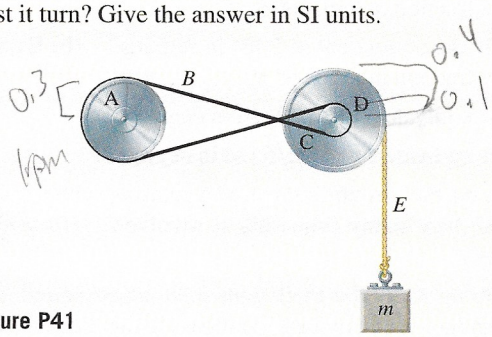

Figure P41

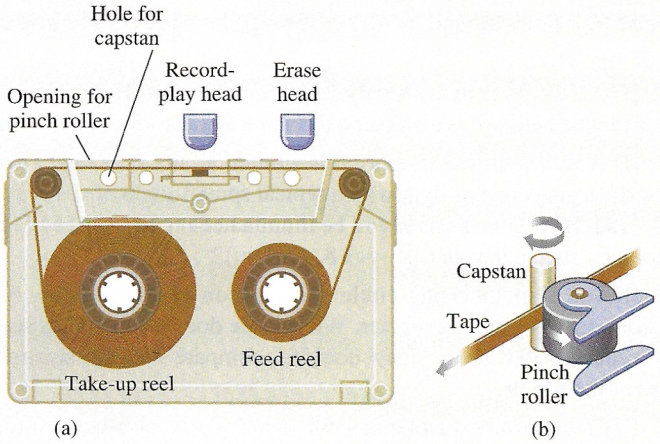

Figure P42

43. [II] New York City is traveling around at a tangential speed of about 353 m/s (i.e., 790 mi/h) as the Earth spins. Assuming the planet is a sphere of radius 6371 km, how long is the perpendicular from the city to the spin axis? Compute the city's latitude (i.e., the angle measured above or below the equator).

44. [II] Two spacecraft are freely coasting in circular orbits, one 2 km beneath the other. Referring to the conclusions of Chapter 5, compare their angular speeds and show that the lower ship will pull ahead of the upper one.

45. [II] A gear train consists of five meshed gears arranged so that the first (20 teeth) drives the second (80 teeth), which drives the third (40 teeth), and so on. If the first is mounted on the shaft of a 1500-rpm motor rotating clockwise, at what speed and in what direction will the fourth (25 teeth) and fifth (75 teeth) gears rotate? Figure out a general rule for the speed and direction of the last gear in such a train.

46. [II] The pegged wheel in Fig. P46 was a precursor of the modern cam. Here it's shown operating a trip hammer the same way it was used to crush ore and forge metal 1000 years ago in Europe. At what speed should the central drive shaft be turned, presumably by a waterwheel, for the hammer to pound away at one smash every 3 s?

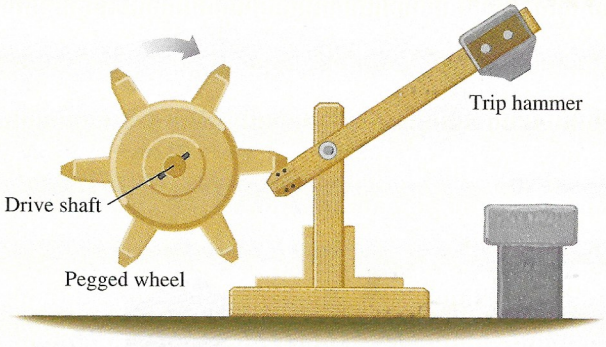

Figure P46

47. [III] A cylindrical wheel is rotating with a constant angular acceleration of 4.0 rad/s^2. At the instant it reaches an angular speed of 2.0 rad/s, a point on its rim experiences a total acceleration of 8.0 m/s^2. What is the radius of the wheel?

48. [III] A cord is wrapped around a 0.24-m-diameter pulley and the free end is tied to a weight. That weight is allowed to descend at a constant acceleration. A stopwatch is started at the instant when the weight reaches a speed of 0.02 m/s. At a time of $t = 2.0$ s, the weight has dropped an additional 0.10 m. Take $y = 0$ to occur at $t = 0$ and show that

$$y = (0.02t + 15 \times 10^{-3}t^2)\ \text{m}$$

Prove that for any point on the circumference

$$a_C = (33 \times 10^{-4} + 10 \times 10^{-3}t + 75 \times 10^{-4}t^2)\ \text{m/s}^2$$

and $$a_T = 0.03\ \text{m/s}^2.$$

49. [III] If the hand in Fig. P49 pulls down on the rope moving it at a speed of 2.0 m/s, what will be the resulting velocity of the hanging mass?

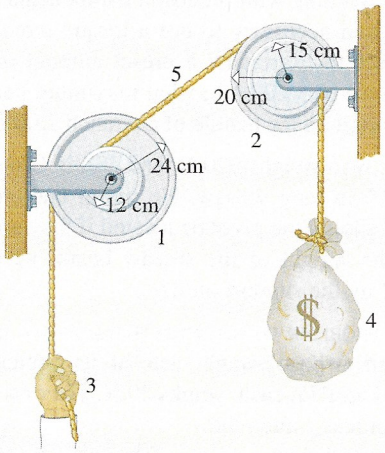

Figure P49

50. [III] Because of tidal friction, the Earth is despinning. Its period is increasing at a rate of roughly 25×10^{-9} s per day. Approximate the corresponding angular acceleration in rad/s^2. Compute the decrease in the Earth's angular speed that would exist one thousand million years from now, assuming α is constant. What will its new period be?

SECTION 8.4: EQUATIONS OF CONSTANT ANGULAR ACCELERATION

51. [I] A videodisc revolves at 1800 rpm beneath a laser read-out head. If the beam is 12 cm from the center of the disc, how many meters of data pass beneath it in 0.10 s?

52. [I] A variable speed electric drill motor turning at 100 rev/s is uniformly accelerated at 50.0 rev/s^2 up to 200 rev/s. How many turns does it make in the process?

53. [I] Placed on a long incline, a wheel is released from rest and rolls for 30.0 s until it reaches a speed of 10.0 rad/s. Assume its acceleration is constant, what angle did it turn through?

54. [I] A large motor-driven grindstone is spinning at 4 rad/s when the power is turned off. If it rotates through 100 rad as it uniformly comes to rest, what is its angular acceleration?

55. [II] A ring-shaped space satellite is revolving at 100 rev/min when its despin rockets are fired and it decelerates at a constant 2.0 rad/s^2. How long must the rockets fire in order to bring the craft's rotation to a stop? Through what angle will it turn in the process? [*Hint: The change in the speed over the time is the acceleration. And that will give you the time. There are several ways to get the angular displacement. Watch out for signs; t is positive.*]

56. [II] An antique spring-driven Victrola phonograph plays recordings at 78 rpm. At the end of each record the arm hits a lever that activates a brake that brings the platter to rest in about 1 s. Through how many radians does it turn in the process of stopping?

57. [II] A wheel is revolving at 20.0 rad/s when a brake is engaged and the wheel is brought to a uniform stop in 15.92 revolutions. How long did it take to stop the wheel and what was the deceleration?

58. [II] A bicycle with 24-in.-diameter wheels is traveling at 10 mi/h. At what angular speed do the wheels turn? How long do they take to turn once around?

59. [II] THIS PROBLEM DEALS WITH ANGULAR ACCELERATION. A large horizontal disc, which can revolve about a vertical axis, begins at rest and attains a speed of 25.0 rad/s. It does this while turning around exactly 10 times. (a) What was its average angular speed? (b) What was its angular displacement? (c) How long did it take to go the 10 turns? (d) Show that the disc had an average angular acceleration of 4.98 rad/s^2.

60. [II] THIS PROBLEM EXAMINES ANGULAR DISPLACEMENT. An electric motor attached to a set of fan blades starts from rest and accelerates at an average rate of 4.01 rad/s^2. After exactly 1 minute and 2 seconds the fuse blows and the motor coasts to a stop 120 s later. (a) What was the maximum angular speed it reached? (b) What was its average speed during the positive acceleration phase? (c) What was its average speed during the negative acceleration phase? (d) What was its angular displacement during the positive acceleration phase? (e) What was its angular displacement during the negative acceleration phase? (f) How many revolutions did the blades make in total?

61. [II] A 1.0-m-diameter nontranslating disk is made to accelerate from rest up to 20 rpm at a rate of 5 rad/s^2. Through how many turns will it revolve in the process? How far will a point on its rim travel while all this is happening?

62. [II] A bicycle has its gears set so that the front sprocket, which is driven by the pedals, has 52 teeth whereas the rear one, to which

it is attached via the chain, has 16 teeth. If it's pedaled at a most efficient 50 rpm and has 24-in. wheels, how fast is the bicycle moving? Give the answer in SI units.

63. [II] A chimp sitting on a yellow unicycle with a wheel diameter of 20 in. is pedaling away at 100 rpm. How fast does it travel? Give the answer in SI units.

64. [II] A wheel of radius R is freely rolling along a flat surface at an angular rate of ω. Determine, analytically, the linear speed (with respect to the ground at any instant) of (a) the center of the wheel (b) the topmost point, and (c) the point in contact with the ground.

65. [II] An electric circular saw reaches an operating speed of 1500 rpm in the process of revolving through 200 turns. Assuming the angular acceleration is constant, determine its value. How long does it take to get up to speed? Now redo the problem using the average angular speed.

66. [III] If the hand in Problem 49 uniformly accelerates the rope downward from rest at $1\frac{1}{3}$ m/s^2, how fast will the hanging mass be moving 1.0 s later?

67. [III] A 30-cm-diameter turntable platter of a record player is attached, by a belt (to reduce vibrations), to a motor-driven pulley 2.0 cm in diameter (Fig. P67). Determine the motor's angular acceleration if the platter is to reach $33\frac{1}{3}$ rpm in 6.0 s. How many rotations will it make before reaching operating speed?

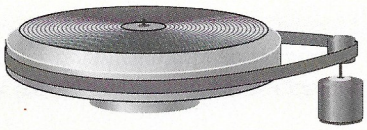

Figure P67

68. [III] An antique rim-drive record player has a 6.0-cm-diameter rubber wheel rotating in contact with the inner surface of the 30-cm-diameter platter (Fig. P68). If the turntable is to go from $33\frac{1}{3}$ rpm to 78 rpm in 3.0 s, what must be the angular acceleration of the drive wheel?

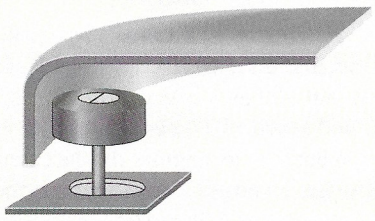

Figure P68

SECTION 8.5: TORQUE

SECTION 8.6: SECOND CONDITION OF EQUILIBRIUM

69. [I] A force of 100 N is applied perpendicularly to the middle of a meter stick; the stick lies north-south, the force points east. What is the size and sense of the torque around each end of the stick?

70. [I] Determine the torques about the elbow and shoulder produced by the 20-N weight in the outstretched hand in Fig. P70.

71. [I] Compute the torque about the pivot O, generated by the 100-N force on the gearshift lever in Fig. P71.

72. [I] Figure P72 shows a tendon exerting an 80-N force on bones in the lower leg. Assume the tendon acts horizontally 0.06 m from the knee pivot. Draw a simplified version of the system, and compute the tendon's torque about the pivot.

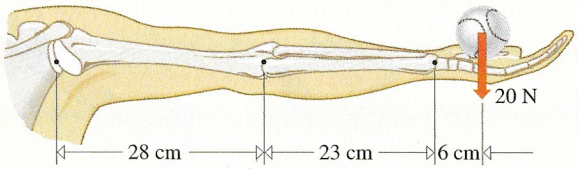

Figure P70

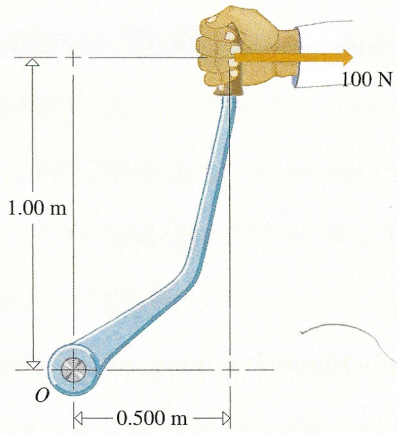

Figure P71

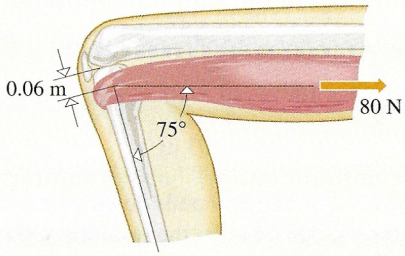

Figure P72

73. [I] While working with precision components, especially out in space, it is often necessary to use a torque wrench, a device that allows the user to exert only a preset amount of torque. Having dialed in a value of 35.0 N·m, what maximum perpendicular force should be exerted on the handle of a wrench 25.0 cm from the bolt?

74. [I] Harry, who weighs 320 N, and 200-N Gretchen are about to play on a 5.00-m-long seesaw. He sits at one end and she at the other. Where should the pivot be located if they are to be balanced? Neglecting the weight of the seesaw beam, what is the reaction force exerted by the support on it?

75. [I] THIS PROBLEM DEALS WITH ROTATIONAL EQUILIBRIUM. The uniform beam (whose weight acts at its center), and the mass on the left in Fig. P75, each weighs 20 N. The central pivot is essentially frictionless, and the system is in equilibrium. (a) Draw a free-body diagram of the beam. (b) How much does the mass on the right weigh? (c) Determine the reaction force exerted on the beam by the pivot.

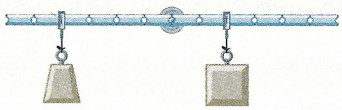

Figure P75

76. [I] THIS PROBLEM DEALS WITH ROTATIONAL EQUILIBRIUM. The uniform beam in Fig. P76 (whose weight acts at its center) is com-