Chapter 5
Energy

Quick Quizzes

1. (c). The work done by the force is $W = F(\Delta x)\cos\theta$, where θ is the angle between the direction of the force and the direction of the displacement (positive x-direction). Thus, the work has its largest positive value in (c) where $\theta = 0°$, the work done in (a) is zero since $\theta = 90°$, the work done in (d) is negative since $90° < \theta < 270°$, and the work done is most negative in (b) where $\theta = 180°$.

2. (d). All three balls have the same speed the moment they hit the ground because all start with the same kinetic energy and undergo the same change in gravitational potential energy.

3. (c). They both start from rest, so the initial kinetic energy is zero for each of them. They have the same mass and start from the same height, so they have the same initial potential energy. Since neither spends energy overcoming friction, all of their original potential energy will be converted into kinetic energy as they move downward. Thus, they will have equal kinetic energies when they reach the ground.

4. (c). The decrease in mechanical energy of the system is $f_k\Delta x$. This has a smaller value on the tilted surface for two reasons: (1) the force of kinetic friction f_k is smaller because the normal force is smaller, and (2) the displacement Δx is smaller because a component of the gravitational force is pulling on the book in the direction opposite to its velocity.

Answers to Even Numbered Conceptual Questions

2. **(a)** The chicken does positive work on the ground. **(b)** No work is done. **(c)** The crane does positive work on the bucket. **(d)** The force of gravity does negative work on the bucket. **(e)** The leg muscles do negative work on the individual.

4. **(a)** Kinetic energy is always positive. Mass and speed squared are both positive. **(b)** Gravitational potential energy can be negative when the object is lower than the chosen reference level.

6. **(a)** Kinetic energy is proportional to the speed squared. Doubling the speed makes the object's kinetic energy four times larger. **(b)** If the total work done on an object in some process is zero, its speed must be the same at the final point as it was at the initial point.

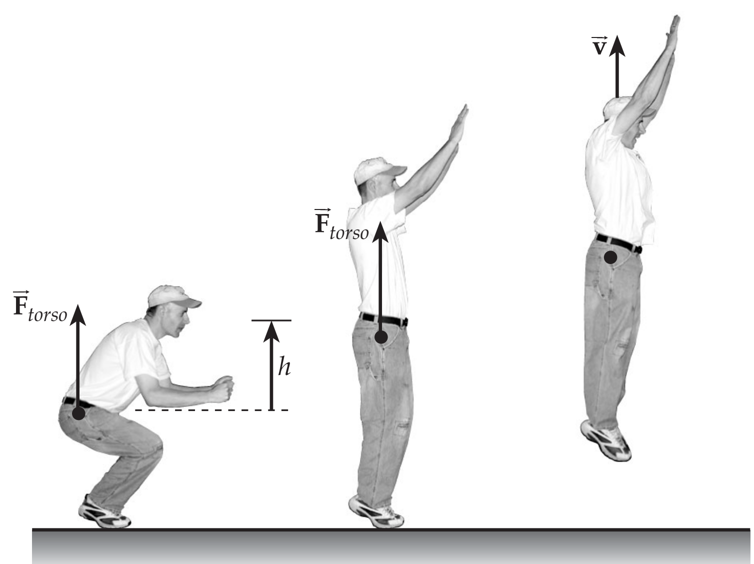
8. The total energy of the bowling ball is conserved. Because the ball initially has gravitational potential energy mgh and no kinetic energy, it will again have zero kinetic energy when it returns to its original position. Air resistance and friction at the support will cause the ball to come back to a point slightly below its initial position. On the other hand, if anyone gives a forward push to the ball anywhere along its path, the demonstrator will have to duck.

10. **(a)** The effects are the same except for such features as having to overcome air resistance outside. **(b)** The person must lift his body slightly with each step on the tilted treadmill. Thus, the effect is that of running uphill.

12. Both the force of kinetic friction exerted on the sled by the snow and the resistance force exerted on the moving sled by the air will do negative work on the sled. Since the sled is maintaining constant velocity, some towing agent must do an equal amount of positive work, so the net work done on the sled is zero.

14. The kinetic energy is converted to internal energy within the brake pads of the car, the roadway, and the tires.

16. Work is actually performed by the thigh bone (the femur) on the hips as the torso moves upwards a distance h. The force on the torso $\vec{\mathbf{F}}_{torso}$ is approximately the same as the normal force (since the legs are relatively light and are not moving much), and the work done by $\vec{\mathbf{F}}_{torso}$ minus the work done by gravity is equal to the change in kinetic energy of the torso.



At full extension the torso would continue upwards, leaving the legs behind on the ground (!), except that the torso now does work on the legs, increasing their speed (and decreasing the torso speed) so that both move upwards together.

Note: An alternative way to think about problems that involve internal motions of an object is to note that the net work done on an object is equal to the net force times the displacement of the center of mass. Using this idea, the effect of throwing the arms upwards during the extension phase is accounted for by noting that the position of the center of mass is higher on the body with the arms extended, so that total displacement of the center of mass is greater.

18. The normal force is always perpendicular to the surface and the motion is generally parallel to the surface. Thus, in most circumstances, the normal force is perpendicular to the displacement and does no work. The force of static friction does no work because there is no displacement of the object relative to the surface in a static situation.

20. Before the jump, the system (vaulter plus pole) has kinetic energy. After the vaulter leaves the ground and the pole is bent, the system has less kinetic energy, but the gravitational potential energy of the system increases and some energy is stored as elastic potential energy in the bent pole. When the vaulter reaches the top of the vault, the kinetic energy is at its minimum, the gravitational potential energy is at its maximum, and no energy is stored in the pole, which is now straight. Some mechanical energy is lost due to air resistance and the frictional force between the pole and the ground during the ascent.

Answers to Even Numbered Problems

2. 30.6 m

4. 1.6 kJ

6. **(a)** 900 J **(b)** 0.383

8. **(a)** 31.9 J **(b)** 0 **(c)** 0 **(d)** 31.9 J

10. 160 m/s

12. **(a)** –168 J **(b)** –184 J **(c)** 500 J **(d)** 148 J **(e)** 5.64 m/s

14. 90.0 J

16. **(a)** 1.2 J **(b)** 5.0 m/s **(c)** 6.3 J

18. 2.0 m

20. 0.5 m

22. **(a)** 0.768 m **(b)** 1.68×10^5 J

24. 26.5 m/s

26. 5.1 m

28. **(a)** 9.90 m/s **(b)** 7.67 m/s

30. **(a)** $v_B = 5.94$ m/s, $v_C = 7.67$ m/s **(b)** 147 J

32. 5.11 m/s

34. 61 m

36. **(a)** 9.90 m/s **(b)** 11.8 J

38. **(a)** No, $f_k = \mu_k\left(mg - F\sin\theta\right)$
(b) $W_F = Fx\cos\theta,\ W_{f_k} = -\mu_k\left(mg - F\sin\theta\right)x$
(c) normal force, gravitational force, and vertical component of applied force
(d) $f_k = 4.23$ N, $W_F = 47.9$ J, $W_{f_k} = -16.9$ J

40. 77 m/s

42. **(a)** $2.29\ \text{m/s}$ **(b)** 15.6 J

44. $\frac{h}{5}\left(4\sin^2\theta+1\right)$

46. 1.5 m (measured along the incline)

48. **(a)** 21 kJ **(b)** 0.92 hp

50. $2.9\ \text{m/s}$

52. 194 m

54. **(a)** 7.92 hp **(b)** 14.9 hp

56. **(a)** 7.50 J **(b)** 15.0 J **(c)** 7.50 J **(d)** 30.0 J

58. $1.9\ \text{m/s}$

60. 0.116 m

62. $1.4\ \text{m/s}$

64. 3.9 kJ

66. **(a)** 582 trips **(b)** 90.5 W (0.121 hp)

68. 895 J

70. **(a)** $3.1\times10^2\ \text{J}$ **(b)** $-1.5\times10^2\ \text{J}$ **(c)** 0 **(d)** $1.5\times10^2\ \text{J}$

72. **(a)** $3.8\times10^2\ \text{J}$ for javelin, $7.3\times10^2\ \text{J}$ for discus, $8.1\times10^2\ \text{J}$ for shot
(b) 1.9×10^2 N on javelin, $3.6\times10^2\ \text{N}$ on discus, $4.1\times10^2\ \text{N}$ on shot
(c) Yes

74. 4.9 J

76. 0.115

78. **(b)** $2.06\ \text{m/s}$

80. **(a)** $5.03\times10^7\ \text{J}$ **(b)** 0.60

82. **(a)** 25.8 m **(b)** $2.77\,g$ or $27.1\ \text{m/s}^2$

84. **(a)** Choose the spring constant so the weight of a tray stretches all four springs a distance equal to the thickness of a tray.

(b) $316\ \mathrm{N/m}$, The length and width of a tray are not needed.

86. **(a)** $21.0\ \mathrm{m/s}$ **(b)** $16.1\ \mathrm{m/s}$

88. **(a)** $14.1\ \mathrm{m/s}$ **(b)** $-7.90\ \mathrm{kJ}$ **(c)** $800\ \mathrm{N}$ **(d)** $771\ \mathrm{N}$

Problem Solutions

5.1 If the weights are to move at constant velocity, the net force on them must be zero. Thus, the force exerted on the weights is upward, parallel to the displacement, with magnitude 350 N. The work done by this force is

$$W = (F\cos\theta)s = [(350\ \text{N})\cos 0°](2.00\ \text{m}) = \boxed{700\ \text{J}}$$

5.2 To lift the bucket at constant speed, the woman exerts an upward force whose magnitude is $F = mg = (20.0\ \text{kg})(9.80\ \text{m/s}^2) = 196\ \text{N}$. The work done is $W = (F\cos\theta)s$, so the displacement is

$$s = \frac{W}{F\cos\theta} = \frac{6.00\times10^3\ \text{J}}{(196\ \text{N})\cos 0°} = \boxed{30.6\ \text{m}}$$

5.3 $W = (F\cos\theta)s = \left[(5.00\times10^3\ \text{N})\cos 0°\right](3.00\times10^3\ \text{m}) = 1.50\times10^7\ \text{J} = \boxed{15.0\ \text{MJ}}$

5.4 The applied force makes an angle of 25° with the displacement of the cart. Thus, the work done on the cart is

$$W = (F\cos\theta)s = [(35\ \text{N})\cos 25°](50\ \text{m}) = 1.6\times10^3\ \text{J} = \boxed{1.6\ \text{kJ}}$$

5.5 (a) The force of gravity is given by $mg = (5.00\ \text{kg})(9.80\ \text{m/s}^2) = 49.0\ \text{N}$ and is directed downwards. The angle between the force of gravity and the direction of motion is $\theta = 90.0° - 30.0° = 60.0°$, and so the work done by gravity is given as

$$W_g = (F\cos\theta)s = [(49.0\ \text{N})\cos 60.0°](2.50\ \text{m}) = \boxed{61.3\ \text{J}}$$

(b) The normal force exerted on the block by the incline is $n = mg\cos 30.0°$, so the friction force is

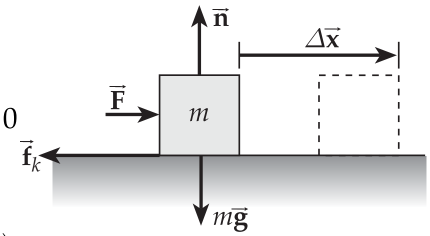
$$f_k = \mu_k n = (0.436)(49.0\ \text{N})\cos 30.0° = 18.5\ \text{N}$$

This force is directed opposite to the displacement (that is $\theta = 180°$), and the work it does is

$$W_f = (f_k\cos\theta)s = [(18.5\ \text{N})\cos 180°](2.50\ \text{m}) = \boxed{-46.3\ \text{J}}$$

(c) Since the normal force is perpendicular to the displacement; $\theta = 90°$, $\cos\theta = 0$, and the work done by the normal force is $\boxed{\text{zero}}$.

5.6 (a) $W_F = F(\Delta x)\cos\theta = (150\ \text{N})(6.00\ \text{m})\cos 0° = \boxed{900\ \text{J}}$



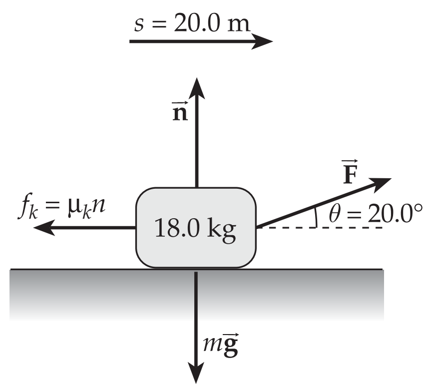
(b) Since the crate moves at constant velocity, $a_x = a_y = 0$

Thus, $\Sigma F_x = 0 \Rightarrow f_k = F = 150\ \text{N}$

Also, $\Sigma F_y = 0 \Rightarrow n = mg = (40.0\ \text{kg})(9.80\ \text{m/s}^2) = 392\ \text{N}$

so $\mu_k = \dfrac{f_k}{n} = \dfrac{150\ \text{N}}{392\ \text{N}} = \boxed{0.383}$

5.7 (a) $\Sigma F_y = F\sin\theta + n - mg = 0$



$$n = mg - F\sin\theta$$

$$\Sigma F_x = F\cos\theta - \mu_k n = 0$$

$$n = \frac{F\cos\theta}{\mu_k}$$

$$\therefore \quad mg - F\sin\theta = \frac{F\cos\theta}{\mu_k}$$

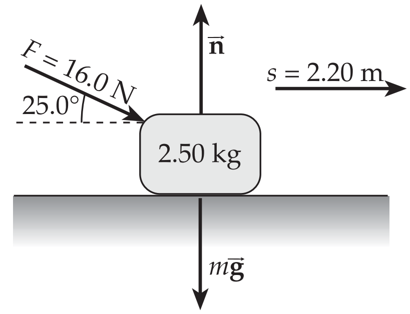
$$F = \frac{\mu_k mg}{\mu_k\sin\theta + \cos\theta} = \frac{(0.500)(18.0\ \text{kg})(9.80\ \text{m/s}^2)}{(0.500)\sin 20.0° + \cos 20.0°} = \boxed{79.4\ \text{N}}$$

(b) $W_F = (F\cos\theta)s = [(79.4\ \text{N})\cos 20.0°](20.0\ \text{m}) = 1.49\times10^3\ \text{J} = \boxed{1.49\ \text{kJ}}$

(c) $f_k = F\cos\theta = 74.6\ \text{N}$

$W_f = (f_k\ \cos\theta)s = [(74.6\ \text{N})\cos 180°](20.0\ \text{m}) = -1.49\times10^3\ \text{J} = \boxed{-1.49\ \text{kJ}}$

5.8 (a) $W_F = (F\cos\theta)s = [(16.0\text{ N})\cos 25.0°](2.20\text{ m})$



$W_F = \boxed{31.9\text{ J}}$

(b) $W_n = (n\cos 90°)s = \boxed{0}$

(c) $W_g = (mg\cos 90°)s = \boxed{0}$

(d) $W_{net} = W_F + W_n + W_g = 31.9\text{ J} + 0 + 0 = \boxed{31.9\text{ J}}$

5.9 (a) The work-energy theorem, $W_{net} = KE_f - KE_i$, gives

$$5000\text{ J} = \frac{1}{2}(2.50\times 10^3\text{ kg})v^2 - 0\text{, or}\qquad v = \boxed{2.00\text{ m/s}}$$

(b) $W = (F\cos\theta)s = (F\cos 0°)(25.0\text{ m}) = 5000\text{ J}$, so $F = \boxed{200\text{ N}}$

5.10 Requiring that $KE_{ping\ pong} = KE_{bowling}$ with $KE = \frac{1}{2}mv^2$, we have

$$\frac{1}{2}(2.45\times 10^{-3}\text{ kg})v^2 = \frac{1}{2}(7.00\text{ kg})(3.00\text{ m/s})^2\text{, giving } v = \boxed{160\text{ m/s}}$$

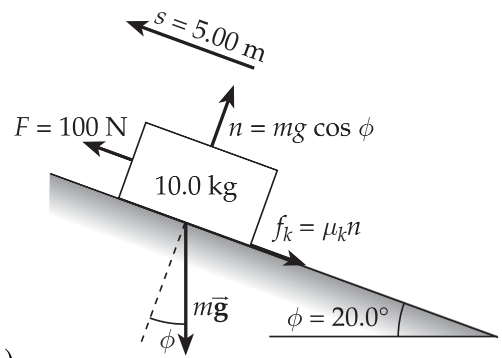
5.11 The person's mass is $m = \frac{w}{g} = \frac{700\text{ N}}{9.80\text{ m/s}^2} = 71.4\text{ kg}$. The net upward force acting on the body is $F_{net} = 2(355\text{ N}) - 700\text{ N} = 10.0\text{ N}$. The final upward velocity can then be calculated from the work-energy theorem as

$$W_{net} = KE_f - KE_i = \frac{1}{2}mv^2 - \frac{1}{2}mv_i^2$$

or $$(F_{net}\cos\theta)s = [(10.0\text{ N})\cos 0°](0.250\text{ m}) = \frac{1}{2}(71.4\text{ kg})v^2 - 0$$

which gives $v = \boxed{0.265\text{ m/s upward}}$

5.12 (a) $W_g = [mg\cos\theta]s = [mg\cos(90.0° + \phi)]s$



$$W_g = [(10.0\text{ kg})(9.80\text{ m/s}^2)\cos 110°](5.00\text{ m})$$

$$= \boxed{-168\text{ J}}$$

(b) $W_f = (f_k\cos\theta)s = [(\mu_k n)\cos 180°]s$

$$= [0.400(98.0\text{ N }\cos 20.0°)\cos 180°](5.00\text{ m})$$

$$= \boxed{-184\text{ J}}$$

(c) $W_F = (F\cos\theta)s = [(100\text{ N})\cos 0°](5.00\text{ m}) = \boxed{500\text{ J}}$

(d) $\Delta KE = W_{net} = W_g + W_f + W_F = \boxed{148\text{ J}}$

(e) $\Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mv_i^2$

$$v = \sqrt{\frac{2(\Delta KE)}{m} + v_i^2} = \sqrt{\frac{2(148\text{ J})}{10.0\text{ kg}} + (1.50\text{ m/s})^2} = \boxed{5.64\text{ m/s}}$$

5.13 (a) We use the work-energy theorem to find the work.

$$W = \Delta KE = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = 0 - \frac{1}{2}(70\text{ kg})(4.0\text{ m/s})^2 = \boxed{-5.6\times 10^2\text{ J}}$$

(b) $W = (F\cos\theta)s = (f_k\cos 180°)s = (-\mu_k n)s = (-\mu_k mg)s$,

so $$s = -\frac{W}{\mu_k mg} = -\frac{(-5.6\times 10^2\text{ J})}{(0.70)(70\text{ kg})(9.80\text{ m/s}^2)} = \boxed{1.2\text{ m}}$$

5.14 At the top of the arc, $v_y = 0$, and $v_x = v_{0x} = v_0\cos 30.0° = 34.6\text{ m/s}$

Therefore $v^2 = v_x^2 + v_y^2 = (34.6\text{ m/s})^2$, and

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(0.150\text{ kg})(34.6\text{ m/s})^2 = \boxed{90.0\text{ J}}$$

5.15 (a) The final kinetic energy of the bullet is

$$KE_f = \frac{1}{2}mv^2 = \frac{1}{2}\left(2.0\times10^{-3}\text{ kg}\right)\left(300\text{ m/s}\right)^2 = \boxed{90\text{ J}}$$

(b) We know that $W = \Delta KE$, and also $W = \left(F_{\text{av}}\cos\theta\right)s$.

Thus, $F_{\text{av}} = \dfrac{\Delta KE}{s\cos\theta} = \dfrac{90\text{ J} - 0}{(0.50\text{ m})\cos 0°} = \boxed{1.8\times10^2\text{ N}}$

5.16 (a) $KE_A = \dfrac{1}{2}mv_A^2 = \dfrac{1}{2}\left(0.60\text{ kg}\right)\left(2.0\text{ m/s}\right)^2 = \boxed{1.2\text{ J}}$

(b) $KE_B = \dfrac{1}{2}mv_B^2$, so $v_B = \sqrt{\dfrac{2\left(KE_B\right)}{m}} = \sqrt{\dfrac{2(7.5\text{ J})}{0.60\text{ kg}}} = \boxed{5.0\text{ m/s}}$

(c) $W_{net} = \Delta KE = KE_B - KE_A = (7.5 - 1.2)\text{ J} = \boxed{6.3\text{ J}}$

5.17 $W_{net} = \left(F_{road}\cos\theta_1\right)s + \left(F_{resist}\cos\theta_2\right)s = \left[\left(1\,000\text{ N}\right)\cos 0°\right]s + \left[(950\text{ N})\cos 180°\right]s$

$W_{net} = \left(1\,000\text{ N} - 950\text{ N}\right)(20\text{ m}) = 1.0\times10^3\text{ J}$

Also, $W_{net} = KE_f - KE_i = \dfrac{1}{2}mv^2 - 0$, so

$$v = \sqrt{\frac{2W_{net}}{m}} = \sqrt{\frac{2\left(1.0\times10^3\text{ J}\right)}{2000\text{ kg}}} = \boxed{1.0\text{ m/s}}$$

5.18 The initial kinetic energy of the sled is

$$KE_i = \frac{1}{2}mv_i^2 = \frac{1}{2}\left(10\text{ kg}\right)\left(2.0\text{ m/s}\right)^2 = 20\text{ J}$$

and the friction force is $f_k = \mu_k n = \mu_k\, mg = (0.10)(98\text{ N}) = 9.8\text{ N}$

$W_{net} = \left(f_k\cos 180°\right)s = KE_f - KE_i$, so $s = \dfrac{0 - KE_i}{f_k\cos 180°} = \dfrac{-20\text{ J}}{-9.8\text{ N}} = \boxed{2.0\text{ m}}$

5.19 With only a conservative force acting on the falling ball,

$$\left(KE + PE_g\right)_i = \left(KE + PE_g\right)_f \qquad \text{or} \qquad \tfrac{1}{2}mv_i^2 + mgy_i = \tfrac{1}{2}mv_f^2 + mgy_h$$

Applying this to the motion of the ball gives $0 + mgy_i = \frac{1}{2}mv_f^2 + 0$

$$\text{or} \qquad y_i = \frac{v_f^2}{2g} = \frac{(9.0\ \text{m/s})^2}{2\left(9.80\ \text{m/s}^2\right)} = \boxed{4.1\ \text{m}}$$

5.20 Applying $W_{nc} = (KE + PE)_f - (KE + PE)_i$ to the jump of the "original" flea gives

$$F_m d = \left(0 + mgy_f\right) - (0 + 0) \qquad \text{or} \qquad y_f = \frac{F_m d}{mg}$$

where F_m is the force exerted by the muscle and d is the length of contraction.

If we scale the flea by a factor *f*, the muscle force increases by f^2 and the length of contraction increases by *f*. The mass, being proportional to the volume which increases by f^3, will also increase by f^3. Putting these factors into our expression for y_f gives

$$\left(y_f\right)_{\substack{super\\flea}} = \frac{\left(f^2 F_m\right)(fd)}{\left(f^3 m\right)g} = \frac{F_m d}{mg} = y_f \approx \boxed{0.5\ \text{m}}$$

so the "super flea" cannot jump any higher!

This analysis is used to argue that most animals should be able to jump to approximately the same height (~0.5 m). Data on mammals from elephants to shrews tend to support this.

5.21 Once the athlete leaves the trampoline, only the conservative gravitational force acts on her. Thus, $(KE + PE)_i = (KE + PE)_f$ with $PE_i = 0$ if we choose the level of the trampoline to be the reference level for gravitational potential energy.

(a) At $y = h_{\max}$, $v_f = 0$ and conservation of mechanical energy yields

$$mgh_{\max} = \tfrac{1}{2}mv_i^2 \qquad \text{or} \qquad h_{\max} = \frac{v_i^2}{2g} = \frac{(9.0\ \text{m/s})^2}{2\left(9.80\ \text{m/s}^2\right)} = \boxed{4.1\ \text{m}}$$

(b) When $y = \frac{1}{2}h_{\max}$ during the upward trip, conservation of mechanical energy gives

$$\tfrac{1}{2}mv^2 + mg\left(\tfrac{1}{2}h_{\max}\right) = \tfrac{1}{2}mv_i^2, \quad \text{or}$$

$$v = +\sqrt{v_i^2 - gh_{\max}} = \sqrt{(9.0\ \text{m/s})^2 - (9.80\ \text{m/s}^2)(4.1\ \text{m})} = \boxed{6.4\ \text{m/s}}$$

5.22 (a) When equilibrium is reached, the total spring force supporting the load equals the weight of the load, or $F_{s,\,total} = F_{s,\,leaf} + F_{s,\,helper} = w_{load}$. Let k_ℓ and k_h represent the spring constants of the leaf spring and the helper spring, respectively. Then, if x_ℓ is the distance the leaf spring is compressed, the condition for equilibrium becomes

$$k_\ell x_\ell + k_h\left(x_\ell - y_0\right) = w_{load}$$

or
$$x_\ell = \frac{w_{load} + k_h y_0}{k_\ell + k_h} = \frac{5.00\times10^5\ \text{N} + \left(3.60\times10^5\ \text{N/m}\right)(0.500\ \text{m})}{5.25\times10^5\ \text{N/m} + 3.60\times10^5\ \text{N/m}} = \boxed{0.768\ \text{m}}$$

(b) The work done compressing the springs equals the total elastic potential energy at equilibrium. Thus, $W = \frac{1}{2}k_\ell x_\ell^2 + \frac{1}{2}k_h\left(x_\ell - 0.500\ \text{m}\right)^2$

or $$W = \tfrac{1}{2}\left(5.25\times10^5\ \text{N/m}\right)(0.768\ \text{m})^2 + \tfrac{1}{2}\left(3.60\times10^5\ \text{N/m}\right)(0.268\ \text{m})^2 = \boxed{1.68\times10^5\ \text{J}}$$

5.23 While the motorcycle is in the air, only the conservative gravitational force acts on cycle and rider. Thus, $\frac{1}{2}mv_f^2 + mgy_f = \frac{1}{2}mv_i^2 + mgy_i$, which gives

$$\Delta y = y_f - y_i = \frac{v_i^2 - v_f^2}{2g} = \frac{(35.0\ \text{m/s})^2 - (33.0\ \text{m/s})^2}{2\left(9.80\ \text{m/s}^2\right)} = \boxed{6.94\ \text{m}}$$

5.24 Let m be the mass of the ball, R the radius of the circle, and F the 30.0 N force. With $y = 0$ at the bottom of the circle, $W_{nc} = (KE + PE)_f - (KE + PE)_i$ yields

$$(F\cos 0°)\pi R = \left(\frac{1}{2}mv_f^2 + 0\right) - \left(\frac{1}{2}mv_i^2 + mg(2R)\right)$$

or $$v_f = \sqrt{\frac{2F(\pi R)}{m} + v_i^2 + 4gR}$$

Thus, $$v_f = \sqrt{\frac{2(30.0\text{ N})\pi(0.600\text{ m})}{0.250\text{ kg}} + (15.0\text{ m/s})^2 + 4(9.80\text{ m/s}^2)(0.600\text{ m})}$$

giving $v_f = \boxed{26.5\text{ m/s}}$

5.25 The total work done by the two bicep muscles as they contract is

$$W_{biceps} = 2F_{\text{av}}\Delta x = 2(800\text{ N})(0.075\text{ m}) = \boxed{1.2\times 10^2\text{ J}}$$

The total work done on the body as it is lifted 40 cm during a chin-up is

$$W_{chin-up} = mgh = (75\text{ kg})(9.80\text{ m/s}^2)(0.40\text{ m}) = \boxed{2.9\times 10^2\text{ J}}$$

Since $W_{chin-up} > W_{biceps}$, it is clear that $\boxed{\text{addition muscles must be involved}}$

5.26 Using conservation of mechanical energy, we have

$$\frac{1}{2}mv_f^2 + mgy_f = \frac{1}{2}mv_i^2 + 0$$

or $$y_f = \frac{v_i^2 - v_f^2}{2g} = \frac{(10\text{ m/s})^2 - (1.0\text{ m/s})^2}{2(9.80\text{ m/s}^2)} = \boxed{5.1\text{ m}}$$

5.27 Since no non-conservative forces do work, we use conservation of mechanical energy, with the zero of potential energy selected at the level of the base of the hill. Then, $\frac{1}{2}mv_f^2 + mgy_f = \frac{1}{2}mv_i^2 + mgy_i$ with $y_f = 0$ yields

$$y_i = \frac{v_f^2 - v_i^2}{2g} = \frac{(3.00\ \text{m/s})^2 - 0}{2(9.80\ \text{m/s}^2)} = \boxed{0.459\ \text{m}}$$

Note that this result is independent of the mass of the child and sled.

5.28 (a) We take the zero of potential energy at the level of point B, and use conservation of mechanical energy to obtain $\frac{1}{2}mv_B^2 + 0 = \frac{1}{2}mv_A^2 + mgy_A$, or

$$v_B = \sqrt{v_A^2 + 2gy_A} = \sqrt{0 + 2(9.80\ \text{m/s}^2)(5.00\ \text{m})} = \boxed{9.90\ \text{m/s}}$$

(b) At point C, with the starting point at A, we again use conservation of mechanical energy. This gives $\frac{1}{2}mv_C^2 + mgy_C = \frac{1}{2}mv_A^2 + mgy_A$, and yields

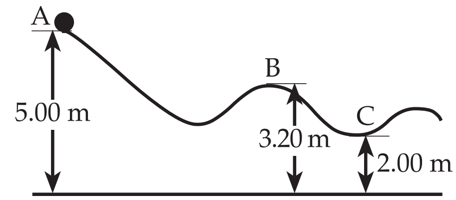
$$v_C = \sqrt{v_A^2 + 2g(y_A - y_C)} = \sqrt{0 + 2(9.80\ \text{m/s}^2)(3.00\ \text{m})} = \boxed{7.67\ \text{m/s}}$$

5.29 Consider the interval from when the ball starts from rest ($v_i = 0$) at $y_i = +10.0\ \text{m}$ until it comes to rest ($v_f = 0$) at $y_f = -3.20\ \text{mm} = -3.20 \times 10^{-3}\ \text{m}$. The non-conservative retarding force exerted by the plate does negative work on the ball during the last 3.20 mm of the it's travel. The work-energy theorem $W_{nc} = (KE + PE)_f - (KE + PE)_i$ applied to the ball during this interval gives $-F_{\text{av}}\left|y_f - 0\right| = \left(0 + mgy_f\right) - \left(0 + mgy_i\right)$

or $$F_{\text{av}} = \frac{mg\left(y_f - y_i\right)}{-\left|y_f\right|} = \frac{(5.00\text{kg})(9.80\ \text{m/s}^2)\left(-3.20 \times 10^{-3}\ \text{m} - 10.0\ \text{m}\right)}{-3.20 \times 10^{-3}\ \text{m}} = 1.53 \times 10^5\ \text{N}$$

Thus, $\boxed{\vec{\mathbf{F}}_{\text{av}} = 1.53 \times 10^5\ \text{N upward}}$

5.30 (a) From conservation of mechanical energy,



$$\frac{1}{2}mv_B^2 + mgy_B = \frac{1}{2}mv_A^2 + mgy_A \text{, or}$$

$$v_B = \sqrt{v_A^2 + 2g\left(y_A - y_B\right)}$$

$$= \sqrt{0 + 2\left(9.80 \text{ m/s}^2\right)\left(1.80 \text{ m}\right)} = \boxed{5.94 \text{ m/s}}$$

Similarly,

$$v_C = \sqrt{v_A^2 + 2g\left(y_A - y_C\right)} = \sqrt{0 + 2g\left(5.00 \text{ m} - 2.00 \text{ m}\right)} = \boxed{7.67 \text{ m/s}}$$

(b) $$\left.W_g\right)_{A\to C} = \left(PE_g\right)_A - \left(PE_g\right)_C = mg\left(y_A - y_C\right) = \left(49.0 \text{ N}\right)\left(3.00 \text{ m}\right) = \boxed{147 \text{ J}}$$

5.31 (a) We choose the zero of potential energy at the level of the bottom of the arc. The initial height of Tarzan above this level is

$$y_i = \left(30.0 \text{ m}\right)\left(1 - \cos 37.0°\right) = 6.04 \text{ m}$$

Then, using conservation of mechanical energy, we find

$$\frac{1}{2}mv_f^2 + 0 = \frac{1}{2}mv_i^2 + mgy_i$$

or $$v_f = \sqrt{v_i^2 + 2gy_i} = \sqrt{0 + 2\left(9.80 \text{ m/s}^2\right)\left(6.04 \text{ m}\right)} = \boxed{10.9 \text{ m/s}}$$

(b) In this case, conservation of mechanical energy yields

$$v_f = \sqrt{v_i^2 + 2gy_i} = \sqrt{\left(4.00 \text{ m/s}\right)^2 + 2\left(9.80 \text{ m/s}^2\right)\left(6.04 \text{ m}\right)} = \boxed{11.6 \text{ m/s}}$$

5.32 Realize that all three masses have identical *speeds* at each point in the motion and that $v_i = 0$. Then, conservation of mechanical energy gives

$$KE_f = PE_i - PE_f \text{, or}$$

$$\frac{1}{2}(m_1 + m_2 + m_3)v_f^2 = \left[m_1\left(y_{1i} - y_{1f}\right) + m_2\left(y_{2i} - y_{2f}\right) + m_3\left(y_{3i} - y_{3f}\right)\right]g$$

Thus, $\frac{1}{2}(30.0)v_f^2 = \left[(5.00)(-4.00\ \text{m}) + (10.0)(0) + (15.0)(+4.00\ \text{m})\right]\left(9.80\ \text{m/s}^2\right)$

yielding $v_f = \boxed{5.11\ \text{m/s}}$

5.33 (a) Use conservation of mechanical energy from when the projectile is at rest within the gun until it reaches maximum height.

Then, $\left(KE + PE_g + PE_s\right)_f = \left(KE + PE_g + PE_s\right)_i$ becomes

$$0 + mgy_{max} + 0 = 0 + 0 + \frac{1}{2}kx_i^2$$

or $$k = \frac{2mgy_{max}}{x_i^2} = \frac{2\left(20.0\times10^{-3}\ \text{kg}\right)\left(9.80\ \text{m/s}^2\right)(20.0\ \text{m})}{(0.120\ \text{m})^2} = \boxed{544\ \text{N/m}}$$

(b) This time, we use conservation of mechanical energy from when the projectile is at rest within the gun until it reaches the equilibrium position of the spring. This gives

$$KE_f = \left(PE_g + PE_s\right)_i - \left(PE_g + PE_s\right)_f = \left(-mgx_i + \frac{1}{2}kx_i^2\right) - (0 + 0)$$

$$v_f^2 = \left(\frac{k}{m}\right)x_i^2 - 2gx_i$$

$$= \left(\frac{544\ \text{N/m}}{20.0\times10^{-3}\ \text{kg}}\right)(0.120\ \text{m})^2 - 2\left(9.80\ \text{m/s}^2\right)(0.120\ \text{m})$$

yielding $v_f = \boxed{19.7\ \text{m/s}}$

5.34 At maximum height, $v_y = 0$ and $v_x = v_{0x} = (40\ \text{m/s})\cos 60° = 20\ \text{m/s}$

Thus, $v_f = \sqrt{v_x^2 + v_y^2} = 20\ \text{m/s}$. Choosing $PE_g = 0$ at the level of the launch point, conservation of mechanical energy gives $PE_f = KE_i - KE_f$, and the maximum height reached is

$$y_f = \frac{v_i^2 - v_f^2}{2g} = \frac{(40\ \text{m/s})^2 - (20\ \text{m/s})^2}{2(9.80\ \text{m/s}^2)} = \boxed{61\ \text{m}}$$

5.35 Choose $PE_g = 0$ at the level of the release point and use conservation of mechanical energy from release until the block reaches maximum height. Then,

$KE_f = KE_i = 0$ and we have $(PE_g + PE_s)_f = (PE_g + PE_s)_i$, or

$mgy_{\text{max}} + 0 = 0 + \frac{1}{2}kx_i^2$ which yields

$$y_{\text{max}} = \frac{kx_i^2}{2mg} = \frac{(5.00 \times 10^3\ \text{N/m})(0.100\ \text{m})^2}{2(0.250\ \text{kg})(9.80\ \text{m/s}^2)} = \boxed{10.2\ \text{m}}$$

5.36 (a) Choose $PE_g = 0$ at the level of point B. Between A and B, we can use conservation of mechanical energy, $KE_B + (PE_g)_B = KE_A + (PE_g)_A$, which becomes

$\frac{1}{2}mv_B^2 + 0 = 0 + mgy_A$ or

$$v_B = \sqrt{2gy_A} = \sqrt{2(9.80\ \text{m/s}^2)(5.00\ \text{m})} = \boxed{9.90\ \text{m/s}}$$

(b) Again, choose $PE_g = 0$ at the level of point B. Between points B and C, we use the work-energy theorem in the form

$W_{nc} = (KE + PE_g)_C - (KE + PE_g)_B = 0 + mgy_C - \frac{1}{2}mv_B^2 - 0$ to find

$$W_{nc} = (0.400\ \text{kg})(9.80\ \text{m/s}^2)(2.00\ \text{m}) - \frac{1}{2}(0.400\ \text{kg})(9.90\ \text{m/s})^2 = -11.8\ \text{J}$$

Thus, $\boxed{11.8\ \text{J}}$ of energy is spent overcoming friction between B and C.

5.37 (a) When the child slides down a frictionless surface, the only non-conservative force acting on the child is the normal force. At each instant, this force is perpendicular to the motion and, hence, does no work. Thus, conservation of mechanical energy $\boxed{\text{can be used}}$ in this case.

(b) The equation for conservation of mechanical energy, $(KE+PE)_f = (KE+PE)_i$, for this situation is $\frac{1}{2}\cancel{m}v_f^2 + \cancel{m}gy_f = \frac{1}{2}\cancel{m}v_i^2 + \cancel{m}gy_i$. Notice that the mass of the child cancels out of the equation, so $\boxed{\text{the mass of the child is not a factor}}$ in the frictionless case.

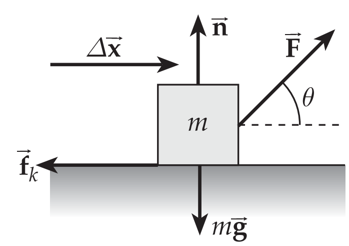
(c) Observe that solving the energy conservation equation from above for the final speed gives $v_f = \sqrt{v_i^2 + 2g\left(y_i - y_f\right)}$. Since the child starts with the same initial speed ($v_i = 0$) and has the same change in altitude in both cases, $\boxed{v_f \text{ is the same}}$ in the two cases.

(d) $\boxed{\text{Work done by a non-conservative force must be accounted for}}$ when friction is present. This is done by using the work-energy theorem rather than conservation of mechanical energy.

(e) From Part (b), conservation of mechanical energy gives the final speed as

$$v_f = \sqrt{v_i^2 + 2g\left(y_i - y_f\right)} = \sqrt{0 + 2\left(9.80\ \text{m/s}^2\right)(12.0\ \text{m})} = \boxed{15.3\ \text{m/s}}$$

5.38 (a) $\Sigma F_y = 0 \quad \Rightarrow \quad n + F\sin\theta - mg = 0$



or $\qquad n = mg - F\sin\theta$

The friction force is then

$$f_k = \mu_k n = \boxed{\mu_k\left(mg - F\sin\theta\right)}$$

(b) The work done by the applied force is

$$W_F = F\left|\Delta\vec{\mathbf{x}}\right|\cos\theta = \boxed{Fx\cos\theta}$$

and the work done by the friction force is $W_{f_k} = f_k\left|\Delta\vec{\mathbf{x}}\right|\cos\phi$ where ϕ is the angle between the direction of $\vec{\mathbf{f}}_k$ and $\Delta\vec{\mathbf{x}}$. Thus, $W_{f_k} = f_k x\cos 180° = \boxed{-\mu_k\left(mg - F\sin\theta\right)x}$

(c) The forces that do no work are those perpendicular to the direction of the displacement $\Delta\vec{\mathbf{x}}$. These are $\boxed{\vec{\mathbf{n}},\ m\vec{\mathbf{g}},\ \text{and the vertical component of } \vec{\mathbf{F}}}$

(d) For Part (a): $n = mg - F\sin\theta = (2.00\ \text{kg})(9.80\ \text{m/s}^2) - (15.0\ \text{N})\sin 37.0° = 10.6\ \text{N}$

$$f_k = \mu_k n = (0.400)(10.6\ \text{N}) = \boxed{4.23\ \text{N}}$$

For Part (b): $W_F = Fx\cos\theta = (15.0\ \text{N})(4.00\ \text{m})\cos 37.0° = \boxed{47.9\ \text{J}}$

$$W_{f_k} = f_k x\cos\phi = (4.23\ \text{N})(4.00\ \text{m})\cos 180° = \boxed{-16.9\ \text{J}}$$

5.39 We shall take $PE_g = 0$ at the lowest level reached by the diver under the water. The diver falls a total of 15 m, but the non-conservative force due to water resistance acts only during the last 5.0 m of fall. The work-energy theorem then gives

$$W_{nc} = \left(KE + PE_g\right)_f - \left(KE + PE_g\right)_i$$

or $$\left(F_{\text{av}}\cos 180°\right)(5.0\ \text{m}) = (0+0) - \left[0 + (70\ \text{kg})\left(9.80\ \text{m/s}^2\right)(15\ \text{m})\right]$$

This gives the average resistance force as $F_{\text{av}} = 2.1\times 10^3\ \text{N} = \boxed{2.1\ \text{kN}}$

5.40 Since the plane is in level flight, $\left(PE_g\right)_f = \left(PE_g\right)_i$ and the work-energy theorem reduces to $W_{nc} = W_{thrust} + W_{resistance} = KE_f - KE_i$, or

$$\left(F\cos 0°\right)s + \left(f\cos 180\right)s = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

This gives

$$v_f = \sqrt{v_i^2 + \frac{2(F-f)s}{m}} = \sqrt{(60\ \text{m/s})^2 + \frac{2\left[(7.5-4.0)\times 10^4\ \text{N}\right](500\ \text{m})}{1.5\times 10^4\ \text{kg}}} = \boxed{77\ \text{m/s}}$$

5.41 Choose $PE_g = 0$ at the level of the bottom of the driveway.

Then $W_{nc} = \left(KE + PE_g\right)_f - \left(KE + PE_g\right)_i$ becomes

$$\left(f\cos 180°\right)s = \left[\frac{1}{2}mv_f^2 + 0\right] - \left[0 + mg\left(s\sin 20°\right)\right].$$

Solving for the final speed gives $v_f = \sqrt{(2gs)\sin 20° - \dfrac{2fs}{m}}$, or

or $$v_f = \sqrt{2\left(9.80\ \text{m/s}^2\right)(5.0\ \text{m})\sin 20° - \frac{2\left(4.0\times 10^3\ \text{N}\right)(5.0\ \text{m})}{2.10\times 10^3\ \text{kg}}} = \boxed{3.8\ \text{m/s}}$$

5.42 (a) Choose $PE_g = 0$ at the level of the bottom of the arc. The child's initial vertical displacement from this level is

$$y_i = (2.00\ \text{m})(1 - \cos 30.0°) = 0.268\ \text{m}$$

In the absence of friction, we use conservation of mechanical energy as

$\left(KE + PE_g\right)_f = \left(KE + PE_g\right)_i$, or $\frac{1}{2}mv_f^2 + 0 = 0 + mgy_i$, which gives

$$v_f = \sqrt{2gy_i} = \sqrt{2\left(9.80\ \text{m/s}^2\right)(0.268\ \text{m})} = \boxed{2.29\ \text{m/s}}$$

(b) With a non-conservative force present, we use

$W_{nc} = \left(KE + PE_g\right)_f - \left(KE + PE_g\right)_i = \left(\frac{1}{2}mv_f^2 + 0\right) - \left(0 + mgy_i\right)$, or

$$W_{nc} = m\left(\frac{v_f^2}{2} - gy_i\right)$$

$$= (25.0\ \text{kg})\left[\frac{(2.00\ \text{m/s})^2}{2} - \left(9.80\ \text{m/s}^2\right)(0.268\ \text{m})\right] = -15.6\ \text{J}$$

Thus, $\boxed{15.6\ \text{J}}$ of energy is spent overcoming friction.

5.43 (a) We use conservation of mechanical energy, $(KE + PE_g)_f = (KE + PE_g)_i$, for the trip down the frictionless ramp. With $v_i = 0$, this reduces to

$$v_f = \sqrt{2g(y_i - y_f)} = \sqrt{2(9.80\ \text{m/s}^2)[(3.00\ \text{m})\sin 30.0°]} = \boxed{5.42\ \text{m/s}}$$

(b) Using the work-energy theorem,

$$W_{nc} = (KE + PE_g)_f - (KE + PE_g)_i$$

for the trip across the rough floor gives

$$(f_k \cos 180°)s = (0+0) - \left(\frac{1}{2}mv_i^2 + 0\right), \text{ or } f_k\, s = \mu_k (mg)s = \frac{1}{2}mv_i^2$$

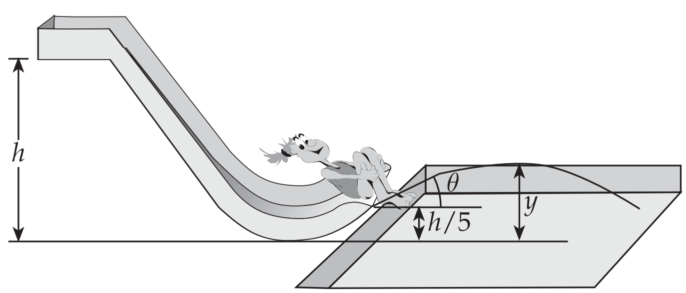
Thus, the coefficient of kinetic friction is

$$\mu_k = \frac{v_i^2}{2gs} = \frac{(5.42\ \text{m/s})^2}{2(9.80\ \text{m/s}^2)(5.00\ \text{m})} = \boxed{0.300}$$

(c) All of the initial mechanical energy, $(KE + PE_g)_i = 0 + mgy_i$, is spent overcoming friction on the rough floor. Therefore, the energy "lost" is

$$mgy_i = (10.0\ \text{m})(9.80\ \text{m/s}^2)[(3.00\ \text{m})\sin 30.0°] = \boxed{147\ \text{J}}$$

5.44 Choose $PE_g = 0$ at water level and use $(KE + PE_g)_f = (KE + PE_g)_i$ for the trip down the curved slide. This gives



$$\frac{1}{2}mv^2 + mg\left(\frac{h}{5}\right) = 0 + mgh, \text{ so the}$$

speed of the child as she leaves the end of the slide is $v = \sqrt{2g(4h/5)}$

The vertical component of this launch velocity is

$$v_{0y} = v\sin\theta = \sin\theta\sqrt{2g\left(\frac{4h}{5}\right)}$$

At the top of the arc, $v_y = 0$. Thus, $v_y^2 = v_{0y}^2 + 2a_y(\Delta y)$ gives the maximum height the child reaches during the airborne trip as

$$0 = \sin^2\theta\left[2g\left(\frac{4h}{5}\right)\right] + 2(-g)\left(y_{\max} - \frac{h}{5}\right)$$

This may be solved for $y_{\max}$ to yield $y_{\max} = \boxed{\frac{h}{5}(4\sin^2\theta + 1)}$

5.45 Choose $PE_g = 0$ at the level of the base of the hill and let x represent the distance the skier moves along the horizontal portion before coming to rest. The normal force exerted on the skier by the snow while on the hill is $n_1 = mg\cos 10.5°$ and, while on the horizontal portion, $n_2 = mg$.

Consider the entire trip, starting from rest at the top of the hill until the skier comes to rest on the horizontal portion. The work done by friction forces is

$$W_{nc} = \left[(f_k)_1 \cos 180°\right](200\text{ m}) + \left[(f_k)_2 \cos 180°\right]x$$

$$= -\mu_k(mg\cos 10.5°)(200\text{ m}) - \mu_k(mg)x$$

Applying $W_{nc} = (KE + PE_g)_f - (KE + PE_g)_i$ to this complete trip gives

$$-\mu_k(mg\cos 10.5°)(200\text{ m}) - \mu_k(mg)x = [0+0] - [0 + mg(200\text{ m})\sin 10.5°]$$

or $x = \left(\dfrac{\sin 10.5°}{\mu_k} - \cos 10.5°\right)(200\text{ m})$. If $\mu_k = 0.0750$, then $x = \boxed{289\text{ m}}$

5.46 The normal force exerted on the sled by the track is $n = mg\cos\theta$ and the friction force is $f_k = \mu_k n = \mu_k\, mg\cos\theta$.

If s is the distance measured along the incline that the sled travels, applying $W_{nc} = (KE + PE_g)_f - (KE + PE_g)_i$ to the entire trip gives

$$\left[(\mu_k\, mg\cos\theta)\cos 180°\right]s = \left[0 + mgs(\sin\theta)\right] - \left[\frac{1}{2}mv_i^2 + 0\right]$$

or $s = \dfrac{v_i^2}{2g(\sin\theta + \mu_k\cos\theta)} = \dfrac{(4.0\text{ m/s})^2}{2(9.80\text{ m/s}^2)(\sin 20° + 0.20\cos 20°)} = \boxed{1.5\text{ m}}$

5.47 (a) Consider the entire trip and apply $W_{nc} = \left(KE + PE_g\right)_f - \left(KE + PE_g\right)_i$ to obtain

$$\left(f_1 \cos 180°\right)d_1 + \left(f_2 \cos 180°\right)d_2 = \left(\frac{1}{2}mv_f^2 + 0\right) - \left(0 + mgy_i\right), \text{ or}$$

$$v_f = \sqrt{2\left(g\,y_i - \frac{f_1 d_1 + f_2 d_2}{m}\right)}$$

$$= \sqrt{2\left(\left(9.80\ \text{m/s}^2\right)(1000\ \text{m}) - \frac{(50.0\ \text{N})(800\ \text{m}) + (3600\ \text{N})(200\ \text{m})}{80.0\ \text{kg}}\right)}$$

which yields $v_f = \boxed{24.5\ \text{m/s}}$

(b) $\boxed{\text{Yes}}$, this is too fast for safety.

(c) Again, apply $W_{nc} = \left(KE + PE_g\right)_f - \left(KE + PE_g\right)_i$, now with d_2 considered to be a variable, $d_1 = 1000\ \text{m} - d_2$, and $v_f = 5.00\ \text{m/s}$. This gives

$$\left(f_1 \cos 180°\right)\left(1000\ \text{m} - d_2\right) + \left(f_2 \cos 180°\right)d_2 = \left(\frac{1}{2}mv_f^2 + 0\right) - \left(0 + mgy_i\right)$$

which reduces to $-(1000\ \text{m})\,f_1 + f_1\,d_2 - f_2\,d_2 = \frac{1}{2}mv_f^2 - mgy_i$. Therefore,

$$d_2 = \frac{(mg)\,y_i - (1000\ \text{m})\,f_1 - \frac{1}{2}mv_f^2}{f_2 - f_1}$$

$$= \frac{(784\ \text{N})(1000\ \text{m}) - (1000\ \text{m})(50.0\ \text{N}) - \frac{1}{2}(80.0\ \text{kg})(5.00\ \text{m/s})^2}{3600\ \text{N} - 50.0\ \text{N}} = \boxed{206\ \text{m}}$$

(d) In reality, the air drag will depend on the skydiver's speed. It will be larger than her 784 N weight only after the chute is opened. It will be nearly equal to 784 N before she opens the chute and again before she touches down, whenever she moves near terminal speed.

5.48 (a) $W_{nc} = \Delta KE + \Delta PE$, but $\Delta KE = 0$ because the speed is constant. The skier rises a vertical distance of $\Delta y = (60\ \text{m})\sin 30° = 30\ \text{m}$. Thus,

$$W_{nc} = (70\ \text{kg})\left(9.80\ \text{m/s}^2\right)(30\ \text{m}) = 2.06 \times 10^4\ \text{J} = \boxed{21\ \text{kJ}}$$

(b) The time to travel 60 m at a constant speed of 2.0 m/s is 30 s. Thus, the required power input is

$$\mathcal{P} = \frac{W_{nc}}{\Delta t} = \frac{2.06 \times 10^4 \text{ J}}{30 \text{ s}} = (686 \text{ W})\left(\frac{1 \text{ hp}}{746 \text{ W}}\right) = \boxed{0.92 \text{ hp}}$$

5.49 (a) The sewage lifted each day has a mass of

$$m = (1\,890\,000 \text{ L})\left(\frac{10^{-3} \text{ m}^3}{1 \text{ L}}\right)(1\,050 \text{ kg/m}^3) = 1.98 \times 10^6 \text{ kg}$$

Since both the pressure and the pipe diameter are the same at the output port as at the input port, the speed of the liquid is unchanged ($KE_f = KE_i$). Thus, the work output by the pump each day is

$$W_{output} = (KE + PE)_f - (KE + PE)_i = mg(y_f - y_i)$$

or $W_{output} = (1.98 \times 10^6 \text{ kg})(9.80 \text{ m/s}^2)(5.49 \text{ m}) = 1.07 \times 10^8 \text{ J}$

The power output of the pump is then

$$\mathcal{P}_{output} = \frac{W_{output}}{\Delta t} = \frac{1.07 \times 10^8 \text{ J}}{1 \text{ day}}\left(\frac{1 \text{ day}}{8.64 \times 10^4 \text{ s}}\right) = 1.24 \times 10^3 \text{ W} = \boxed{1.24 \text{ kW}}$$

(b) The efficiency of this pumping station is

$$efficiency = \frac{\mathcal{P}_{output}}{\mathcal{P}_{input}} \times 100\% = \frac{1.24 \text{ kW}}{5.90 \text{ kW}} \times 100\% = \boxed{20.9\%}$$

5.50 Let ΔN be the number of steps taken in time Δt. We determine the number of steps per unit time by

$$\text{Power} = \frac{\text{work done}}{\Delta t} = \frac{(\text{work per step per unit mass})(\text{mass})(\#\text{ steps})}{\Delta t},$$

or $$70 \text{ W} = \left(0.60 \frac{\text{J/step}}{\text{kg}}\right)(60 \text{ kg})\left(\frac{\Delta N}{\Delta t}\right), \text{ giving } \frac{\Delta N}{\Delta t} = 1.9 \text{ steps/s}$$

The running speed is then

$$v_{\text{av}} = \frac{\Delta x}{\Delta t} = \left(\frac{\Delta N}{\Delta t}\right)(\text{distance traveled per step}) = \left(1.9 \frac{\text{step}}{\text{s}}\right)\left(1.5 \frac{\text{m}}{\text{step}}\right) = \boxed{2.9 \text{ m/s}}$$

5.51 Assuming a level track, $PE_f = PE_i$, and the work done on the train is

$$W_{nc} = (KE+PE)_f - (KE+PE)_i$$

$$= \tfrac{1}{2}m\left(v_f^2 - v_i^2\right) = \tfrac{1}{2}(0.875\text{ kg})\left[(0.620\text{ m/s})^2 - 0\right] = 0.168\text{ J}$$

The power delivered by the motor is then

$$\mathcal{P} = \frac{W_{nc}}{\Delta t} = \frac{0.168\text{ J}}{21.0\times10^{-3}\text{ s}} = \boxed{8.01\text{ W}}$$

5.52 The useful work done is 40.0% of the energy stored in the battery, or

$$W_{nc} = 0.40(120\text{ Wh})\left(\frac{3\,600\text{ J}}{1\text{ Wh}}\right) = 1.73\times10^5\text{ J}$$

Assuming constant speed of the scooter ($KE_f = KE_i$),

$$W_{nc} = (KE+PE)_f - (KE+PE)_i = mg\left(y_f - y_i\right)$$

or $$\left(y_f - y_i\right) = \frac{W_{nc}}{mg} = \frac{1.73\times10^5\text{ J}}{890\text{ N}} = \boxed{194\text{ m}}$$

5.53 (a) The acceleration of the car is $a = \dfrac{v-v_0}{t} = \dfrac{18.0\text{ m/s}-0}{12.0\text{ s}} = 1.50\text{ m/s}^2$. Thus, the constant forward force due to the engine is found from $\Sigma F = F_{engine} - F_{air} = ma$ as

$$F_{engine} = F_{air} + ma = 400\text{ N} + \left(1.50\times10^3\text{ kg}\right)\left(1.50\text{ m/s}^2\right) = 2.65\times10^3\text{ N}$$

The average velocity of the car during this interval is $v_{\text{av}} = \dfrac{v+v_0}{2} = 9.00\text{ m/s}$, so the average power input from the engine during this time is

$$\mathcal{P}_{\text{av}} = F_{engine}\,v_{\text{av}} = \left(2.65\times10^3\text{ N}\right)(9.00\text{ m/s})\left(\frac{1\text{ hp}}{746\text{ W}}\right) = \boxed{32.0\text{ hp}}$$

(b) At $t = 12.0\text{ s}$, the instantaneous velocity of the car is $v = 18.0\text{ m/s}$ and the instantaneous power input from the engine is

$$\mathcal{P} = F_{engine}\,v = \left(2.65\times10^3\text{ N}\right)(18.0\text{ m/s})\left(\frac{1\text{ hp}}{746\text{ W}}\right) = \boxed{63.9\text{ hp}}$$

5.54 (a) The acceleration of the elevator during the first 3.00 s is

$$a = \frac{v - v_0}{t} = \frac{1.75 \text{ m/s} - 0}{3.00 \text{ s}} = 0.583 \text{ m/s}^2$$

so $F_{net} = F_{motor} - mg = ma$ gives the force exerted by the motor as

$$F_{motor} = m(a+g) = (650 \text{ kg})\left[(0.583 + 9.80) \text{ m/s}^2\right] = 6.75 \times 10^3 \text{ N}$$

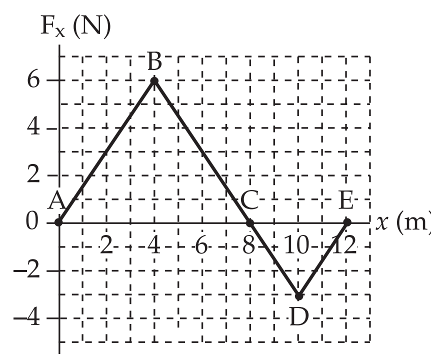
The average velocity of the elevator during this interval is $v_{av} = \dfrac{v + v_0}{2} = 0.875 \text{ m/s}$ so the average power input from the motor during this time is

$$\mathcal{P}_{av} = F_{motor} v_{av} = \left(6.75 \times 10^3 \text{ N}\right)(0.875 \text{ m/s})\left(\frac{1 \text{ hp}}{746 \text{ W}}\right) = \boxed{7.92 \text{ hp}}$$

(b) When the elevator moves upward with a constant speed of $v = 1.75 \text{ m/s}$, the upward force exerted by the motor is $F_{motor} = mg$ and the instantaneous power input from the motor is

$$\mathcal{P} = (mg)v = (650 \text{ kg})\left(9.80 \text{ m/s}^2\right)(1.75 \text{ m/s})\left(\frac{1 \text{ hp}}{746 \text{ W}}\right) = \boxed{14.9 \text{ hp}}$$

5.55 The work done on the particle by the force F as the particle moves from $x = x_i$ to $x = x_f$ is the area under the curve from x_i to x_f.



(a) For $x = 0$ to $x = 8.00$ m,

$$W = \text{area of triangle } ABC = \frac{1}{2}\overline{AC} \times \text{altitude}$$

$$W_{0\to 8} = \frac{1}{2}(8.00 \text{ m})(6.00 \text{ N}) = \boxed{24.0 \text{ J}}$$

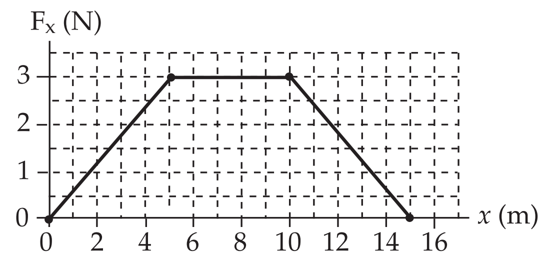
(b) For $x = 8.00$ m to $x = 10.0$ m,

$$W_{8\to 10} = \text{area of triangle } CDE = \frac{1}{2}\overline{CE} \times \text{altitude}$$

$$= \frac{1}{2}(2.00 \text{ m})(-3.00 \text{ N}) = \boxed{-3.00 \text{ J}}$$

(c) $W_{0\to 10} = W_{0\to 8} + W_{8\to 10} = 24.0\text{ J} + (-3.00\text{ J}) = \boxed{21.0\text{ J}}$

5.56 W equals the area under the Force-Displacement Curve



(a) For the region $0 \le x \le 5.00$ m,

$$W = \frac{(3.00\text{ N})(5.00\text{ m})}{2} = \boxed{7.50\text{ J}}$$

(b) For the region $5.00\text{ m} \le x \le 10.0\text{ m}$,

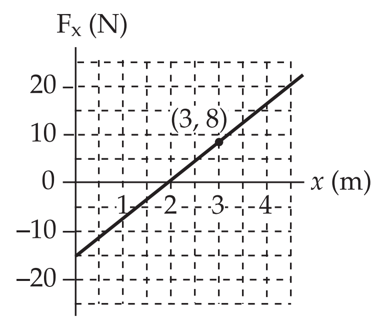
$$W = (3.00\text{ N})(5.00\text{ m}) = \boxed{15.0\text{ J}}$$

(c) For the region $10.0\text{ m} \le x \le 15.0\text{ m}$, $W = \dfrac{(3.00\text{ N})(5.00\text{ m})}{2} = \boxed{7.50\text{ J}}$

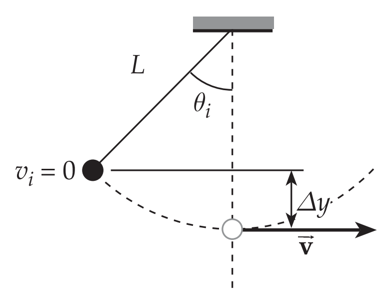
(d) For the region $0 \le x \le 15.0$ m, $W = (7.50 + 15.0 + 7.50)\text{ J} = \boxed{30.0\text{ J}}$

5.57 (a) $F_x = (8x - 16)$ N

(b) $W_{net} = \dfrac{-(2.00\text{ m})(16.0\text{ N})}{2} + \dfrac{(1.00\text{ m})(8.00\text{ N})}{2} = \boxed{-12.0\text{ J}}$



5.58 The support string always lies along a radius line of the circular path followed by the bob. This means that the tension force in the string is always perpendicular to the motion of the bob and does no work. Thus, mechanical energy is conserved and (taking $y = 0$ at the point of support) this gives



$$\tfrac{1}{2}mv^2 = \tfrac{1}{2}mv_i^2 + mg(y_i - y_f) = 0 + mg(-L\cos\theta_i) - mg(-L)\text{, or}$$

$$v = \sqrt{2gL(1-\cos\theta_i)} = \sqrt{2(9.8\text{ m/s}^2)(2.0\text{ m})(1-\cos 25°)}$$

$$v = \boxed{1.9\text{ m/s}}$$

5.59 (a) The equivalent spring constant of the bow is given by $F = kx$ as

$$k = \frac{F_f}{x_f} = \frac{230 \text{ N}}{0.400 \text{ m}} = \boxed{575 \text{ N/m}}$$

(b) From the work-energy theorem applied to this situation,

$$W_{nc} = \left(KE + PE_g + PE_s\right)_f - \left(KE + PE_g + PE_s\right)_i = \left(0 + 0 + \frac{1}{2}kx_f^2\right) - (0 + 0 + 0)$$

The work done pulling the bow is then

$$W_{nc} = \frac{1}{2}kx_f^2 = \frac{1}{2}(575 \text{ N/m})(0.400 \text{ m})^2 = \boxed{46.0 \text{ J}}$$

5.60 Choose $PE_g = 0$ at the level where the block comes to rest against the spring. Then, in the absence of work done by non-conservative forces, the conservation of mechanical energy gives

$$\left(KE + PE_g + PE_s\right)_f = \left(KE + PE_g + PE_s\right)_i$$

or $\quad 0 + 0 + \frac{1}{2}kx_f^2 = 0 + mg\,L\sin\theta + 0$. Thus,

$$x_f = \sqrt{\frac{2mg\,L\sin\theta}{k}} = \sqrt{\frac{2(12.0 \text{ kg})(9.80 \text{ m/s}^2)(3.00 \text{ m})\sin 35.0°}{3.00 \times 10^4 \text{ N/m}}} = \boxed{0.116 \text{ m}}$$

5.61 (a) From $v^2 = v_0^2 + 2a_y(\Delta y)$, we find the speed just before touching the ground as

$$v = \sqrt{0 + 2(9.80 \text{ m/s}^2)(1.0 \text{ m})} = \boxed{4.4 \text{ m/s}}$$

(b) Choose $PE_g = 0$ at the level where the feet come to rest. Then $W_{nc} = \left(KE + PE_g\right)_f - \left(KE + PE_g\right)_i$ becomes

$$\left(F_{\text{av}} \cos 180°\right)s = (0 + 0) - \left(\frac{1}{2}mv_i^2 + mg\,s\right)$$

or $$F_{\text{av}} = \frac{mv_i^2}{2s} + mg = \frac{(75 \text{ kg})(4.4 \text{ m/s})^2}{2\left(5.0 \times 10^{-3} \text{ m}\right)} + (75 \text{ kg})(9.80 \text{ m/s}^2) = \boxed{1.5 \times 10^5 \text{ N}}$$

5.62 From the work-energy theorem,

$$W_{nc} = \left(KE + PE_g + PE_s\right)_f - \left(KE + PE_g + PE_s\right)_i$$

we have $\left(f_k \cos 180°\right)s = \left(\frac{1}{2}mv_f^2 + 0 + 0\right) - \left(0 + 0 + \frac{1}{2}kx_i^2\right)$, or

$$v_f = \sqrt{\frac{kx_i^2 - 2f_k s}{m}} = \sqrt{\frac{(8.0\ \text{N/m})\left(5.0\times10^{-2}\ \text{m}\right)^2 - 2(0.032\ \text{N})(0.15\ \text{m})}{5.3\times10^{-3}\ \text{kg}}} = \boxed{1.4\ \text{m/s}}$$

5.63 (a) The two masses will pass when both are at $y_f = 2.00\ \text{m}$ above the floor. From conservation of energy, $\left(KE + PE_g + PE_s\right)_f = \left(KE + PE_g + PE_s\right)_i$

$$\frac{1}{2}\left(m_1 + m_2\right)v_f^2 + \left(m_1 + m_2\right)gy_f + 0 = 0 + m_1 g y_{1i} + 0\text{, or}$$

$$v_f = \sqrt{\frac{2m_1 g\, y_{1i}}{m_1 + m_2} - 2g\, y_f}$$

$$= \sqrt{\frac{2(5.00\ \text{kg})\left(9.80\ \text{m/s}^2\right)(4.00\ \text{m})}{8.00\ \text{kg}} - 2\left(9.80\ \text{m/s}^2\right)(2.00\ \text{m})}$$

This yields the passing speed as $v_f = \boxed{3.13\ \text{m/s}}$.

(b) When $m_1 = 5.00\ \text{kg}$ reaches the floor, $m_2 = 3.00\ \text{kg}$ is $y_{2f} = 4.00\ \text{m}$ above the floor. Thus, $\left(KE + PE_g + PE_s\right)_f = \left(KE + PE_g + PE_s\right)_i$ becomes

$$\frac{1}{2}\left(m_1 + m_2\right)v_f^2 + m_2 g\, y_{2f} + 0 = 0 + m_1 g y_{1i} + 0\text{, or } v_f = \sqrt{\frac{2g\left(m_1 y_{1i} - m_2 y_{2f}\right)}{m_1 + m_2}}$$

Thus,

$$v_f = \sqrt{\frac{2\left(9.80\ \text{m/s}^2\right)\left[(5.00\ \text{kg})(4.00\ \text{m}) - (3.00\ \text{kg})(4.00\ \text{m})\right]}{8.00\ \text{kg}}} = \boxed{4.43\ \text{m/s}}$$

(c) When the 5.00-kg hits the floor, the string goes slack and the 3.00-kg becomes a projectile launched straight upward with initial speed $v_{0y} = 4.43 \text{ m/s}$. At the top of its arc, $v_y = 0$ and $v_y^2 = v_{0y}^2 + 2a_y(\Delta y)$ gives

$$\Delta y = \frac{v_y^2 - v_{0y}^2}{2a_y} = \frac{0 - (4.43 \text{ m/s})^2}{2(-9.80 \text{ m/s}^2)} = \boxed{1.00 \text{ m}}$$

5.64 The normal force the incline exerts on block A is $n_A = (m_A g)\cos 37°$, and the friction force is $f_k = \mu_k n_A = \mu_k m_A g \cos 37°$. The vertical distance block A rises is $\Delta y_A = (20 \text{ m})\sin 37° = 12 \text{ m}$, while the vertical displacement of block B is $\Delta y_B = -20 \text{ m}$.

We find the common final speed of the two blocks by use of

$$W_{nc} = (KE + PE_g)_f - (KE + PE_g)_i = \Delta KE + \Delta PE_g$$

This gives $-(\mu_k m_A g \cos 37°)s = \left[\frac{1}{2}(m_A + m_B)v_f^2 - 0\right] + \left[m_A g(\Delta y_A) + m_B g(\Delta y_B)\right]$

or

$$v_f^2 = \frac{2g\left[-m_B(\Delta y_B) - m_A(\Delta y_A) - (\mu_k m_A \cos 37°)s\right]}{m_A + m_B}$$

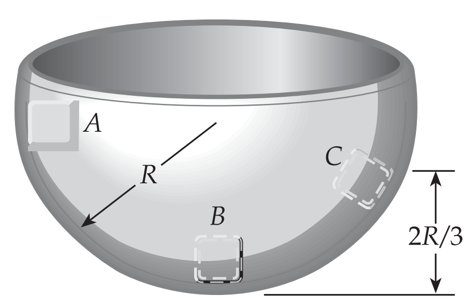
$$= \frac{2(9.80 \text{ m/s}^2)\left[-(100 \text{ kg})(-20 \text{ m}) - (50 \text{ kg})(12 \text{ m}) - 0.25(50 \text{ kg})(20 \text{ m})\cos 37°\right]}{150 \text{ kg}}$$

which yields $v_f^2 = 157 \text{ m}^2/\text{s}^2$

The change in the kinetic energy of block A is then

$$\Delta KE_A = \frac{1}{2}m_A v_f^2 - 0 = \frac{1}{2}(50 \text{ kg})(157 \text{ m}^2/\text{s}^2) = 3.9 \times 10^3 \text{ J} = \boxed{3.9 \text{ kJ}}$$

5.65 Since the bowl is smooth (that is, frictionless), mechanical energy is conserved or $(KE + PE)_f = (KE + PE)_i$. Also, if we choose $y = 0$ (and hence, $PE_g = 0$) at the lowest point in the bowl, then $y_A = +R$, $y_B = 0$, and $y_C = 2R/3$



(a) $\left(PE_g\right)_A = mgy_A = mgR$, or

$$\left(PE_g\right)_A = (0.200\text{ kg})\left(9.80\text{ m/s}^2\right)(0.300\text{ m}) = \boxed{0.588\text{ J}}$$

(b) $KE_B = KE_A + PE_A - PE_B = 0 + mgy_A - mgy_B = 0.588\text{ J} - 0 = \boxed{0.588\text{ J}}$

(c) $KE_B = \frac{1}{2}mv_B^2 \quad \Rightarrow \quad v_B = \sqrt{\dfrac{2\,KE_B}{m}} = \sqrt{\dfrac{2(0.588\text{ J})}{0.200\text{ kg}}} = \boxed{2.42\text{ m/s}}$

(d) $\left(PE_g\right)_C = mgy_C = (0.200\text{ kg})\left(9.80\text{ m/s}^2\right)\left[\dfrac{2(0.300\text{ m})}{3}\right] = \boxed{0.392\text{ J}}$

$$KE_C = KE_B + PE_B - PE_C = 0.588\text{ J} + 0 - 0.392\text{ J} = \boxed{0.196\text{ J}}$$

5.66 When 1 pound (454 grams) of fat is metabolized, the energy released is $E = (454\text{ g})(9.00\text{ kcal/g}) = 4.09\times10^3\text{ kcal}$. Of this, 20.0% goes into mechanical energy (climbing stairs in this case). Thus, the mechanical energy generated by metabolizing 1 pound of fat is

$$E_m = (0.200)\left(4.09\times10^3\text{ kcal}\right) = 817\text{ kcal}$$

Each time the student climbs the stairs, she raises her body a vertical distance of $\Delta y = (80\text{ steps})(0.150\text{ m/step}) = 12.0\text{ m}$. The mechanical energy required to do this is $\Delta PE_g = mg(\Delta y)$, or

$$\Delta PE_g = (50.0\text{ kg})\left(9.80\text{ m/s}^2\right)(12.0\text{ m}) = \left(5.88\times10^3\text{ J}\right)\left(\frac{1\text{ kcal}}{4186\text{ J}}\right) = 1.40\text{ kcal}$$

(a) The number of times the student must climb the stairs to metabolize 1 pound of fat is $N = \dfrac{E_m}{\Delta PE_g} = \dfrac{817\text{ kcal}}{1.40\text{ kcal/trip}} = \boxed{582\text{ trips}}$

It would be more practical for her to reduce food intake.

(b) The useful work done each time the student climbs the stairs is $W = \Delta PE_g = 5.88\times10^3\text{ J}$ Since this is accomplished in 65.0 s, the average power output is

$$\mathcal{P}_{\text{av}} = \frac{W}{t} = \frac{5.88\times10^3\text{ J}}{65.0\text{ s}} = \boxed{90.5\text{ W}} = (90.5\text{ W})\left(\frac{1\text{ hp}}{746\text{ W}}\right) = \boxed{0.121\text{ hp}}$$

5.67 (a) The person walking uses $E_w = (220 \text{ kcal})\left(\dfrac{4\,186 \text{ J}}{1 \text{ kcal}}\right) = 9.21 \times 10^5 \text{ J}$ of energy while going 3.00 miles. The quantity of gasoline which could furnish this much energy is $V_1 = \dfrac{9.21 \times 10^5 \text{ J}}{1.30 \times 10^8 \text{ J/gal}} = 7.08 \times 10^{-3} \text{ gal}$. This means that the walker's fuel economy in equivalent miles per gallon is

$$\textit{fuel economy} = \frac{3.00 \text{ mi}}{7.08 \times 10^{-3} \text{ gal}} = \boxed{423 \text{ mi/gal}}$$

(b) In 1 hour, the bicyclist travels 10.0 miles and uses

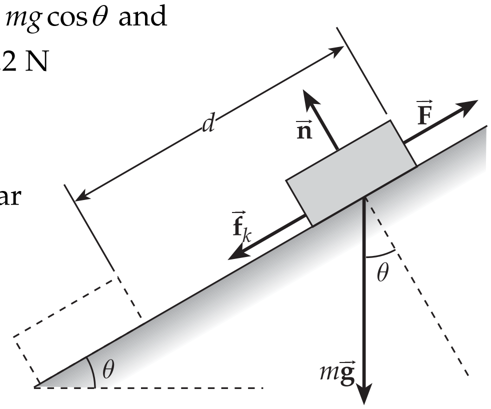
$$E_B = (400 \text{ kcal})\left(\frac{4\,186 \text{ J}}{1 \text{ kcal}}\right) = 1.67 \times 10^6 \text{ J}$$

which is equal to the energy available in $V_2 = \dfrac{1.67 \times 10^6 \text{ J}}{1.30 \times 10^8 \text{ J/gal}} = 1.29 \times 10^{-2} \text{ gal}$

of gasoline. Thus, the equivalent fuel economy for the bicyclist is

$$\frac{10.0 \text{ mi}}{1.29 \times 10^{-2} \text{ gal}} = \boxed{776 \text{ mi/gal}}$$

5.68 Consider the free-body diagram given at the right. The box has zero acceleration perpendicular to the incline. Thus, $\Sigma F_\perp = 0 \ \Rightarrow \ n = mg\cos\theta$ and $f_k = \mu_k n = \mu_k mg\cos\theta = (0.220)(80.0 \text{ N})\cos 30.0° = 15.2 \text{ N}$



Of the forces acting on the box, $\vec{\mathbf{F}}$ and $\vec{\mathbf{f}}_k$ are non-conservative forces that do work, $\vec{\mathbf{n}}$ is perpendicular to the displacement and does no work, and $m\vec{\mathbf{g}}$ is the conservative gravitational force.

From $W_{nc} = (KE + PE)_f - (KE + PE)_i$, the change in kinetic energy as the box moves distance d up the incline is

$$KE_f - KE_i = W_{nc} - \left[\left(PE_g\right)_f - \left(PE_g\right)_i\right] = (F - f_k)d - mg\left(y_f - y_i\right)$$

Since $y_f - y_i = d\sin\theta = (20.0 \text{ m})\sin 30.0° = 10.0 \text{ m}$, this becomes

$$\Delta KE = (100 \text{ N} - 15.2 \text{ N})(20.0 \text{ m}) - (80.0 \text{ N})(10.0 \text{ m}) = \boxed{895 \text{ J}}$$

5.69 (a) Use conservation of mechanical energy, $(KE+PE_g)_f=(KE+PE_g)_i$, from the start to the end of the track to find the speed of the skier as he leaves the track. This gives $\frac{1}{2}mv^2+mgy_f=0+mgy_i$, or

$$v=\sqrt{2g(y_i-y_f)}=\sqrt{2(9.80\ \text{m/s}^2)(40.0\ \text{m})}=\boxed{28.0\ \text{m/s}}$$

(b) At the top of the parabolic arc the skier follows after leaving the track, $v_y=0$ and $v_x=(28.0\ \text{m/s})\cos 45.0°=19.8\ \text{m/s}$. Thus, $v_{top}=\sqrt{v_x^2+v_y^2}=19.8\ \text{m/s}$. Applying conservation of mechanical energy from the end of the track to the top of the arc gives $\frac{1}{2}m(19.8\ \text{m/s})^2+mg\,y_{\max}=\frac{1}{2}m(28.0\ \text{m/s})^2+mg(10.0\ \text{m})$, or

$$y_{\max}=10.0\ \text{m}+\frac{(28.0\ \text{m/s})^2-(19.8\ \text{m/s})^2}{2(9.80\ \text{m/s}^2)}=\boxed{30.0\ \text{m}}$$

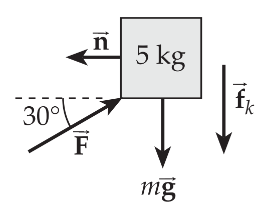
(c) Using $\Delta y=v_{0y}t+\frac{1}{2}a_yt^2$ for the flight from the end of the track to the ground gives

$$-10.0\ \text{m}=\left[(28.0\ \text{m/s})\sin 45.0°\right]t+\frac{1}{2}(-9.80\ \text{m/s}^2)t^2$$

The positive solution of this equation gives the total time of flight as $t=4.49$ s. During this time, the skier has a horizontal displacement of

$$\Delta x=v_{0x}t=\left[(28.0\ \text{m/s})\cos 45.0°\right](4.49\ \text{s})=\boxed{89.0\ \text{m}}$$

5.70 First, determine the magnitude of the applied force by considering a free-body diagram of the block. Since the block moves with constant velocity, $\Sigma F_x=\Sigma F_y=0$



From $\Sigma F_x=0$, we see that $n=F\cos 30°$

Thus, $f_k=\mu_k n=\mu_k F\cos 30°$

and $\Sigma F_y=0$ becomes

$$F\sin 30°=mg+\mu_k F\cos 30°\text{ , or}$$

$$F=\frac{mg}{\sin 30°-\mu_k\cos 30°}=\frac{(5.0\ \text{kg})(9.80\ \text{m/s}^2)}{\sin 30°-(0.30)\cos 30°}=2.0\times 10^2\ \text{N}$$

(a) The applied force makes a 60° angle with the displacement up the wall. Therefore,

$$W_F = \left(F\cos 60°\right)s = \left[\left(2.0\times 10^2\text{ N}\right)\cos 60°\right](3.0\text{ m}) = \boxed{3.1\times 10^2\text{ J}}$$

(b) $W_g = \left(mg\cos 180°\right)s = (49\text{ N})(-1.0)(3.0\text{ m}) = \boxed{-1.5\times 10^2\text{ J}}$

(c) $W_n = \left(n\cos 90°\right)s = \boxed{0}$

(d) $PE_g = mg\left(\Delta y\right) = (49\text{ N})(3.0\text{ m}) = \boxed{1.5\times 10^2\text{ J}}$

5.71 The force constant of the spring is $k = 1.20\ \text{N/cm} = 120\ \text{N/m}$. If the spring is initially compressed a distance x_i, the vertical distance the ball rises as the spring returns to the equilibrium position is

$$y_f = x_i \sin 10.0°$$

In the absence of friction, we apply $\left(KE + PE_g + PE_s\right)_f = \left(KE + PE_g + PE_s\right)_i$ from the release of the plunger to when the spring has returned to the equilibrium position and obtain $\frac{1}{2}mv_f^2 + mg\left(x_i \sin 10.0°\right) + 0 = 0 + 0 + \frac{1}{2}kx_i^2$, or

$$v_f = \sqrt{\frac{kx_i^2}{m} - 2g\,x_i \sin 10.0°}$$

$$= \sqrt{\frac{(120\ \text{N/m})\left(5.00\times 10^{-2}\ \text{m}\right)^2}{0.100\ \text{kg}} - 2\left(9.80\ \text{m/s}^2\right)\left(5.00\times 10^{-2}\ \text{m}\right)\sin 10.0°}$$

This yields $v_f = \boxed{1.68\ \text{m/s}}$

5.72 If a projectile is launched, in the absence of air resistance, with speed v_0 at angle θ above the horizontal, the time required to return to the original level is found from $\Delta y = v_{0y}t + \frac{1}{2}a_y t^2$ as $0 = \left(v_0 \sin\theta\right)t - \frac{g}{2}t^2$, which gives $t = \frac{2v_0 \sin\theta}{g}$. The range is the horizontal displacement occurring in this time.

Thus, $R = v_{0x}\,t = \left(v_0 \cos\theta\right)\left(\dfrac{2v_0 \sin\theta}{g}\right) = \dfrac{v_0^2\left(2\sin\theta\cos\theta\right)}{g} = \dfrac{v_0^2 \sin\left(2\theta\right)}{g}$

Maximum range occurs when $\theta = 45°$, giving $v_0^2 = g\,R_{\max}$. The minimum kinetic energy required to reach a given maximum range is then

$$KE = \frac{1}{2}mv_0^2 = \frac{1}{2}mg\,R_{max}$$

(a) The minimum kinetic energy needed in the record throw of each object is

Javelin: $KE = \dfrac{1}{2}\left(0.80\text{ kg}\right)\left(9.80\text{ m/s}^2\right)\left(98\text{ m}\right) = \boxed{3.8 \times 10^2\text{ J}}$

Discus: $KE = \dfrac{1}{2}\left(2.0\text{ kg}\right)\left(9.80\text{ m/s}^2\right)\left(74\text{ m}\right) = \boxed{7.3 \times 10^2\text{ J}}$

Shot: $KE = \dfrac{1}{2}\left(7.2\text{ kg}\right)\left(9.80\text{ m/s}^2\right)\left(23\text{ m}\right) = \boxed{8.1 \times 10^2\text{ J}}$

(b) The average force exerted on an object during launch, when it starts from rest and is given the kinetic energy found above, is computed from $W_{net} = F_{\text{av}}\,s = \Delta KE$ as $F_{\text{av}} = \dfrac{KE - 0}{s}$. Thus, the required force for each object is

Javelin: $F_{\text{av}} = \dfrac{3.8 \times 10^2\text{ J}}{2.00\text{ m}} = \boxed{1.9 \times 10^2\text{ N}}$

Discus: $F_{\text{av}} = \dfrac{7.3 \times 10^2\text{ J}}{2.00\text{ m}} = \boxed{3.6 \times 10^2\text{ N}}$

Shot: $F_{\text{av}} = \dfrac{8.1 \times 10^2\text{ J}}{2.00\text{ m}} = \boxed{4.1 \times 10^2\text{ N}}$

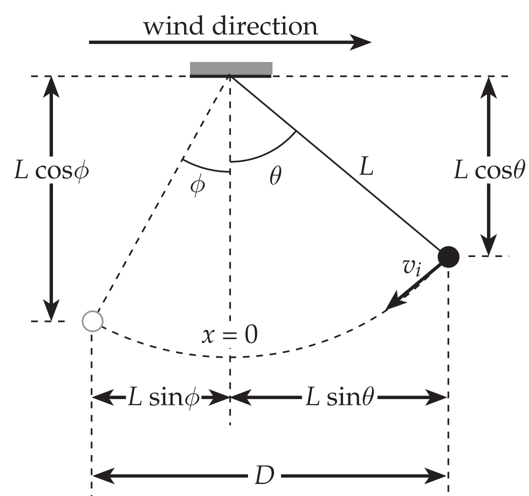
(c) $\boxed{\text{Yes}}$. If the muscles are capable of exerting $4.1\times10^2\ \text{N}$ on an object and giving that object a kinetic energy of $8.1\times10^2\ \text{J}$, as in the case of the shot, those same muscles should be able to give the javelin a launch speed of

$$v_0=\sqrt{\frac{2KE}{m}}=\sqrt{\frac{2\left(8.1\times10^2\ \text{J}\right)}{0.80\ \text{kg}}}=45\ \text{m/s}$$

with a resulting range of $R_{\max}=\dfrac{v_0^2}{g}=\dfrac{\left(45\ \text{m/s}\right)^2}{9.80\ \text{m/s}^2}=2.1\times10^2\ \text{m}$

Since this far exceeds the record range for the javelin, one must conclude that air resistance plays a very significant role in these events.

5.73 The potential energy associated with the wind is $PE_w=F\,x$, where x is measured horizontally from directly below the pivot of the swing and positive when moving into the wind, negative when moving with the wind. We choose $PE_g=0$ at the level of the pivot as shown in the figure. Also, note that $D=L\sin\phi+L\sin\theta$



so $\phi=\sin^{-1}\left(\dfrac{D}{L}-\sin\theta\right)$, or

$$\phi=\sin^{-1}\left(\frac{50.0\ \text{m}}{40.0\ \text{m}}-\sin 50.0^\circ\right)=28.94^\circ.$$

(a) Use conservation of mechanical energy, including the potential energy associated with the wind. The final kinetic energy is zero if Jane barely makes it to the other side, and $\left(KE+PE_g+PE_w\right)_f=\left(KE+PE_g+PE_w\right)_i$ becomes

$$0+mg\left(-L\cos\phi\right)+F\left(+L\sin\phi\right)=\frac{1}{2}mv_i^2+mg\left(-L\cos\theta\right)+F\left(-L\sin\theta\right)$$

or $v_i=\sqrt{2gL\left(\cos\theta-\cos\phi\right)+\dfrac{2FL}{m}\left(\sin\theta+\sin\phi\right)}$

where m is the mass of Jane alone. This yields $v_i=\boxed{6.15\ \text{m/s}}$

(b) Again, using conservation of mechanical energy with $KE_f = 0$

$$\left(KE + PE_g + PE_w\right)_f = \left(KE + PE_g + PE_w\right)_i \text{ gives}$$

$$0 + Mg\left(-L\cos\theta\right) + F\left(-L\sin\theta\right) = \frac{1}{2}Mv_i^2 + Mg\left(-L\cos\phi\right) + F\left(+L\sin\phi\right)$$

where $M = 130\text{ kg}$ is the combined mass of Tarzan and Jane. Thus,

$$v_i = \sqrt{2gL\left(\cos\phi - \cos\theta\right) - \frac{2FL}{M}\left(\sin\theta + \sin\phi\right)} \text{ which gives } v_i = \boxed{9.87\text{ m/s}}$$

5.74 When the hummingbird is hovering, the magnitude of the average upward force exerted by the air on the wings (and hence, the average downward force the wings exert on the air) must be $F_{\text{av}} = mg$ where mg is the weight of the bird. Thus, if the wings move downward distance d during a wing stroke, the work done each beat of the wings is

$$W_{beat} = F_{\text{av}}d = mgd = \left(3.0\times10^{-3}\text{ kg}\right)\left(9.80\text{ m/s}^2\right)\left(3.5\times10^{-2}\text{ m}\right) = 1.0\times10^{-3}\text{ J}$$

In one minute, the number of beats of the wings that occur is

$$N = \left(80\text{ beats/s}\right)\left(60\text{ s/min}\right) = 4.8\times10^3\text{ beats/min}$$

so the total work preformed in one minute is

$$W_{total} = NW_{beat}\left(1\text{ min}\right) = \left(4.8\times10^3\ \frac{\text{beats}}{\text{min}}\right)\left(1.0\times10^{-3}\ \frac{\text{J}}{\text{beat}}\right)\left(1\text{ min}\right) = \boxed{4.9\text{ J}}$$

5.75 We choose $PE_g = 0$ at the level where the spring is relaxed ($x = 0$), or at the level of position B.

(a) At position A, $KE = 0$ and the total energy of the system is given by

$$E = \left(0 + PE_g + PE_s\right)_A = mg\,x_1 + \frac{1}{2}k\,x_1^2\text{, or}$$

$$E = \left(25.0\text{ kg}\right)\left(9.80\text{ m/s}^2\right)\left(-0.100\text{ m}\right) + \frac{1}{2}\left(2.50\times10^4\text{ N/m}\right)\left(-0.100\text{ m}\right)^2 = \boxed{101\text{ J}}$$

(b) In position C, $KE = 0$ and the spring is uncompressed so $PE_s = 0$

Hence, $E = \left(0 + PE_g + 0\right)_C = mg\,x_2$

or $x_2 = \dfrac{E}{mg} = \dfrac{101\text{ J}}{(25.0\text{ kg})(9.80\text{ m/s}^2)} = \boxed{0.410\text{ m}}$

(c) At Position B, $PE_g = PE_s = 0$ and $E = (KE + 0 + 0)_B = \dfrac{1}{2}mv_B^2$

Therefore, $v_B = \sqrt{\dfrac{2E}{m}} = \sqrt{\dfrac{2(101\text{ J})}{25.0\text{ kg}}} = \boxed{2.84\text{ m/s}}$

(d) Where the velocity (and hence the kinetic energy) is a maximum, the acceleration is $a_y = \dfrac{\Sigma F_y}{m} = 0$ (at this point, an upward force due to the spring exactly balances the downward force of gravity). Thus, taking upward as positive, $\Sigma F_y = -kx - mg = 0$ or

$$x = -\frac{mg}{k} = -\frac{245\text{ kg}}{2.50\times10^4\text{ N/m}} = -9.80\times10^{-3}\text{ m} = \boxed{-9.80\text{ mm}}$$

(e) From the total energy, $E = KE + PE_g + PE_s = \dfrac{1}{2}mv^2 + mg\,x + \dfrac{1}{2}k\,x^2$, we find

$$v = \sqrt{\frac{2E}{m} - 2g\,x - \frac{k}{m}x^2}$$

Where the speed, and hence kinetic energy is a maximum (that is, at $x = -9.80\text{ mm}$), this gives $v_{\max} = \boxed{2.85\text{ m/s}}$

5.76 When the block moves distance x down the incline, the work done by the friction force is $W_f = (f_k \cos 180°)x = -\mu_k n x = -\mu_k (mg\cos\theta)x$. From the work-energy theorem, $W_{nc} = (KE + PE_g + PE_s)_f - (KE + PE_g + PE_s)_i$, we find

$$W_{nc} = W_f = -\mu_k (mg\cos\theta)x = \Delta KE + \Delta PE_g + \Delta PE_s .$$

Since the block is at rest at both the start and the end, this gives

$$-\mu_k (19.6\text{ N } \cos 37.0°)(0.200\text{ m})$$
$$= 0 + (19.6\text{ N})(-0.200\text{ m } \sin 37.0°) + \frac{1}{2}(100\text{ N/m})(0.200\text{ m})^2$$

or $\mu_k = \boxed{0.115}$

5.77 Choose $PE_g = 0$ at the level of the river. Then $y_i = 36.0\text{ m}$, $y_f = 4.00$, the jumper falls 32.0 m, and the cord stretches 7.00 m. Between the balloon and the level where the diver stops momentarily, $(KE + PE_g + PE_s)_f = (KE + PE_g + PE_s)_i$ gives

$$0 + (700\text{ N})(4.00\text{ m}) + \frac{1}{2}k(7.00\text{ m})^2 = 0 + (700\text{ N})(36.0\text{ m}) + 0$$

or $k = \boxed{914\text{ N/m}}$

5.78 (a) Since the tension in the string is always perpendicular to the motion of the object, the string does no work on the object. Then, mechanical energy is conserved: $(KE + PE_g)_f = (KE + PE_g)_i$

Choosing $PE_g = 0$ at the level where the string attaches to the cart, this gives

$$0 + mg(-L\cos\theta) = \frac{1}{2}mv_0^2 + mg(-L), \text{ or } \boxed{v_0 = \sqrt{2gL(1-\cos\theta)}}$$

(b) If $L = 1.20$ m and $\theta = 35.0°$, the result of part (a) gives

$$v_0 = \sqrt{2(9.80\text{ m/s}^2)(1.20\text{ m})(1-\cos 35.0°)} = \boxed{2.06\text{ m/s}}$$

5.79 From the work-energy theorem, $W_{net} = KE_f - KE_i$. Since the package moves with constant velocity, $KE_f = KE_i$ giving $W_{net} = \boxed{0}$

Note that the above result can also be obtained by the following reasoning:
Since the object has zero acceleration, the net (or resultant) force acting on it must be zero. The net work done is $W_{net} = F_{net} d = \boxed{0}$

The work done by the conservative gravitational force is

$$W_{grav} = -\Delta PE_g = -mg\left(y_f - y_i\right) = -mg\left(d\sin\theta\right)$$

or $$W_{grav} = -\left(50\text{ kg}\right)\left(9.80\text{ m/s}^2\right)\left(340\text{ m}\right)\sin 7.0° = \boxed{-2.0\times10^4\text{ J}}$$

The normal force is perpendicular to the displacement. The work it does is

$$W_{normal} = nd\cos 90° = \boxed{0}$$

Since the package moves up the incline at constant speed, the net force parallel to the incline is zero. Thus, $\Sigma F_{\parallel} = 0 \;\Rightarrow\; f_s - mg\sin\theta = 0$ or $f_s = mg\sin\theta$

The work done by the friction force in moving the package distance d up the incline is

$$W_{friction} = f_k d = \left(mg\sin\theta\right)d = \left[\left(50\text{ kg}\right)\left(9.80\text{ m/s}^2\right)\sin 7.0°\right]\left(340\text{ m}\right) = \boxed{2.0\times10^4\text{ J}}$$

5.80 (a) $E_{released} = W_{grav} = -\Delta PE_g = -N\left[mg\left(\Delta y\right)\right]$, or

$$E_{released} = -\left(375\,000\right)\left[\left(36.0\text{ kg}\right)\left(9.80\text{ m/s}^2\right)\left(-0.380\text{ m}\right)\right] = \boxed{5.03\times10^7\text{ J}}$$

(b) The energy carried by the seismic wave is

$$E_{seismic} = E_{released}\times 1.00\% = \left(5.03\times10^7\text{ J}\right)\left(1.00\times10^{-2}\right) = 5.03\times10^5\text{ J}$$

and the magnitude on the Richter scale is

$$M = \frac{\log E - 4.8}{1.5} = \frac{\log\left(5.03\times10^5\right) - 4.8}{1.5} = \boxed{0.60}$$

5.81 (a) While the car moves at constant speed, the tension in the cable is $F = mg\sin\theta$, and the power input is $\mathcal{P} = Fv = mgv\sin\theta$ or

$$\mathcal{P} = (950\ \text{kg})(9.80\ \text{m/s}^2)(2.20\ \text{m/s})\sin 30.0° = 1.02\times10^4\ \text{W} = \boxed{10.2\ \text{kW}}$$

(b) While the car is accelerating, the tension in the cable is

$$F_a = mg\sin\theta + ma = m\left(g\sin\theta + \frac{\Delta v}{\Delta t}\right)$$

$$= (950\ \text{kg})\left[(9.80\ \text{m/s}^2)\sin 30.0° + \frac{2.20\ \text{m/s} - 0}{12.0\ \text{s}}\right] = 4.83\times10^3\ \text{N}$$

Maximum power input occurs the last instant of the acceleration phase. Thus,

$$\mathcal{P}_{\text{max}} = F_a v_{\text{max}} = (4.83\times10^3\ \text{N})(2.20\ \text{m/s}) = \boxed{10.6\ \text{kW}}$$

(c) The work done by the motor in moving the car up the frictionless track is

$$W_{nc} = (KE+PE)_f - (KE+PE)_i = KE_f + \left(PE_g\right)_f - 0 = \tfrac{1}{2}mv_f^2 + mg(L\sin\theta)$$

or $W_{nc} = (950\ \text{kg})\left[\tfrac{1}{2}(2.20\ \text{m/s})^2 + (9.80\ \text{m/s}^2)(1\,250\ \text{m})\sin 30.0°\right] = \boxed{5.82\times10^6\ \text{J}}$

5.82 Each 5.00-m length of the cord will stretch 1.50 m when the tension in the cord equals the weight of the jumper (that is, when $F_s = w = mg$). Thus, the elongation in a cord of original length L when $F_s = w$ will be

$$x = \left(\frac{L}{5.00\ \text{m}}\right)(1.50\ \text{m}) = 0.300L$$

and the force constant for the cord of length L is $\quad k = \dfrac{F_s}{x} = \dfrac{w}{0.300L}$

(a) In the bungee-jump from the balloon, the daredevil drops $y_i - y_f = 55.0$ m

The stretch of the cord at the start of the jump is $x_i = 0$, and that at the lowest point is $x_f = 55.0\ \text{m} - L$. Since $KE_i = KE_f = 0$ for the fall, conservation of mechanical energy gives

$$0 + \left(PE_g\right)_f + \left(PE_s\right)_f = 0 + \left(PE_g\right)_i + \left(PE_s\right)_i \quad\Rightarrow\quad \tfrac{1}{2}k\left(x_f^2 - x_i^2\right) = mg\left(y_i - y_f\right)$$

or $\frac{1}{2}\left(\frac{\cancel{m}\cancel{g}}{0.300L}\right)(55.0\text{ m}-L)^2=\cancel{m}\cancel{g}(55.0\text{ m})$

which reduces to $L^2-(143\text{ m})L+3.03\times10^3\text{ m}^2=0$, and has solutions of $L=117\text{ m}$ or $L=25.8\text{ m}$. Only the $L=\boxed{25.8\text{ m}}$ solution is physically acceptable!

(b) During the jump, $\Sigma F_y=ma_y \Rightarrow kx-mg=ma_y$ or $\left(\frac{\cancel{m}g}{0.300L}\right)x-\cancel{m}g=\cancel{m}a_y$

Thus, $a_y=\left(\frac{x}{0.300L}-1\right)g$

which has maximum value at $x=x_{\text{max}}=55.0\text{ m}-L=29.2\text{ m}$

$$\left(a_y\right)_{\text{max}}=\left[\frac{29.2\text{ m}}{0.300(25.8\text{ m})}-1\right]g=\boxed{2.77g}=\boxed{27.1\text{ m/s}^2}$$

5.83 Careful examination of Figure P5.83 reveals that if, during some time interval, block B moves upward 1.00 cm, block A will move downward 2.00 cm and the distance separating the two blocks increases by 3.00 cm. Generalizing, we conclude that when the vertical separation between the blocks increases by h, block B moves upward distance $h/3$ and block A moves downward distance $2h/3$. Also, if at any instant during the motion block A has speed v, the speed of block B will be $v/2$.

Choosing $y=0$ at the level where both blocks start from rest and making use of the above observations, conservation of mechanical energy gives

$$\tfrac{1}{2}m\left(v_A\right)_f^2+\tfrac{1}{2}m\left(v_B\right)_f^2+mg\left(y_A\right)_f+mg\left(y_B\right)_f=\tfrac{1}{2}m\left(v_A\right)_i^2+\tfrac{1}{2}m\left(v_B\right)_i^2+mg\left(y_A\right)_i+mg\left(y_B\right)_i$$

or $\quad \tfrac{1}{2}mv^2+\tfrac{1}{2}m(v/2)^2+mg(-2h/3)+mg(+h/3)=0+0+0+0$

This reduces to $\frac{5}{8}v^2-\frac{gh}{3}=0$, or $v=\sqrt{\frac{gh}{3}\left(\frac{8}{5}\right)}=\boxed{\sqrt{\frac{8gh}{15}}}$

5.84 (a) Realize that, with the specified arrangement of springs, each spring supports one-fourth the weight of the load (shelf plus trays). Thus, adding the weight ($w=mg$) of one tray to the load increases the tension in each spring by $\Delta F=mg/4$. If this increase in tension causes an additional elongation in each spring equal to the thickness of a tray, the upper surface of the stack of trays stays at a fixed level above the floor as trays are added to or removed from the stack.

(b) If the thickness of a single tray is t, the force constant each spring should have to allow the fixed-level tray dispenser to work properly is

$$k = \frac{\Delta F}{\Delta x} = \frac{mg/4}{t} = \frac{mg}{4t} \text{ or } k = \frac{(0.580\ \text{kg})(9.80\ \text{m/s}^2)}{4(0.450\times 10^{-2}\ \text{m})} = \boxed{316\ \text{N/m}}$$

The $\boxed{\text{length and width of a tray}}$ are unneeded pieces of data.

5.85 When the cyclist travels at constant speed, the magnitude of the forward static friction force on the drive wheel equals that of the retarding air resistance force. Hence, the friction force is proportional to the square of the speed, and her power output may be written as

$$\mathcal{P} = f_s v = (kv^2)v = kv^3$$

where k is a proportionality constant.

If the heart rate R is proportional to the power output, then $R = k'\mathcal{P} = k'(kv^3) = k'kv^3$ where k' is also a proportionality constant.

The ratio of the heart rate R_2 at speed v_2 to the rate R_1 at speed v_1 is then

$$\frac{R_2}{R_1} = \frac{k'kv_2^3}{k'kv_1^3} = \left(\frac{v_2}{v_1}\right)^3 \text{ giving } v_2 = v_1\left(\frac{R_2}{R_1}\right)^{1/3}$$

Thus, if $R = 90.0$ beats/min at $v = 22.0$ km/h, the speed at which the rate would be 136 beats/min is

$$v = (22.0\ \text{km/h})\left(\frac{136\ \text{beats/min}}{90.0\ \text{beats/min}}\right)^{1/3} = \boxed{25.2\ \text{km/h}}$$

and the speed at which the rate would be 166 beats/min is

$$v = (22.0\ \text{km/h})\left(\frac{166\ \text{beats/min}}{90.0\ \text{beats/min}}\right)^{1/3} = \boxed{27.0\ \text{km/h}}$$

5.86 (a) The needle has maximum speed during the interval between when the spring returns to normal length and the needle tip first contacts the skin. During this interval, the kinetic energy of the needle equals the original elastic potential energy of the spring, or $\frac{1}{2}mv_{\max}^2 = \frac{1}{2}kx_i^2$. This gives

$$v_{\max} = x_i\sqrt{\frac{k}{m}} = \left(8.10\times10^{-2}\ \text{m}\right)\sqrt{\frac{375\ \text{N/m}}{5.60\times10^{-3}\ \text{kg}}} = \boxed{21.0\ \text{m/s}}$$

(b) If F_1 is the force the needle must overcome as it penetrates a thickness x_1 of skin and soft tissue while F_2 is the force overcame while penetrating thickness x_2 of organ material, application of the work-energy theorem from the instant before skin contact until the instant before hitting the stop gives

$$W_{net} = -F_1x_1 - F_2x_2 = \tfrac{1}{2}mv_f^2 - \tfrac{1}{2}mv_{\max}^2$$

or $v_f = \sqrt{v_{\max}^2 - \dfrac{2\left(F_1x_1 + F_2x_2\right)}{m}}$

$$v_f = \sqrt{\left(21.0\ \text{m/s}\right)^2 - \frac{2\left[(7.60\ \text{N})\left(2.40\times10^{-2}\ \text{m}\right) + (9.20\ \text{N})\left(3.50\times10^{-2}\ \text{m}\right)\right]}{5.60\times10^{-3}\ \text{kg}}} = \boxed{16.1\ \text{m/s}}$$

5.87 (a) The average power used by the house is

$$\mathcal{P}_{\text{av}} = \frac{E}{\Delta t} = \frac{600\ \text{kWh}}{30.0\ \text{days}}\left(\frac{3.60\times10^6\ \text{J}}{1\ \text{kWh}}\right)\left(\frac{1\ \text{day}}{8.64\times10^4\ \text{s}}\right) = 833\ \frac{\text{J}}{\text{s}} = 833\ \text{W}$$

and the power-per-area consumption is

$$\frac{\mathcal{P}_{\text{av}}}{A} = \frac{833\ \text{W}}{(13.0\ \text{m})(9.50\ \text{m})} = \boxed{6.75\ \text{W/m}^2}$$

(b) The rate R_f at which the car uses fuel is

$$R_f = \frac{55.0 \text{ mi/h}}{25.0 \text{ mi/gal}} = 2.20 \frac{\text{gal}}{\text{h}}\left(\frac{2.54 \text{ kg}}{1 \text{ gal}}\right) = 5.59 \text{ kg/h}$$

so the power used is

$$\mathcal{P} = \left(5.59 \frac{\text{kg}}{\text{h}}\right)\left(44.0\times10^6 \frac{\text{J}}{\text{kg}}\right)\left(\frac{1 \text{ h}}{3\,600 \text{ s}}\right) = 6.83\times10^4 \frac{\text{J}}{\text{s}} = 68.3 \text{ kW}$$

The power-per-area consumption is then

$$\frac{\mathcal{P}}{A} = \frac{68.3 \text{ kW}}{(2.10 \text{ m})(4.90 \text{ m})} = \boxed{6.64 \text{ kW/m}^2}$$

(c) From the result of Part (b), it is seen that a powerful automobile running on solar power would have to carry a solar panel huge in comparison to the size of the car. Thus, direct use of solar energy is not very practical for conventional automobiles.

5.88 (a) Using conservation of mechanical energy for the trip of the sled down the frictionless slide gives $KE_C + \left(PE_g\right)_C = KE_A + \left(PE_g\right)_A$, or

$$\tfrac{1}{2}\cancel{m}v_C^2 = \tfrac{1}{2}\cancel{m}v_A^2 + \cancel{m}g\left(y_A - y_C\right) \text{ so } v_C = \sqrt{v_A^2 + 2g\left(y_A - y_C\right)}$$

$$v_C = \sqrt{(2.50 \text{ m/s})^2 + 2\left(9.80 \text{ m/s}^2\right)(9.76 \text{ m})} = \boxed{14.1 \text{ m/s}}$$

(b) As the sled goes from point C to point D, the work-energy theorem gives

$$W_{CD} = KE_D - KE_C = 0 - \tfrac{1}{2}mv_C^2 = -\tfrac{1}{2}(80.0 \text{ kg})(14.1 \text{ m/s})^2 = -7.90\times10^3 \text{ J} = \boxed{-7.90 \text{ kJ}}$$

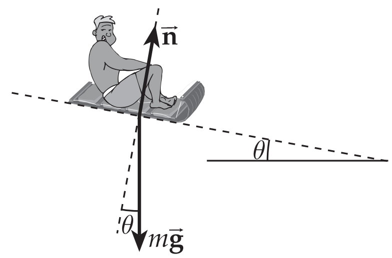
(c) If f is the friction force exerted on the sled by the water between points C and D, then

$$W_{CD} = -f\left(\Delta x_{CD}\right) \text{ or } f = \frac{-W_{CD}}{\Delta x_{CD}} = \frac{-\left(-7.90\times10^3 \text{ J}\right)}{50.0 \text{ m}} = 158 \text{ N}$$

In addition to this horizontal friction force, the water exerts a vertical normal force equal to the weight of the sled and rider, or $n = (80 \text{ kg})\left(9.80 \text{ m/s}^2\right) = 784 \text{ N}$. Thus, the resultant force exerted on the sled by the water is

$$F_R = \sqrt{f^2 + n^2} = \sqrt{(158 \text{ N})^2 + (784 \text{ N})^2} = \boxed{800 \text{ N}}$$

(d) The free-body diagram of the sled at point B on the frictionless slide is as shown at the right. Since the sled has zero acceleration perpendicular to the slide,



$$\Sigma F_{\perp} = ma_{\perp} = 0 \quad \Rightarrow \quad n - mg\cos\theta = 0 \quad \text{or} \quad n = mg\cos\theta$$

But, for the slide shown in Figure P5.88,

$$\theta = \sin^{-1}\left(\frac{9.76\text{ m}}{54.3\text{ m}}\right) = 10.4^\circ$$

The force exerted on the sled by the slide at point B is

$$n = (80.0\text{ kg})(9.80\text{ m/s}^2)\cos 10.4^\circ = \boxed{771\text{ N}}$$

5.89 Observe that when m_3 moves downward 4.0 m, m_1 must move upward 4.0 and m_2 moves 4.0 m on the level surface. Also, each block has the same speed as the other two at each instant. Therefore, if the system starts from rest, and f is the retarding friction force acting on m_2 as it moves distance d, $W_{nc} = (KE+PE)_f - (KE+PE)_i$ gives

$$-fd = \tfrac{1}{2}m_1v^2 + \tfrac{1}{2}m_2v^2 + \tfrac{1}{2}m_3v^2 + m_1g\left(y_{1,f} - y_{1,i}\right) + m_2g\left(y_{2,f} - y_{2,i}\right) + m_3g\left(y_{3,f} - y_{3,i}\right)$$

or $$\tfrac{1}{2}(m_1+m_2+m_3)v^2 = \left[m_1\left(y_{1,i} - y_{1,f}\right) + m_2\left(y_{2,i} - y_{2,f}\right) + m_3\left(y_{3,i} - y_{3,f}\right)\right]g - fd$$

With the given data, this yields

$$\frac{1}{2}(5.0+10+15)v^2 = \left[(5.0)(-4.0\text{ m}) + (10)(0) + (15)(+4.0\text{ m})\right](9.8\text{ m/s}^2) - (30\text{ N})(4.0\text{ m})$$

or $$v = \sqrt{\frac{2(272\text{ J})}{30\text{ kg}}} = \boxed{4.3\text{ m/s}}$$