10. [I] A 2224-N piano is rolled on little wheels a distance of 3.1 m across a horizontal floor by an 890-N piano mover. If, while lifting upward on one end with 111 N, he pushes horizontally with 445 N, how much work will he do?

11. [I] A nurse pushes someone in a wheelchair 100 m doing 400 J of work in the process. What average horizontal force did the nurse exert in the direction of motion?

12. [I] THIS PROBLEM APPLIES THE PHYSICAL CONCEPT OF WORK. A constant horizontal push of 4.0 N is applied to a 5.0-kg bag of marbles which travels 8.2 m at a constant speed across a horizontal table in the direction of the force. (a) What is the value of the horizontal acceleration of the bag? (b) How much work is done in overcoming friction?

13. [I] THIS PROBLEM APPLIES THE PHYSICAL CONCEPT OF WORK. A 20.0-kg dog stands on a frictionless inclined plane. A constant upward 60.0-N force parallel to the incline is applied to the butt of the dog. As a result the dog slides upward 12.0 m along the surface. (a) What is the component of the applied force in the direction of the motion? (b) How much work is done on the dog by that force? (c) What was this work done against?

14. [I] A newspaper delivery boy pulls horizontally on a rubber-wheeled cart that has a coefficient of rolling friction of 0.02 and a mass of 25 kg. It travels 10 km on level streets. How much work does he do in overcoming friction between the cart and the ground?

**15.** [I] When a solid-fuel rocket burns, the flame front advances into the material in a direction perpendicular to the ignited surface. By configuring the fuel core in various ways and lighting it along the entire length, one can obtain all sorts of performance characteristics. Figure P15 shows a starred-cavity motor. How much work was done by the device in the first 90 s of flight if the rocket rose vertically to a height of 2.0 km in that time?

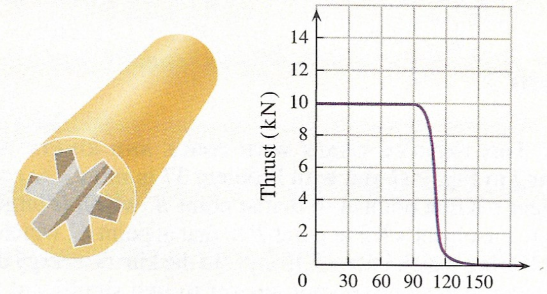


**Figure P15**

16. [II] A rigid steel crowbar is rested on an upright brick standing near the back of a car. The end of the bar touches the bottom of the bumper 30 cm from its pivot point on the brick. Someone pushes straight down on the other end of the bar, 270 cm from the pivot point, and raises the car's chassis 5.0 cm. Given ideally that the work-in equals the work-out, if it takes 3200 N to raise the car, how much force did the person exert on the bar?

SOLUTION: The two distances to the pivot are 30 cm and 270 cm which are in the ratio of 1 to 9. Accordingly, the geometry is such that if one end goes up 5.0 cm, the other goes down 9 times as much, or 45.0 cm. The work done on the car is $W = Fh = (3200\text{ N})(5.0 \times 10^{-2}\text{ m}) = 1.6 \times 10^2$ J and that must be the work done by the person. Thus $1.6 \times 10^2\text{ J} = Fl$, $F = (1.6 \times 10^2\text{ J})/(45.0 \times 10^{-2}\text{ m}) = 3.6 \times 10^2$ N.

17. [II] Assuming no friction and weightless pulleys, how much rope will have to be drawn off if the weight in Fig. P17 is to be raised 1.0 m? Remember: ideally, work-in equals work-out.

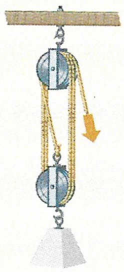

**Figure P17**

18. [II] A pickup truck is hauling a barge along a canal at a constant speed. The truck, driving parallel to the waterway, is attached to the barge by a cable tied to the bow making a 30° angle with the forward direction. If the truck exerts a force of 1000 N on the cable, how much work is done in overcoming friction as the barge is moved 10 km?

19. [II] A person having a mass of 59.1 kg stands before a flight of 30 stairs each of which is 25.0 cm high. He runs up 20 stairs, turns around, walks down 10, changes his mind, and goes up the remaining 20. How much work did he do in overcoming gravity?

20. [II] While testing a model of a cannon, a 1.0-kg ball is fired straight up into the air. It rises 22.5 m and falls back to the height at which it was launched. What is the net amount of work done on the ball by gravity?

SOLUTION: Gravity does the same amount of negative work on the way up as positive work on the way down, and so the net work it does is zero.

**21.** [II] A 100-N box, which is on the ground, is slid along a 13-m-long ramp up to a platform 5.0 m above the ground. How much work is done if friction is negligible? How much work would have been done if the box were lifted straight up to the platform? [*Hint: Use the definition of work where it is the component of the weight down the incline ($F_W \sin\theta$) that must be overcome. Notice that* $\sin\theta = 5/13$.]

22. [II] Several crates, having a total weight of 400 N, are loaded into a 10.0-kg wagon that is then pulled up a wooden ramp 10.0-m long making an angle of 30.0°. Knowing that friction was negligible, how much work was done?

23. [II] Starting from rest, a 25.0-kg kid runs up a 5.0-m long slide. At the end he is standing still 3.0 m higher than at the start; how much work did he do?

24. [II] A 50-kg keg of beer slides upright down a 3.0-m-long plank leading from the back of a truck 1.5 m high to the ground. Determine the amount of work done on the keg by gravity.

SOLUTION: The keg descends 1.5 m in the gravitational field. $W_g = F_W h = mgh = (50\text{ kg})(9.81\text{ m/s}^2)(1.5\text{ m}) = 7.4 \times 10^2$ J.

25. [II] The newspaper boy in Problem 14 pushes his cart 25 m along a road inclined at 10°. How much work does he do to overcome road friction?

26. [II] Five fat dictionaries, each 10-cm thick and each 2.5 kg, are resting side by side flat on a table 1.0 m high. How much work would it take to stack them one atop the other?

**27.** [II] A constant force of 100 N is applied to an object over a straight distance of 2.0 m parallel to the displacement. Draw a work diagram ($F$ vs. $l$) with a scale of 1.0 cm = 10 N and 1.0 cm = 0.25 m. (a) What was the total work done? (b) How much work does an area of 1.0 $cm^2$ equal? (c) What is the area under the curve?

28. [II] Efficiency is defined as work-out/work-in. Muscles operate with an efficiency of about 20% in converting energy internally into work externally. Accordingly, how much energy will be expended

by a 60-kg person in the process of ascending several flights of stairs to a height of 25 m?

29. [II] A variable force, depicted in Fig. P29, acts on a 10-kg body. How much work does it do in moving the body from $x = 2$ to $x = 6$? What is the total amount of work done in going from $x = 0$ to $x = 10$? Over which 1-m interval was the smallest amount of work done? How much work is done in going from $x = 2$ to $x = 12$?

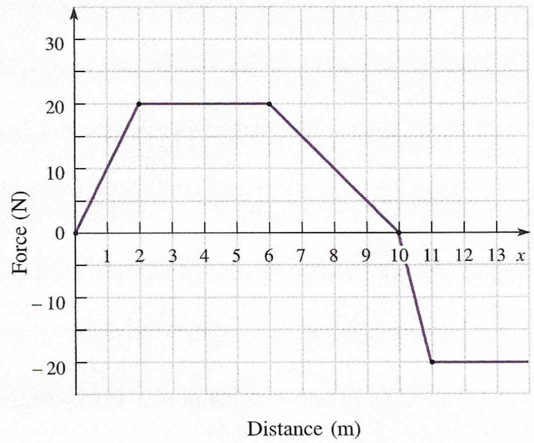


**Figure P29**

30. [II] THIS PROBLEM EXAMINES WORK DONE OVERCOMING FRICTION. A locked car weighing 6.0 kN has its parking brake on. The coefficient of kinetic friction for rubber on concrete is 1. (a) What will be the value of the friction force on the car once it is set in motion? (b) What force must be exerted horizontally to slide the car at a slow constant speed? (c) How much work will be expended in pushing the car, very slowly, 10.0 m horizontally?

31. [II] THIS PROBLEM EXAMINES WORK DONE OVERCOMING FRICTION. A string making an angle of 30.0° up from the horizontal is attached to a bust of Newton which is being dragged at a constant speed across the floor. (a) What is the significance of the fact that the speed is constant? (b) If the tension in the string is 10.0 N, what is the magnitude of the component of the tensile force parallel to the floor? (c) How much work is done in overcoming friction while the bust moves 3.0 m?

## SECTION 6.2: KINETIC ENERGY

32. [I] Which graph in Fig. P32 best represents the kinetic energy of a mass as a function of speed?

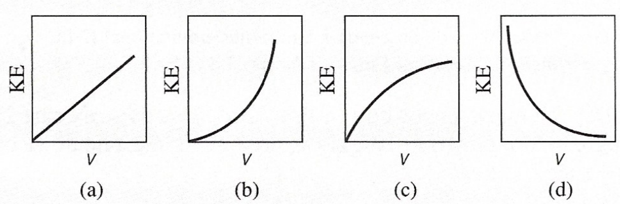


**Figure P32**

33. [I] Rockets fire, and a $3.20 \times 10^4$ kg spaceship moves straight away from a docking station reaching a top speed of 200 m/s. With respect to an observer on the station, what's the ship's maximum kinetic energy?

34. [I] The record average speed for the men's 10-km walk is 4.4 m/s. How much kinetic energy would a 70-kg athlete have at that speed?

35. [I] The men's world swimming record for the 50-m freestyle corresponds to an average speed of about 2.29 m/s. If the swimmer has a mass of 75.0 kg, what's his average kinetic energy during the race?

36. [I] A major concern in the design of spacecraft is the presence in space of tiny, high-speed meteoroids. Micrometeoroids, as they're called, have been detected traveling as fast as 70 km/s. Compute the kinetic energy of a 1.0-g mass moving at that rate.

37. [I] THIS PROBLEM DEALS WITH FORCE AND KINETIC ENERGY. Figure P37 is the force versus distance curve for a changing force acting on an object that was at rest at $t = 0$. The direction of motion, across a frictionless horizontal surface, is always along the line-of-action of the force. (a) When is the object's acceleration constant? (b) When is the object's acceleration not constant? (c) When is the object's acceleration zero? (d) Is the object moving and/or accelerating at each of the following points: point-*A*, point-*B*, point-*C*, point-*E*, point-*F*, and point-*H*? (e) During which interval, if any, was the kinetic energy nonzero and constant?

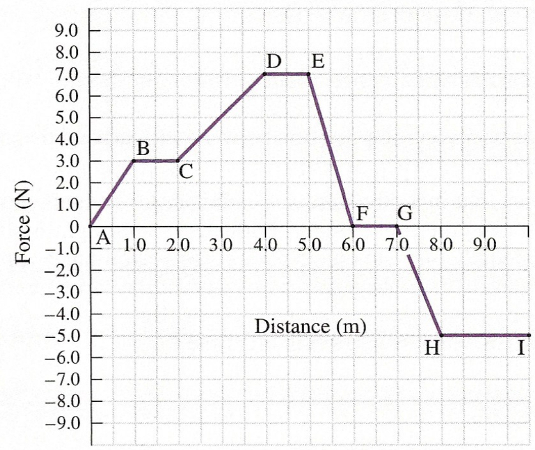


**Figure P37**

38. [I] THIS PROBLEM DEALS WITH FORCE AND KINETIC ENERGY. Referring to Fig. P37 and with Problem 37 in mind, (a) compare the object's KE at point-*A* to that at point-*B*, which is larger? (b) Compare the object's KE at point-*B* to that at point-*C*, which is larger? (c) During which interval, if any, did the kinetic energy decrease and by how much? Give your answer to two significant figures.

**39.** [I] It has been suggested that a controlled fusion reaction (a mini-H-bomb) could be achieved by causing a small (on the order of 1 mm), extremely high-speed projectile to hit a stationary target, both made of the appropriate materials. Determine the kinetic energy of a 0.5-g mass traveling at 200 km/s.

40. [I] One ton of uranium-235 can provide about $7.4 \times 10^{16}$ J of nuclear energy. If that much energy went into accelerating a $3.5 \times 10^6$-kg spaceship (that's the size of a fully loaded *Saturn V* Moon rocket) from rest, what would its final speed be?

**SOLUTION:** There are $7.4 \times 10^{16}$ J available that will go into KE and so KE $= \frac{1}{2}mv^2 = \frac{1}{2}(3.5 \times 10^6 \text{ kg})\, v^2 = 7.4 \times 10^{16}$ J: solving for $v$: $v^2 = 2(7.4 \times 10^{16} \text{ J})/(3.5 \times 10^6 \text{ kg}) = 4.229 \times 10^{10} \text{ m}^2/\text{s}^2$: $v = 2.1 \times 10^5$ m/s.

*41.* [I] A 6.5-g bullet is fired from a 2.0-kg rifle with a speed of 300 m/s. What is the kinetic energy of the bullet?

42. [II] Suppose that a 0.149-kg baseball is traveling at 40.0 m/s. How much work must be done on the ball to stop it? If it's brought to rest in 2.0 cm, what average force must act on the ball?

43. [II] The shot used by male shot-putters has a mass of 7.26 kg. A

good throw (which might go roughly 23 m) would correspond to a launch at about 14 m/s. Determine the shot's kinetic energy and compare that to the kinetic energy of a 149-g baseball thrown at a record pitching speed of 45 m/s. Can you explain the difference, that is, where does that energy difference go when a baseball is thrown? Surely the pitcher is trying just as hard as the shot-putter.

44. [II] During a throw (Problem 43) a shot is initially swung around (see Fig. P44) in a circle reaching a speed of about 3.5 m/s. It is then accelerated, more or less, in a straight line over a distance of about 1.7 m, leaving the hand at roughly 14 m/s. (a) How much kinetic energy does the shot initially get in the turning phase? (b) How much kinetic energy does it pick up in the straight-line portion of the launch? (c) What's the average force exerted on the shot during this latter part of the launch? Compare this to the measured peak force of 600 N. Is that reasonable?

**Figure P44**

45. [II] While swinging a golf club, about 30% of the work done by the player goes into the KE of his arms and body, 20% becomes the KE of the club's shaft, and the remaining 50% ends up as the KE of the head. Typically, a 0.20-kg club head attains a top speed of 50 m/s. Determine the total amount of work done by the swinger.

46. [II] A video of a 70.0-kg male sprinter shows him going from zero to 3.0 m/s on the first step, reaching 4.2 m/s on the second step, and 5.1 m/s on the third step. Compare the speed he gained in each step and the energy gained in each. What can be said about the work he was doing? Remember too that the faster a muscle must act, the less work it can perform.

47. [II] Laboratory studies have shown that a runner at a speed of 6 m/s in still air uses about 7.5 % of his total energy output in overcoming air drag. And that increases to 13% at about 10 m/s. Ignoring all other losses, how much metabolic energy, or work, must a 70-kg sprinter do to reach a speed of 10 m/s?

48. [III] A runner accelerates to a top speed of 9.9 m/s, taking a number of strides ($N$). If the average horizontal force exerted on the ground is 1.5 times body-weight, and if it acts during each stride over a length of $\frac{1}{3}$ m, determine the value of $N$.

49. [III] A 0.046-kg golf ball is driven from rest to 70 m/s in about 1.0 ms. Determine the kinetic energy of the ball, and approximate the distance over which the club acted on the ball.

## SECTION 6.3: POTENTIAL ENERGY

50. [I] What is the kinetic and potential energy of a Boeing 747 airliner weighing $2.22 \times 10^6$ N, flying at 268 m/s (i.e., 600 mi/h) at an altitude of 6.1 km (i.e., $20 \times 10^3$ ft)?

**SOLUTION:** $\text{KE} = \frac{1}{2}mv^2 = \frac{1}{2}[(2.22 \times 10^6\ \text{N})/g](268\ \text{m/s})^2 = 8.13 \times 10^9\ \text{J}$: $\text{PE}_G = mgh = (2.22 \times 10^6\ \text{N})/g)(g)(6.1 \times 10^3\ \text{m}) = 1.35 \times 10^{10}\ \text{J}$.

51. [I] A single barrel of oil contains the equivalent *chemical*-PE of about $6 \times 10^9$ J. How high in the air could that much energy raise a million kilogram load, assuming it is all converted to *gravitational*-PE? [*Hint: Use the definition of* $\text{PE}_G$ *assuming g is constant.*]

52. [I] The energy content of beer is about $1.8 \times 10^6$ J/kg. If that energy could be turned completely into *gravitational*-PE, how much beer would we need to raise a 1.0-kg mass 1.0 km into the air?

53. [I] The daily food intake for an adult male is equivalent to about $1.3 \times 10^7$ J. Assuming 100% efficiency in its utilization, roughly how high a mountain could an 80-kg man climb on that much energy?

54. [I] A uniform rod 6.0-m long, weighing 60 N, is pivoted about a horizontal axis 1.0 m up from its center so that it hangs vertically. Neglecting friction, (a) what's the net work done on the rod by gravity in the process of raising its end, making it horizontal? (See if you can come up with two ways to do this.) (b) What change in potential energy, if any, has the rod experienced?

55. [I] THIS PROBLEM EXAMINES THE RELATIVE NATURE OF POTENTIAL ENERGY. Figure P55 shows a car of mass $m$ at the start of a roller-coaster ride. (a) Write an expression for the weight of the car. (b) What are the heights of point-$A$, point-$B$, and point-$D$ above the ground? (b) Write expressions for the car's gravitational potential energy at point-$A$, point-$B$, and point-$D$ with respect to the ground as the zero of $\text{PE}_G$.

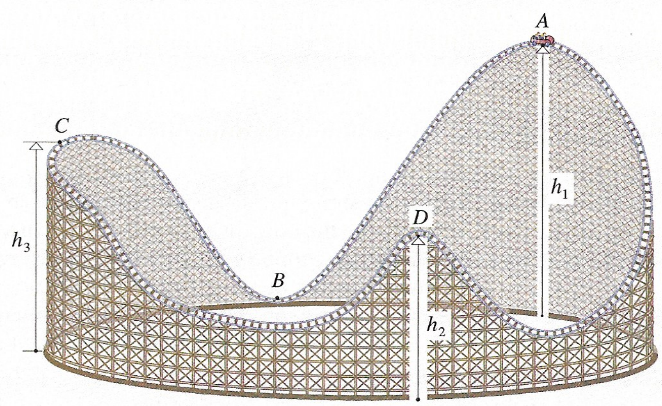


**Figure P55**

56. [I] THIS PROBLEM EXAMINES THE RELATIVE NATURE OF POTENTIAL ENERGY. Figure P55 shows a car of mass $m$ at the start of a rollercoaster ride. (a) What change in height does it experience in going from point-$A$ to point-$D$? (b) Write an expression for the change in the car's gravitational potential energy when it goes from point-$A$ to point-$D$. Take the ground as the zero of $\text{PE}_G$: $h_1 > h_2 > h_3$.

57. [I] THIS PROBLEM EXAMINES THE RELATIVE NATURE OF POTENTIAL ENERGY. Figure P55 shows a car of mass $m$ at the start of a roller-coaster ride. (a) What is the height of point-$A$, measured with respect to point-$C$? (b) Write an expression for the car's gravitational potential energy at point-$A$ with respect to point-$C$ as the zero of $\text{PE}_G$.

58. [I] THIS PROBLEM EXAMINES THE RELATIVE NATURE OF POTENTIAL ENERGY. Figure P55 shows a car of mass $m$ at the start of a roller-coaster ride. (a) What are the heights of point-$A$ and point-$D$ measured with respect to point-$C$? (b) Write an expression for the change in the car's gravitational potential energy when it goes from point-$A$ to point-$D$. Take point-$C$ as the zero of $\text{PE}_G$: $h_1 > h_2 > h_3$.

59. [I] A car with a mass of 1000 kg is at rest at the base of a hill. It accelerates up the incline reaching a speed of 20 m/s at a height of 100 m. What is the total increase in mechanical energy (KE plus $\text{PE}_G$) at that point?

60. [II] A 60-kg person is slowly doing chin-ups, during each one of which her mass (i.e. her *c.g.*, p. 249) can be considered to rise just about $\frac{1}{2}$ m. If the biceps contract roughly 4.0 cm in the process of each lift, how much tension is there, on average, in the muscles of each arm?

61. [II] A 1000-kg car at rest at the top of a hill accelerates down the road, reaching a speed of 20 m/s after descending a height of

100 m. What was its total change in mechanical energy (KE plus $PE_G$) as of that moment?

62. [II] A 10.0-kg package is raised from rest by an elevator at a constant acceleration of 2.00 m/s$^2$ for 20.0 s. (a) What is its KE at $t$ = 10.0 s? (b) What is its increase in gravitational potential energy after 10.0 s? (c) Assuming no losses, how much work was done on it by the elevator in 10.0 s?

**SOLUTION:** (a) First find the speed at $t = 10.0$ s: $v = at = (2.00\ \text{m/s}^2)(10.0\ \text{s}) = 20.0$ m/s and so KE $= \frac{1}{2}mv^2 = \frac{1}{2}(10.0\ \text{kg})(20.0\ \text{m/s})^2 = 2.00$ kJ. (b) We need the height: $l = \frac{1}{2}at^2 = \frac{1}{2}(2.00\ \text{m/s}^2)(10.0\ \text{s})^2 = 100$ m. Hence, $PE_G = mgh = (10.0\ \text{kg})g(100\ \text{m}) = 9.81 \times 10^3$ J. $W = \Delta KE + \Delta PE_G = 2.00\ \text{kJ} + 9.81\ \text{kJ} = 11.81$ kJ.

63. [II] A 100-N weight sitting on the floor is tied to a light rope that passes over a very light frictionless pulley 20 m above it. The other end of the rope hangs down to the floor where it is being held by a 10-N monkey named George. Suppose George now climbs 10 m above the floor. (a) How much work does he do? (b) How much rope ends up on the floor? (c) What is the total change in *gravitational*-PE of the system?

64. [II] During a vertical jump, a person crouches down to lower his or her center and then leaps straight up. The leg muscles essentially do all the work, accelerating the body over a push-off distance of about $\frac{1}{3}$ m. Typically, people can support an additional load using the legs equal to their own weight, but only with considerable effort. Let's suppose then that our person can push off with a muscle-force equal to 1.5 times body-weight. Neglecting losses due to friction, how high can our friend jump?

65. [II] Imagine that you have a large number ($N$) of thin metal plates each of mass $m$ that are to be stacked one on top of the other to make a vertical column. (a) Approximately how much work must be done to raise the last plate to the top if the height is $h$? (b) Roughly how much *gravitational*-PE is stored in the column?

66. [II] Consider a vertical cylindrical storage tank, sealed at the bottom and rising to a height $h$. With the last problem in mind, derive an equation for the exact increase in $PE_G$ that results when $M$ kilograms of water are pumped up from a stream at the level of the base, filling the tank.

67. [II] There are three identical flat stone blocks each 0.50 m high lying on the ground. What is the increase in gravitational potential energy when the blocks are stacked one on top of the other to a height of 1.50 m? Each block weighs 1000 N.

68. [III] A vertical cylinder 2.0-m tall with an inner diameter of 0.305 m is fitted with a piston having a mass of 68.0 kg that can move vertically frictionlessly. A valve at the bottom of the cylinder admits water under pressure and the piston rises 1.22 m up from the bottom. What is the resulting increase in the potential energy of the system given that water has a density of $1.00 \times 10^3$ kg/m$^3$? [*Hint: Remember Problem 66.*]

**69.** [III] (a) Determine the value of the gravitational acceleration at the surface of the Moon. (b) What is the change in the *gravitational*-PE of a 1000-kg spacecraft when it has risen 100 m above the surface? Take the radius of the Moon to be one-fourth that of the Earth and the mass to be about 100 times less.

70. [III] A locomotive exerts a maximum force of $22.7 \times 10^4$ N while pulling a freight train up a $\frac{1}{2}$% grade (i.e., the rise in the roadbed is $\frac{1}{2}$ m per 100 m). The train is 45 cars long, and each one loaded weighs $4.0 \times 10^5$ N. The total friction varies with the load and speed, but in this case, 35 N per $10^4$ N of weight is a reasonable number. Using energy considerations, how far will the train travel while accelerating from a speed of 6.7 m/s to twice that?

SECTION 6.4: MECHANICAL ENERGY

SECTION 6.5: APPLYING CONSERVATION OF ENERGY

71. [I] What is the kinetic energy of a 10.0-kg piece of concrete after it has fallen for 2.00 s from the facade of an old building?

72. [I] A 60-kg stuntperson runs off a cliff at 5.0 m/s and lands safely in the river 10.0 m below. What was the splashdown speed?

**SOLUTION:**: Using Conservation of Energy $E_i = \frac{1}{2}mv_i^2 + mgh = E_f = \frac{1}{2}mv_f^2$ : $v_f^2 = v_i^2 + 2gh$. Solving this for the final speed; $v_f = \sqrt{v_i^2 + 2gh} = \sqrt{(5.0\ \text{m/s})^2 + 2(9.81\ \text{m/s}^2)(10.0\ \text{m})} = 15$ m/s.

**73.** [I] Two automobiles of weight 7.12 kN and 14.24 kN are traveling along horizontally at 96 km/h when they both run out of gas. Luckily, there is a town in a valley not far off, but it's just beyond a 33.5-m-high hill. Assuming that friction can be neglected, which of the cars will make it to town? [*Hint:* $KE_f + PE_{Gf} = KE_i + PE_{Gi}$.]

74. [I] While traveling along at 96 km/h, a 14.2-kN auto runs out of gas 16 km from a service station. Neglecting friction, if the station is on a level 15.2 m above the elevation where the car stalled, how fast will the car be going when it rolls into the station, if in fact it gets there?

75. [I] A kid in a wagon is traveling at 10 m/s just as she reaches the bottom of a hill and begins to climb a second hill. How high up it will she get before the wagon stops, assuming negligible friction losses?

76. [I] A ball having a mass of 0.50 kg is thrown straight up at a speed of 25.0 m/s. (a) How high will it go if there is no friction? (b) If it rises 22 m, what was the average force due to air friction?

77. [I] An athlete whose mass is 55.0 kg steps off a 10.0-m-high platform and drops onto a trampoline, which, while stretching, brings her to a stop 1.00 m above the ground. Assuming no losses, how much energy must have momentarily been stored in the trampoline as she came to rest? How high will she rise?

78. [I] What is the potential energy of a 1.0-kg mass sitting on the surface of the Earth if we take the zero of $PE_G$ at infinity?

79. [I] Figure P55 shows a car of mass $m$ at the start of a roller coaster ride where its speed is just about zero. Write an expression for its speed at point-$D$.

80. [II] A constant force is applied to a 2.5-kg mass which travels from rest up a frictionless 30.0°-inclined plane. The force is 20.0 N parallel to the incline. If the mass moves 10.0 m along the surface of the incline, how much work was done on the object? By how much did its potential energy increase? What's its final speed? Check your answer using $F = ma$.

81. [II] Referring to Problem 78, compute the *gravitational*-PE of a 1.0-kg object at distances of 1, 2, 3, 4, 5, and 10 Earth-radii. Draw a plot of $PE_G$ against $r$ measured from the center of the planet in units of Earth-radii and $r > 1$. Now suppose the object is fired upward with a KE of $5.2 \times 10^7$ J. What is its initial total mechanical energy? Draw a horizontal line on your diagram representing E. Where does it cross your curve, and what is the significance of that point?

82. [II] A 1000-kg car racing up a mountain road runs out of gas at a height of 35 m while traveling at 22 m/s. Cleverly, the driver shifts into neutral and coasts onward. Neglecting all friction losses, will he clear the 65-m peak? Would it help to throw out any extra weight or even jump out and run alongside the car? Not having any brakes, at what speed will he reach the bottom of the mountain?

**SOLUTION:** The car has to coast a height $\Delta h = 65\text{ m} - 35\text{ m} = 30\text{ m}$. At the highest point the car reaches $\Delta PE_G = KE_i$ and so $mg\Delta h = \frac{1}{2}mv_i^2$: using $\Delta h = 30$ m the car needs an initial speed such that $(9.81\text{ m/s}^2)(30\text{ m}) = \frac{1}{2}v_i^2$ and so $v_i = 24.26$ m/s. Thus, traveling at 22 m/s the car will not get to the top. It will go up to some height, stop, and roll back to a height of 35 m again traveling at 22 m/s. Descending 35 m, it will reach a speed $v_f$ such that $mg\Delta h + \frac{1}{2}mv_i^2 = \frac{1}{2}mv_f^2$: $2g\Delta h + v_i^2 = v_f^2$ : $v_f = 34$ m/s.

**83.** [II] If the mass of the Moon is $7.4 \times 10^{22}$ kg and its radius is $1.74 \times 10^6$ m, compute the speed with which an object would have to be fired in order to sail away from it, completely overcoming the Moon's gravity pull.

84. [II] A pendulum consists of a small spherical mass attached to a rope so that its center hangs down a distance $L$ beneath the suspension point. The bob is displaced so that the taut string makes an angle of $\theta_i$ with the vertical, whereupon it is let loose and swings downward. Show that its maximum speed is given by

$$v_{max}^2 = 2gL(1 - \cos\theta_i)$$

85. [II] It's been suggested that we mine either the Moon or some of the asteroids in order to get raw material from which to build space stations. The idea is that removing material from the Moon "would consume only five percent of the energy needed to lift the same payload off Earth." Show that this conclusion is roughly true.

86. [II] At what speed should a space probe be fired from the Earth if it is required to still be traveling at a speed of 5.00 km/s, even after coasting to an exceedingly great distance from the planet (a distance that is essentially infinite)?

87. [II] A satellite is in a circular orbit about the Earth moving at a speed of 1500 m/s. It is desired that by firing its rocket, the craft attain a speed that will allow it to escape the planet. What must that speed be?

88. [III] An inclined plane at 30.0° is 6.40-m long. A book, which has a kinetic coefficient of friction with the incline of 0.20, is placed at the top and immediately begins to slide. Using energy considerations, how long will it take for the book to reach the bottom of the incline?

89. [III] Meteorites typically strike Earth's atmosphere at speeds ranging from $1.4 \times 10^4$ m/s, or 9 mi/s, to about $2.5 \times 10^4$ m/s, or 16 mi/s. On passing through, they lose both mass and speed so that a chunk weighing several newtons (a few pounds) is likely to be traveling between 120 and 240 m/s when it hits ground. Determine a good theoretical number for the minimum speed with which a meteorite will enter the atmosphere.

90. [III] The coefficient of restitution of two colliding bodies is defined as the ratio of their "relative speeds" (after the impact to before the impact). Imagine that we drop a sphere made of some material of interest from an initial height onto a test anvil and measure the final height to which the ball bounces. Derive an expression for the coefficient of restitution in terms of these two heights. If the coefficient for glass on steel is 0.96, to what height will a glass marble bounce off a steel plate when dropped from 1.0 m?

**91.** [III] A light rope is passed over a weightless, frictionless pulley, and masses $m_1$ and $m_2$ are attached to its ends. The arrangement is called Atwood's Machine. The starting configuration corresponds to both masses held at rest at the same height. The two are then released. During some arbitrary interval of time, the heavier one falls a distance $y$ while the lighter one rises a distance $y$. Derive an expression for the speed of either body in terms of $g$, $y$, and the masses.

## SECTION 6.6: POWER

92. [I] THIS PROBLEM EXAMINES ENERGY AND POWER. The maximum power that can be developed by an athlete is $2 \times 10^2$ W. (a) How much energy can that athlete develop in 1 s? (b) How much energy does such a person expend in 20 s of exertion?

93. [I] THIS PROBLEM EXAMINES ENERGY AND POWER. The energy expended in doing one push-up is about $3 \times 10^2$ J. (a) How much power is needed to do 1 push-up per second? (b) How much power must be developed if someone is to do 10 push-ups in 5.0 s?

94. [I] How much power does it take to raise an object weighing 100 N a distance of 20.0 m in 50.0 s?

95. [I] A runner traverses a 50-m-long stretch on a horizontal track in 10 s at a fairly constant speed. All the while she experiences a retarding force of 1.0 N due to air friction. What power was developed in overcoming that friction?

96. [I] A small hoist can raise 100 kg of bricks to the top of a construction project 30 m above the street in half a minute. Determine the power provided.

**SOLUTION:** The work done by the hoist is $W = \Delta PE_G = mgh = (100\text{ kg})(9.81\text{ m/s}^2)(30\text{ m}) = 2.94 \times 10^4$ J and $P = \Delta W/\Delta t = (2.94 \times 10^4\text{ J})/(30\text{ s}) = 9.8 \times 10^2$ W.

**97.** [I] The per capita power consumption in the United States is around 10 kJ each and every second. At what speed would you have to push a car exerting a force of 1.0 kN on it all year, day in and day out, to be equivalent to your share?

98. [I] Prove that 1 hp = 746 W.

99. [I] In Problem 39 we talked about inducing nuclear fusion via a high-speed collision. If the projectile has a mass of 0.5 g and is traveling at 200 km/s, how much power would be provided to the target if the collision lasted 10 ns?

100. [I] A 17.8-kN car is to be accelerated from 0 to 96.5 km/h (60 mi/h) in 10 s. Neglecting all frictional losses, how much power must be supplied in the process (independent of the exact nature of the acceleration)? Incidentally, air friction increases rapidly with speed, becoming a major concern above 64 km/h (40 mi/h).

101. [II] A well has water 20.0 m down from ground level. How much power must a motor supply to a pump if it is to raise 180 liters ($180 \times 10^{-3}$ m$^3$) of water per minute to the surface? The density of water (mass per unit volume) is ($1.00 \times 10^3$ kg/m$^3$).

102. [II] The Zambesi River in Africa rushes over Victoria Falls at a rate of $25 \times 10^6$ gallons per minute. The falls are 108 m high, 1 gallon equals $3.785 \times 10^{-3}$ m$^3$ (or 0.1337 cubic foot), and water has a density of $1.00 \times 10^3$ kg/m$^3$ (each cubic foot weighs 62.4 pounds). Determine the power developed by the water in SI units.

103. [II] A 2.5-hp motor drives a hoist that can raise a load of 50 kg to a height of 20 m. At full power, how long will the hoist take to do it?

104. [II] The belt connecting an auto engine to an air conditioner is moving at 40 m/min and has an effective tension of 20 N. How