21. (*a*) Where does the kinetic energy come from when a car accelerates uniformly starting from rest? (*b*) How is the increase in kinetic energy related to the friction force the road exerts on the tires?
22. Two identical arrows, one with twice the speed of the other, are fired into a bale of hay. Assuming the hay exerts a constant frictional force on the arrows, the faster arrow will penetrate how much farther than the slower arrow? Explain.
23. Analyze the motion of a simple swinging pendulum in terms of energy, (*a*) ignoring friction, and (*b*) taking it into account. Explain why a grandfather clock has to be wound up.
24. When a "superball" is dropped, can it rebound to a height greater than its original height?
25. Suppose you lift a suitcase from the floor to a table. Does the work you do on the suitcase depend on (*a*) whether you lift it straight up or along a more complicated path, (*b*) the time it takes, (*c*) the height of the table, and (*d*) the weight of the suitcase?
26. Repeat the previous question for the *power* needed rather than the work.
27. Why is it easier to climb a mountain via a zigzag trail rather than to climb straight up?
28. Recall from Chapter 4, Example 4–12, that you can use a pulley and ropes to decrease the force needed to raise a heavy load (see Fig. 6–34). But for every meter the load is raised, how much rope must be pulled up? Account for this, using energy concepts.

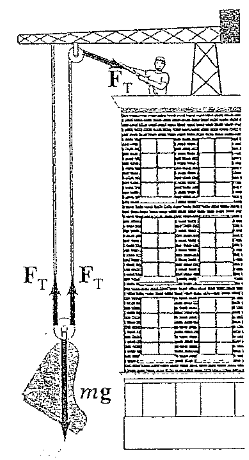

FIGURE 6–34 Question 28.

PROBLEMS

SECTION 6–1

1. (I) A 75.0-kg firefighter climbs a flight of stairs 10.0 m high. How much work is required?
2. (I) A 900-N crate rests on the floor. How much work is required to move it at constant speed (*a*) 6.0 m along the floor against a friction force of 180 N, and (*b*) 6.0 m vertically?
3. (I) How much work did the movers do (horizontally) pushing a 150-kg crate 12.3 m across a rough floor without acceleration, if the effective coefficient of friction was 0.70?
4. (I) A car does 7.0×10^4 J of work in traveling 2.8 km at constant speed. What was the average retarding force (from all sources) acting on the car?
5. (I) How high will a 0.325-kg rock go if thrown straight up by someone who does 115 J of work on it? Neglect air resistance.
6. (I) A hammerhead with a mass of 2.0 kg is allowed to fall onto a nail from a height of 0.40 m. What is the maximum amount of work it could do on the nail? Why do people not just "let it fall" but add their own force to the hammer as it falls?
7. (II) What is the minimum work needed to push a 1000-kg car 300 m up a 17.5° incline? (*a*) Ignore friction. (*b*) Assume the effective coefficient of friction is 0.25.
8. (II) A grocery cart with mass of 18 kg is pushed at constant speed along an aisle by a force $F = 12$ N. The applied force acts at a 20° angle to the horizontal. Find the work done by each of the forces on the cart if the aisle is 15 m long.
9. (II) Eight books, each 4.6 cm thick with mass 1.8 kg, lie flat on a table. How much work is required to stack them one on top of another?
10. (II) A 280-kg piano slides 4.3 m down a 30° incline and is kept from accelerating by a man who is pushing back on it *parallel to the incline* (Fig. 6–35). The effective coefficient of kinetic friction is 0.40. Calculate: (*a*) the force exerted by the man, (*b*) the work done by the man on the piano, (*c*) the work done by the friction force, (*d*) the work done by the force of gravity, and (*e*) the net work done on the piano.

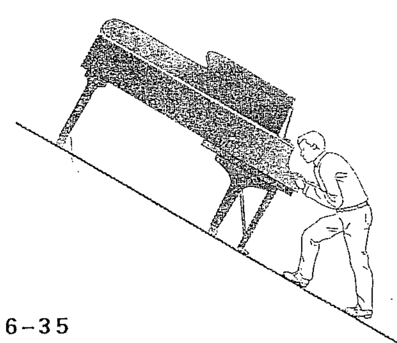

FIGURE 6–35
Problem 10.

11. (II) (*a*) Find the force required to give a helicopter of mass M an acceleration of $0.10\,g$ upward. (*b*) Find the work done by this force as the helicopter moves a distance h upward.

* SECTION 6–2

* 12. (II) In Fig. 6–6a, assume the distance axis is linear and that $d_A = 10.0$ m and $d_B = 35.0$ m. Estimate the work done by this force in moving a 2.80-kg object from d_A to d_B.

* 13. (II) The x component of the force on an object varies as shown in Fig. 6–36. Determine the work done by this force to move the object (*a*) from $x = 0.0$ to $x = 10.0$ m, and (*b*) from $x = 0.0$ to $x = 15.0$ m.

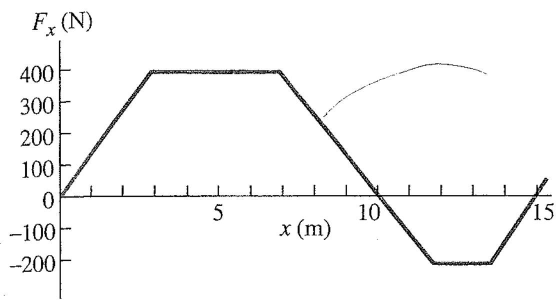

FIGURE 6–36 Problem 13.

* 14. (II) A spring has $k = 88$ N/m. Use a graph to determine the work needed to stretch it from $x = 3.8$ cm to $x = 5.8$ cm, where x is the displacement from its unstretched length.

* 15. (III) The x component of force exerted on a particle increases linearly from zero at $x = 0$, to 24.0 N at $x = 3.0$ m. It remains constant at 24.0 N from $x = 3.0$ m to $x = 8.0$ m, and then decreases linearly to zero at $x = 11.0$ m. Determine the work done to move the particle from $x = 0$ to $x = 11.0$ m graphically by determining the area under the F_x vs. x graph.

* 16. (III) A 1300-kg space vehicle falls from a vertical height of 2500 km above the Earth's surface. Use Eq. 5–4 to estimate how much work is done by the force of gravity in bringing the vehicle to the Earth's surface. (First construct an F vs. r graph, where r is the distance from the Earth's center; then determine the work graphically.)

SECTION 6–3

17. (I) At room temperature, an oxygen molecule, with mass of 5.31×10^{-26} kg, typically has a KE of about 6.21×10^{-21} J. How fast is it moving?

18. (I) (*a*) If the KE of an arrow is doubled, by what factor has its speed increased? (*b*) If its speed is doubled, by what factor does its KE increase?

19. (I) How much work is required to stop an electron ($m = 9.11 \times 10^{-31}$ kg) which is moving with a speed of 1.90×10^{6} m/s?

20. (I) How much work must be done to stop a 1000-kg car traveling at 110 km/h?

21. (II) An automobile is traveling along a highway at 90 km/h. If it travels instead at 100 km/h, what is the percent increase in the automobile's kinetic energy?

22. (II) An 80-g arrow is fired from a bow whose string exerts an average force of 95 N on the arrow over a distance of 80 cm. What is the speed of the arrow as it leaves the bow?

23. (II) A baseball ($m = 140$ g) traveling 35 m/s moves a fielder's glove backward 25 cm when the ball is caught. What was the average force exerted by the ball on the glove?

24. (II) If the speed of a car is increased by 50%, by what factor will its minimum braking distance be increased, assuming all else is the same? Ignore the driver's reaction time.

25. (II) At an accident scene on a level road, investigators measure a car's skid mark to be 88 m long. It was a rainy day and the coefficient of friction was estimated to be 0.42. Use these data to determine the speed of the car when the driver slammed on (and locked) the brakes. (Why does the car's mass not matter?)

26. (II) A softball having a mass of 0.25 kg is pitched at 95 km/h. By the time it reaches the plate, it may have slowed by 10 percent. Neglecting gravity, estimate the average force of air resistance during a pitch, if the distance between the plate and the pitcher is about 15 m.

27. (III) One car has twice the mass of a second car, but only half as much kinetic energy. When both cars increase their speed by 5.0 m/s, they then have the same kinetic energy. What were the original speeds of the two cars?

28. (III) A 220-kg load is lifted 21.0 m vertically with an acceleration $a = 0.150\,g$ by a single cable. Determine (*a*) the tension in the cable, (*b*) the net work done on the load, (*c*) the work done by the cable on the load, (*d*) the work done by gravity on the load, and (*e*) the final speed of the load assuming it started from rest.

SECTIONS 6–4 AND 6–5

29. (I) A spring has a spring constant, k, of 440 N/m. How much must this spring be stretched to store 25 J of potential energy?

30. (I) A 6.0-kg monkey swings from one branch to another 1.2 m higher. What is the change in potential energy?

31. (I) By how much does the gravitational potential energy of a 64-kg pole vaulter change if his center of mass rises about 4.0 m during the jump?

32. (II) In starting an exercise, a 1.60-m tall person lifts a 2.10-kg book on the ground so it is 2.20 m above the ground. What is the potential energy of the book relative to (*a*) the ground, and (*b*) the top of the person's head? (*c*) How is the work done by the person related to the answers in parts (*a*) and (*b*)?

33. (II) A 55-kg hiker starts at an elevation of 1600 m and climbs to the top of a 3100-m peak. (*a*) What is the hiker's change in potential energy? (*b*) What is the minimum work required of the hiker? (*c*) Can the actual work done be more than this? Explain why.

34. (II) (*a*) A spring of spring constant k is initially compressed a distance x_0 from its unstretched length. What is the change in potential energy if it is then compressed to an amount x from its unstretched length? (*b*) Suppose the spring is then *stretched* a distance x_0 from the unstretched length. What is the change in potential energy as compared to when it is compressed by an amount x_0?

SECTIONS 6–6 AND 6–7

35. (I) Jane, looking for Tarzan, is running at top speed (5.6 m/s) and grabs a vine hanging vertically from a tall tree in the jungle. How high can she swing upward? Does the length of the vine (or rope) affect your answer?

36. (I) A novice skier, starting from rest, slides down a frictionless 35.0° incline whose vertical height is 125 m. How fast is she going when she reaches the bottom?

37. (I) A sled is initially given a shove up a frictionless 25.0° incline. It reaches a maximum vertical height 1.35 m higher than where it started. What was its initial speed?

38. (II) In the high jump, the kinetic energy of an athlete is transformed into gravitational potential energy without the aid of a pole. With what minimum speed must the athlete leave the ground in order to lift his center of mass 2.10 m and cross the bar with a speed of 0.70 m/s?

39. (II) A 75-kg trampoline artist jumps vertically upward from the top of a platform with a speed of 5.0 m/s. (*a*) How fast is he going as he lands on the trampoline, 3.0 m below (Fig. 6–37)? (*b*) If the trampoline behaves like a spring of spring constant 5.2×10^4 N/m, how far does he depress it?

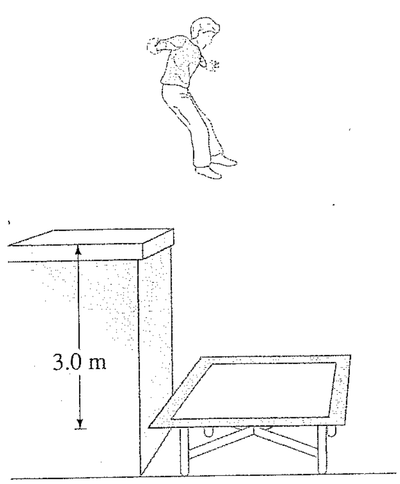

FIGURE 6–37 Problem 39.

40. (II) A roller coaster, shown in Fig. 6–38, is pulled up to point *A* where it and its screaming occupants are released from rest. Assuming no friction, calculate the speed at points *B, C, D*.

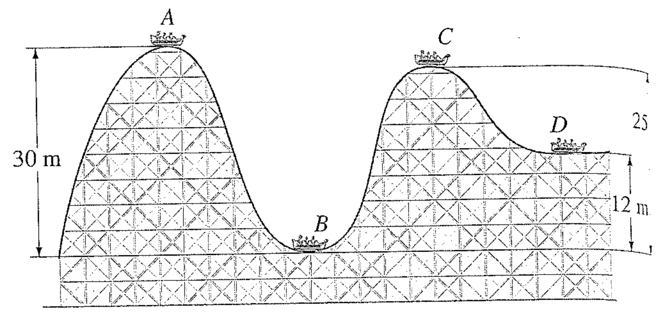

FIGURE 6–38 Problems 40 and 53.

41. (II) A projectile is fired at an upward angle of 45.0° from the top of a 265-m cliff with a speed of 185 m/s. What will be its speed when it strikes the ground below? (Use conservation of energy.)

42. (II) A 60-kg bungee jumper jumps from a bridge. She is tied to a 12-m-long bungee cord and falls a total of 31 m. (*a*) Calculate the spring constant k of the bungee cord. (*b*) Calculate the maximum acceleration experienced by the jumper.

43. (II) A vertical spring (ignore its mass), whose spring constant is 900 N/m, is attached to a table and is compressed 0.150 m. (*a*) What speed can it give to a 0.300-kg ball when released? (*b*) How high above its original position (spring compressed) will the ball fly?

44. (II) A small mass m slides without friction along the looped apparatus shown in Fig. 6–39. If the object is to remain on the track, even at the top of the circle (whose radius is r), from what minimum height h must it be released?

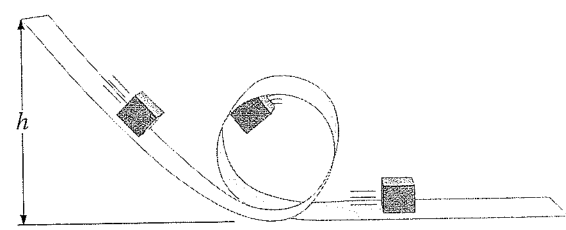

FIGURE 6–39 Problems 44 and 79.

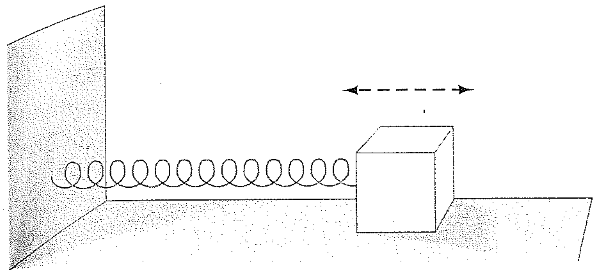

FIGURE 6–40 Problems 45, 55, 56, and 78.

45. (II) A mass m is attached to the end of a spring (constant k), Fig. 6–40. The mass is given an initial displacement x_0, after which it oscillates back and forth. Write a formula for the total mechanical energy (ignore friction and mass of the spring) in terms of position x and speed v.

46. (III) An engineer is designing a spring to be placed at the bottom of an elevator shaft. If the elevator cable should happen to break at a height h above the top of the spring, calculate the value that the spring constant k should have so that passengers undergo an acceleration of no more than $5.0\,g$ when brought to rest. Let M be the total mass of the elevator and passengers.

47. (III) What should be the spring constant k of a spring designed to bring a 1200-kg car to rest from a speed of 100 km/h so that the occupants undergo a maximum acceleration of $5.0\,g$?

48. (III) A cyclist intends to cycle up a 7.50° hill whose vertical height is 120 m. Assuming the mass of bicycle plus person is 75.0 kg, (*a*) calculate how much work must be done against gravity. (*b*) If each complete revolution of the pedals moves the bike 5.10 m along its path, calculate the average force that must be exerted on the pedals tangent to their circular path. Neglect work done by friction and other losses. The pedals turn in a circle of diameter 36.0 cm.

SECTIONS 6–8 AND 6–9

49. (I) Two railroad cars, each of mass 6500 kg and traveling 95 km/h, collide head-on and come to rest. How much thermal energy is produced in this collision?

50. (II) A 17-kg child descends a slide 3.5 m high and reaches the bottom with a speed of 2.5 m/s. How much thermal energy due to friction was generated in this process?

51. (II) A ski starts from rest and slides down a 20° incline 100 m long. (*a*) If the coefficient of friction is 0.090, what is the ski's speed at the base of the incline? (*b*) If the snow is level at the foot of the incline and has the same coefficient of friction, how far will the ski travel along the level? Use energy methods.

52. (II) A 90-kg crate, starting from rest, is pulled across a floor with a constant horizontal force of 350 N. For the first 15 m the floor is frictionless, and for the next 15 m the coefficient of friction is 0.30. What is the final speed of the crate?

53. (II) Suppose the roller coaster in Fig. 6–38 passes point A with a speed of 1.70 m/s. If the average force of friction is equal to one fifth of its weight, with what speed will it reach point B? The distance traveled is 45.0 m.

54. (II) A skier traveling 12.0 m/s reaches the foot of a steady upward 18° incline and glides 12.2 m up along this slope before coming to rest. What was the average coefficient of friction?

55. (III) A 0.520-kg wood block is firmly attached to a very light horizontal spring ($k = 180$ N/m) as shown in Fig. 6–40. It is noted that the block-spring system, when compressed 5.0 cm and released, stretches out 2.3 cm beyond the equilibrium position before stopping and turning back. What is the coefficient of kinetic friction between the block and the table?

56. (III) A 180-g wood block is firmly attached to a very light horizontal spring, Fig. 6–40. The block can slide along a table where the coefficient of friction is 0.30. A force of 20 N compresses the spring 18 cm. If the spring is released from this position, how far beyond its equilibrium position will it stretch on its first swing?

57. (III) In early test flights for the space shuttle using a "glider" (mass of 1000 kg including pilot), it was noted that after a horizontal launch at 500 km/h at a height of 3500 m, the glider eventually landed at a speed of 200 km/h. (*a*) What would its landing speed have been in the absence of air resistance? (*b*) What was the average force of air resistance exerted on it if it came in at a constant glide of 10° to the Earth?

SECTION 6–10

58. (I) How long will it take a 1750-W motor to lift a 285-kg piano to a sixth-story window 16.0 m above?

59. (I) If a car generates 18 hp when traveling at a steady 90 km/h, what must be the average force exerted on the car due to friction and air resistance?

60. (I) (*a*) Show that a British horsepower (550 ft·lb/s) is equal to 746 W. (*b*) What is the horsepower rating of a 100-W lightbulb?

61. (II) Electric energy units are often expressed in the form of "kilowatt-hours." (*a*) Show that one kilowatt-hour (kWh) is equal to 3.6×10^6 J. (*b*) If the typical family of four in the United States uses electric energy at an average rate of 500 W, how many kWh would their electric bill be for one month, and (*c*) how many joules would this be? (*d*) At a cost of \$0.12 per kWh, what would their monthly bill be in dollars? Does the monthly bill depend on the *rate* at which they use the electric energy?

62. (II) A driver notices that her 1000-kg car slows down from 90 km/h to 70 km/h in about 6.0 s on the level when it is in neutral. Approximately what power (watts and hp) is needed to keep the car traveling at a constant 80 km/h?

63. (II) How much work can a 3.0-hp motor do in 1.0 h?

64. (II) A shot-putter accelerates a 7.3-kg shot from rest to 14 m/s. If this motion takes 2.0 s, what average power was developed?

65. (II) A pump is to lift 8.00 kg of water per minute through a height of 3.50 m. What output rating (watts) should the pump motor have?

66. (II) During a workout, the football players at State U ran up the stadium stairs in 61 s. The stairs are 140 m long and inclined at an angle of 30°. If a typical player has a mass of 105 kg, estimate the average power output on the way up. Ignore friction and air resistance.

67. (II) How fast must a cyclist climb a 6.0° hill to maintain a power output of 0.25 hp? Neglect work done by friction and assume the mass of cyclist plus bicycle is 70 kg.

68. (II) A 1000-kg car has a maximum power output of 120 hp. How steep a hill can it climb at a constant speed of 70 km/h if the frictional forces add up to 600 N?

69. (II) Squaw Valley ski area in California claims that its lifts can move 47,000 people per hour. If the average lift carries people about 200 m (vertically) higher, estimate the maximum total power needed.

70. (III) A bicyclist coasts down a 7.0° hill at a steady speed of 5.0 m/s. Assuming a total mass of 75 kg (bicycle plus rider), what must be the cyclist's power output to climb the same hill at the same speed?

GENERAL PROBLEMS

71. A paratrooper fell 370 m after jumping from an aircraft without his parachute opening. He landed in a snowbank, creating a crater 1.1 m deep, but survived with only minor injuries. Assuming the paratrooper's mass was 80 kg and his terminal velocity was 30 m/s, estimate: (*a*) the work done by the snow in bringing him to rest; (*b*) the average force exerted on him by the snow to stop him; and (*c*) the work done on him by air resistance as he fell.

72. Designers of today's cars have built "5 mi/h (8 km/h) bumpers" that are designed to elastically compress and rebound without any physical damage at speeds below 8 km/h. If the material of the bumpers permanently deforms after a compression of 1.5 cm, but remains like an elastic spring up to that point, what must the effective spring constant of the bumper material be, assuming the car has a mass of 1400 kg and is tested by ramming into a solid wall?

73. In a certain library the first shelf is 10.0 cm off the ground, and the remaining 4 shelves are each spaced 30.0 cm above the previous one. If the average book has a mass of 1.5 kg with a height of 20 cm, and an average shelf holds 25 books, how much work is required to fill this bookshelf from scratch, assuming the books are all laying flat on the floor to start?

74. In a film of Jesse Owens's famous long jump in the 1936 Olympics, it is observed that his center of mass rose 1.1 m from launch point to the top of the arc. What minimum speed did he need at launch if he was also noted to be traveling at 6.5 m/s at the top of the arc?

75. A 0.20-kg pinecone falls from a branch 18 m above the ground. (*a*) With what speed would it hit the ground if air resistance could be ignored? (*b*) If it actually hits the ground with a speed of 10.0 m/s, what was the average force of air resistance exerted on it?

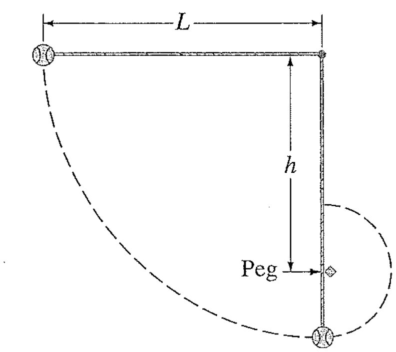

FIGURE 6–41 Problem 76.

76. A ball is attached to a horizontal cord of length L whose other end is fixed, Fig. 6–41. (*a*) If the ball is released, what will be its speed at the lowest point of its path? (*b*) A peg is located a distance h directly below the point of attachment of the cord. If $h = 0.80\,L$, what will be the speed of the ball when it reaches the top of its circular path about the peg?

77. A 65-kg hiker climbs to the top of a 3900-m-high mountain. The climb is made in 5.0 h starting at an elevation of 2200 m. Calculate (*a*) the work done against gravity, (*b*) the average power output in watts and in horsepower, and (*c*) assuming the body is 15% efficient, what rate of energy input was required.

78. A mass m is attached to the end of a spring (constant k) as shown in Fig. 6–40. The mass is given an initial displacement x_0 from equilibrium, and an initial speed v_0. Ignoring friction and the mass of the spring, use energy methods to find (*a*) its maximum speed, and (*b*) its maximum stretch from equilibrium, in terms of the given quantities.

79. The small mass m sliding without friction along the looped apparatus shown in Fig. 6–39 is to remain on the track at all times, even at the very top of the loop of radius r. (a) Calculate, in terms of the given quantities, the minimum release height h (as in Problem 44). Next, if the actual release height is $2h$, calculate (b) the normal force exerted by the track at the bottom of the loop, (c) the normal force exerted by the track at the top of the loop, and (d) the normal force exerted by the track after the block exits the loop onto the flat section.

80. An elevator cable breaks when a 900-kg elevator is 30 m above a huge spring ($k = 4.0 \times 10^5$ N/m) at the bottom of the shaft. Calculate (a) the work done by gravity on the elevator before it hits the spring, (b) the speed of the elevator just before striking the spring, and (c) the amount the spring compresses (note that work is done by both the spring and gravity in this part).

81. Water flows over a dam at the rate of 550 kg/s and falls vertically 80 m before striking the turbine blades. Calculate: (a) the speed of the water just before striking the turbine blades (neglect air resistance), and (b) the rate at which mechanical energy is transferred to the turbine blades, assuming 60% efficiency.

82. A bicyclist of mass 75 kg (including the bicycle) can coast down a 4.0° hill at a steady speed of 10 km/h. Pumping hard, the cyclist can descend the hill at a speed of 30 km/h. Using the same power, at what speed can the cyclist climb the same hill? Assume the force of friction is proportional to the square of the speed v; that is, $F_{fr} = bv^2$, where b is a constant.

83. Show that on a roller coaster with a circular vertical loop (Fig. 6–42), the difference in your apparent weight at the top of the loop and the bottom of the loop is 6 g's—that is, six times your weight. Ignore friction. Show also that as long as your speed is above the minimum needed, this answer doesn't depend on the size of the loop or how fast you go through it.

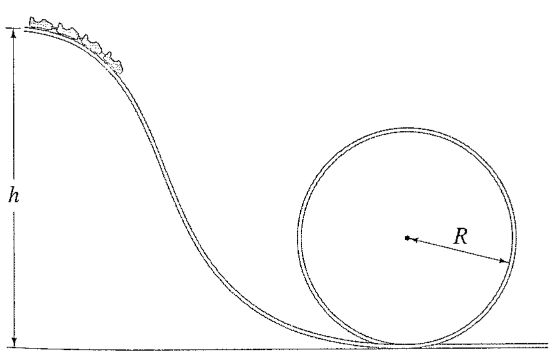

FIGURE 6–42 Problem 83.

84. If you stand on a bathroom scale, the spring inside the scale compresses 0.50 mm, and it tells you your weight is 700 N. Now if you jump on the scale from a height of 1.0 m, what does the scale read at its peak?

85. A 75-kg student runs at 5.0 m/s, grabs a rope, and swings out over a lake (Fig. 6–43). He releases the rope when his velocity is zero. (a) What is the angle θ when he releases the rope? (b) What is the tension in the rope just before he releases it? (c) What is the maximum tension in the rope?

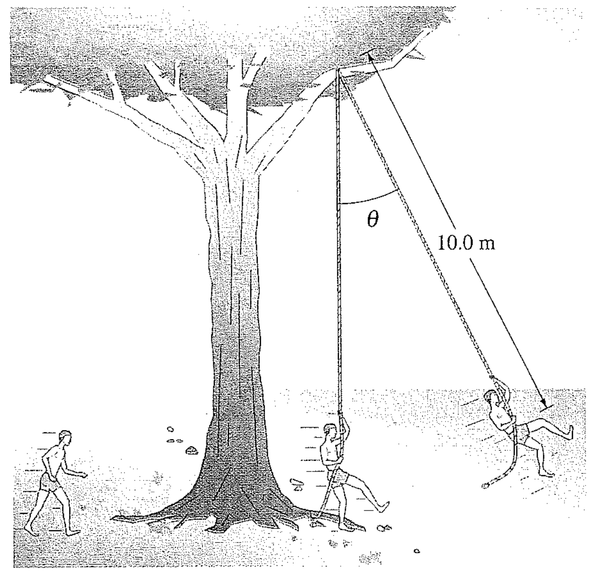

FIGURE 6–43 Problem 85.

86. In the rope climb, a 70-kg athlete climbs a vertical distance of 5.0 m in 9.0 s. What minimum power output was used to accomplish this feat?