CHAPTER 6

Quick Quizzes

1. (d). We are given no information about the masses of the objects. If the masses are the same, the speeds must be the same (so that they have equal kinetic energies), and then $p_1 = p_2$. If the masses are not the same, the speeds will be different, as will the momenta, and either $p_1 < p_2$, or $p_1 > p_2$, depending on which particle has more mass. Without information about the masses, we cannot choose among these possibilities.

2. (c). Because the momentum of the system (boy + raft) remains constant with zero magnitude, the raft moves towards the shore as the boy walks away from the shore.

3. (c) and (e). Because object 1 has larger mass, its acceleration due to the applied force is smaller, and it takes a longer time interval Δt to experience the displacement Δx than does object 2. Thus, the impulse $F\Delta t$ on object 1 is larger than that on object 2. Consequently, object 1 will experience a larger change in momentum than object 2, which tells us that (c) is true. The same force acts on both objects through the same displacement. Thus, the same work is done on each object, so that each must experience the same change in kinetic energy, which tells us that (e) is true.

4. (d).

5. (b). You must conclude that the collision is inelastic because some of the kinetic energy is carried away by mechanical waves––sound. If the collision were elastic, you would not hear any clicking sound.

6. (a).

7. (a). Perfectly inelastic—the two “particles”, skater and Frisbee, are combined after the collision; (b) Inelastic—because the Frisbee bounced back with almost no speed, kinetic energy has been transformed to other forms; (c) Inelastic—the kinetic energy of the Frisbee is the same before and after the collision. Because momentum of the skater-Frisbee system is conserved, however, the skater must be moving after the catch and the throw, so that the final kinetic energy of the system is larger than the initial kinetic energy. This extra energy comes from the muscles of the skater.

8. (b). If all of the initial kinetic energy is transformed, then nothing is moving after the collision. Consequently, the final momentum of the system is necessarily zero. Because momentum of the system is conserved, the initial momentum of the system must be zero. Finally, because the objects are identical, they must have been initially moving toward each other along the same line with the same speed.

Problem Solutions

6.1 $KE = \frac{1}{2}mv^2 = \frac{1}{2}\frac{(mv)^2}{m} = \frac{1}{2}\frac{p^2}{m} = \frac{p^2}{2m}$

6.2 Assume the initial direction of the ball in the $-x$ direction, away from the net.

(a) $Impulse = \Delta p = m\left(v_f - v_i\right) = (0.0600\text{ kg})\left[40.0\text{ m/s} - (-50.0\text{ m/s})\right]$ giving
$Impulse = 5.40\text{ kg}\cdot\text{m/s} = \boxed{5.40\text{ N}\cdot\text{s}}$ toward the net.

(b) $Work = \Delta KE = \frac{1}{2}m\left(v_f^2 - v_i^2\right)$

$$= \frac{(0.0600\text{ kg})\left[(40.0\text{ m/s})^2 - (50.0\text{ m/s})^2\right]}{2} = \boxed{-27.0\text{ J}}$$

6.3 Use $p = mv$:

(a) $p = \left(1.67\times10^{-27}\text{ kg}\right)\left(5.00\times10^{6}\text{ m/s}\right) = \boxed{8.35\times10^{-21}\text{ kg}\cdot\text{m/s}}$

(b) $p = \left(1.50\times10^{-2}\text{ kg}\right)\left(3.00\times10^{2}\text{ m/s}\right) = \boxed{4.50\text{ kg}\cdot\text{m/s}}$

(c) $p = (75.0\text{ kg})(10.0\text{ m/s}) = \boxed{750\text{ kg}\cdot\text{m/s}}$

(d) $p = \left(5.98\times10^{24}\text{ kg}\right)\left(2.98\times10^{4}\text{ m/s}\right) = \boxed{1.78\times10^{29}\text{ kg}\cdot\text{m/s}}$

6.4 (a) Since the ball was thrown straight upward, it is at rest momentarily (v = 0) at its maximum height. Therefore, $p = \boxed{0}$.

(b) The maximum height is found from $v_y^2 = v_{iy}^2 + 2a_y(\Delta y)$ with $v_y = 0$.

$$0 = v_{iy}^2 + 2(-g)(\Delta y)_{max}. \text{ Thus, } (\Delta y)_{max} = \frac{v_{iy}^2}{2g}.$$

We need the velocity at $\Delta y = \frac{(\Delta y)_{max}}{2} = \frac{v_{iy}^2}{4g}$, thus $v_y^2 = v_{iy}^2 + 2a_y(\Delta y)$ gives

$$v_y^2 = v_{iy}^2 + 2(-g)\left(\frac{v_{iy}^2}{4g}\right) = \frac{v_{iy}^2}{2}, \text{ or } v_y = \frac{v_{iy}}{\sqrt{2}} = \frac{15 \text{ m/s}}{\sqrt{2}}.$$

Therefore, $p = mv_y = \frac{(0.10 \text{ kg})(15 \text{ m/s})}{\sqrt{2}} = \boxed{1.1 \text{ kg}\cdot\text{m/s}}$ upward.

6.5 (a) If $p_{ball} = p_{bullet}$,

then $v_{ball} = \frac{m_{bullet}v_{bullet}}{m_{ball}} = \frac{(3.00\times10^{-3} \text{ kg})(1.50\times10^{3} \text{ m/s})}{0.145 \text{ kg}} = \boxed{31.0 \text{ m/s}}$.

(b) The kinetic energy of the bullet is

$$KE_{bullet} = \frac{1}{2}m_{bullet}v_{bullet}^2 = \frac{(3.00\times10^{-3} \text{ kg})(1.50\times10^{3} \text{ m/s})^2}{2} = 3.38\times10^{3} \text{ J}$$

while that of the baseball is $KE_{ball} = \frac{1}{2}m_{ball}v_{ball}^2 = \frac{(0.145 \text{ kg})(31.0 \text{ m/s})^2}{2} = 69.7 \text{ J}$.

The $\boxed{\text{bullet has the larger kinetic energy}}$ by a factor of 48.4.

6.6 From the impulse-momentum theorem, $\bar{F}(\Delta t) = \Delta p = mv_f - mv_i$.

Thus, $\bar{F} = \frac{m(v_f - v_i)}{(\Delta t)} = \frac{(55\times10^{-3} \text{ kg})(2.0\times10^{2} \text{ ft/s} - 0)}{0.0020 \text{ s} - 0}\left(\frac{1 \text{ m/s}}{3.281 \text{ ft/s}}\right) = \boxed{1.7 \text{ kN}}$.

6.7 If the diver starts from rest and drops vertically into the water, the velocity just before impact is found from

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

$$\frac{1}{2}mv_{impact}^2+0=0+mgh \;\Rightarrow\; v_{impact}=\sqrt{2gh}$$

With the diver at rest after an impact time of Δt, the average force during impact is given by $\bar{F}=\frac{m\left(0-v_{impact}\right)}{\Delta t}=\frac{-m\sqrt{2gh}}{\Delta t}$ or $\bar{F}=\frac{m\sqrt{2gh}}{\Delta t}$ (directed upward).

Assuming a mass of 55 kg and an impact time of ~1.0 s, the magnitude of this average force is

$$\left|\bar{F}\right|=\frac{(55\text{ kg})\sqrt{2\left(9.80\text{ m/s}^2\right)(10\text{ m})}}{1.0\text{ s}}=770\text{ N},\text{ or }\boxed{\sim 10^3\text{ N}}.$$

6.8 The speed just before impact is given by $\left(KE+PE_g\right)_f=\left(KE+PE_g\right)_i$ as

$$\frac{1}{2}mv_{impact}^2+0=0+mgh,\text{ or }v_{impact}=\sqrt{2gh}.$$

Taking downward as positive, the impulse-momentum theorem gives the average force as

$$\bar{F}=\frac{\Delta p}{\Delta t}=\frac{m\left(0-v_{impact}\right)}{\Delta t}=\frac{-m\sqrt{2gh}}{\Delta t}=\frac{-(60.0\text{ kg})\sqrt{2\left(9.80\text{ m/s}^2\right)(10.0\text{ m})}}{0.120\text{ s}}.$$

Thus, $\bar{F}=-7.00\times10^3\text{ N}$, or $\bar{F}=\boxed{7.00\times10^3\text{ N (upward)}}$.

6.9 $Impulse=\bar{F}(\Delta t)=\Delta p=m(\Delta v)$.

Thus, $\left|Impulse\right|=m\left|\Delta v\right|=(70.0\text{ kg})(5.20\text{ m/s}-0)=\boxed{364\text{ kg}\cdot\text{m/s}}$, and

$$\left|\bar{F}\right|=\frac{Impulse}{\Delta t}=\frac{364\text{ kg}\cdot\text{m/s}}{0.832\text{ s}}=438\text{ kg}\cdot\text{m/s}^2,$$

or $\mathbf{\bar{F}}=\boxed{438\text{ N directed forward}}$.

6.10 From the impulse-momentum theorem, $\overline{F}(\Delta t) = \Delta p = mv_f - mv_i$, the average force required to hold onto the child is

$$\overline{F} = \frac{m(v_f - v_i)}{(\Delta t)} = \frac{(12 \text{ kg})(0 - 60 \text{ mi/h})}{0.050 \text{ s} - 0}\left(\frac{1 \text{ m/s}}{2.237 \text{ mi/h}}\right) = -6.4 \times 10^3 \text{ N}.$$

Therefore, the magnitude of the needed retarding force is $\boxed{6.4 \times 10^3 \text{ N}}$, or 1400 lbs. A person cannot exert a force of this magnitude and a safety device should be used.

6.11 (a) The impulse equals the area under the *F* versus *t* graph. This area is the sum of the area of the rectangle plus the area of the triangle. Thus,

$$Impulse = (2.0 \text{ N})(3.0 \text{ s}) + \frac{1}{2}(2.0 \text{ N})(2.0 \text{ s}) = \boxed{8.0 \text{ N} \cdot \text{s}}.$$

(b) $Impulse = \overline{F}(\Delta t) = \Delta p = m(v_f - v_i)$.

$$8.0 \text{ N} \cdot \text{s} = (1.5 \text{ kg})v_f - 0, \text{ giving } v_f = \boxed{5.3 \text{ m/s}}.$$

(c) $Impulse = \overline{F}(\Delta t) = \Delta p = m(v_f - v_i)$, so $v_f = v_i + \dfrac{Impulse}{m}$.

$$v_f = -2.0 \text{ m/s} + \frac{8.0 \text{ N} \cdot \text{s}}{1.5 \text{ kg}} = \boxed{3.3 \text{ m/s}}.$$

6.12 (a) Impulse = area under curve = (two triangular areas of altitude 4.00 N and base 2.00 s) + (one rectangular area of width 1.00 s and height of 4.00 N.)

Thus, $$Impulse = 2\left[\frac{(4.00 \text{ N})(2.00 \text{ s})}{2}\right] + (4.00 \text{ N})(1.00 \text{ s}) = \boxed{12.0 \text{ N} \cdot \text{s}}.$$

(b) $Impulse = \overline{F}(\Delta t) = \Delta p = m(v_f - v_i)$, so $v_f = v_i + \dfrac{Impulse}{m}$.

$$v_f = 0 + \frac{12.0 \text{ N} \cdot \text{s}}{2.00 \text{ kg}} = \boxed{6.00 \text{ m/s}}$$

(c) $$v_f = v_i + \frac{Impulse}{m} = -2.00 \text{ m/s} + \frac{12.0 \text{ N} \cdot \text{s}}{2.00 \text{ kg}} = \boxed{4.00 \text{ m/s}}$$

6.13 (a) The impulse is the area under the curve between 0 and 3.0 s.

This is: *Impulse* = (4.0 N)(3.0 s) = $\boxed{12\ \text{N}\cdot\text{s}}$.

(b) The area under the curve between 0 and 5.0 s is:

Impulse = (4.0 N)(3.0 s) + (-2.0 N)(2.0 s) = $\boxed{8.0\ \text{N}\cdot\text{s}}$.

(c) $Impulse = \overline{F}(\Delta t) = \Delta p = m\left(v_f - v_i\right)$, so $v_f = v_i + \dfrac{Impulse}{m}$.

at 3.0 s: $v_f = v_i + \dfrac{Impulse}{m} = 0 + \dfrac{12\ \text{N}\cdot\text{s}}{1.50\ \text{kg}} = \boxed{8.0\ \text{m/s}}$

at 5.0 s: $v_f = v_i + \dfrac{Impulse}{m} = 0 + \dfrac{8.0\ \text{N}\cdot\text{s}}{1.50\ \text{kg}} = \boxed{5.3\ \text{m/s}}$

6.14 (a) $\dfrac{\Delta p_{water}}{\Delta t} = \dfrac{m\left(v_f - v_i\right)}{\Delta t} = \dfrac{(1000\ \text{kg})(0 - 20.0\ \text{m/s})}{60.0\ \text{s}} = \boxed{-333\ \text{N}}$

(b) $\overline{F}_{water} = \dfrac{\Delta p_{water}}{\Delta t} = -333\ \text{N}$, or $\boxed{\text{333 N directed opposite to water flow}}$

(c) From Newton's third law,

$\overline{F}_{building} = -\overline{F}_{water} = +333\ \text{N}$, or $\boxed{\text{333 N in direction of water flow}}$

6.15 (a) $\Delta t = \dfrac{\Delta x}{\overline{v}} = \dfrac{2(\Delta x)}{v_f + v_i} = \dfrac{2(1.20\ \text{m})}{0 + 25.0\ \text{m/s}} = \boxed{9.60\times 10^{-2}\ \text{s}}$

(b) $\overline{F} = \dfrac{\Delta p}{\Delta t} = \dfrac{m(\Delta v)}{\Delta t} = \dfrac{(1400\ \text{kg})(25.0\ \text{m/s})}{9.60\times 10^{-2}\ \text{s}} = \boxed{3.65\times 10^{5}\ \text{N}}$

(c) $\overline{a} = \dfrac{\Delta v}{\Delta t} = \dfrac{25.0\ \text{m/s}}{9.60\times 10^{-2}\ \text{s}} = 260\ \text{m/s}^2 = \left(260\ \text{m/s}^2\right)\left(\dfrac{1\ g}{9.80\ \text{m/s}^2}\right) = \boxed{26.6\ g}$

6.16 Choose the positive direction to be from the pitcher toward home plate.

(a) $Impulse = \overline{F}(\Delta t) = \Delta p = m\left(v_f - v_i\right) = (0.15\text{ kg})\left[(-22\text{ m/s}) - (20\text{ m/s})\right]$

$Impulse = \overline{F}(\Delta t) = -6.3\text{ kg}\cdot\text{m/s}$, or $\boxed{6.3\text{ kg}\cdot\text{m/s toward the pitcher}}$

(b) $\overline{F} = \dfrac{Impulse}{\Delta t} = \dfrac{-6.3\text{ kg}\cdot\text{m/s}}{2.0\times 10^{-3}\text{ s}} = -3.2\times 10^{3}\text{ N}$,

or $\overline{F} = \boxed{3.2\times 10^{3}\text{ N toward the pitcher}}$

6.17 Choose +x in the direction of the initial velocity and +y vertically upward. Consider first the force components exerted on the water by the roof.

$$\left(F_{water}\right)_x = \frac{\Delta p_x}{\Delta t} = \frac{m\left(\Delta v_x\right)}{\Delta t} = \frac{(20.0\text{ kg})\left[(40.0\text{ m/s})\cos 60.0° - 40.0\text{ m/s}\right]}{1.00\text{ s}},$$

or $\left(F_{water}\right)_x = -400\text{ N}$

$$\left(F_{water}\right)_y = \frac{\Delta p_y}{\Delta t} = \frac{m\left(\Delta v_y\right)}{\Delta t} = \frac{(20.0\text{ kg})\left[(40.0\text{ m/s})\sin 60.0° - 0\right]}{1.00\text{ s}} = 693\text{ N}$$

Thus, $F_{water} = \sqrt{F_x^2 + F_y^2} = \sqrt{(-400\text{ N})^2 + (693\text{ N})^2} = 800\text{ N}$

and $\theta = \tan^{-1}\left(\dfrac{F_y}{F_x}\right) = \tan^{-1}\left(\dfrac{693\text{ N}}{-400\text{ N}}\right) = 120°$, so $\mathbf{F}_{water} = 800\text{ N at }120°$.

From Newton's third law, $\mathbf{F}_{roof} = -\mathbf{F}_{water} = 800\text{ N at -}60.0°$,

or $\mathbf{F}_{roof} = \boxed{800\text{ N at }60.0°\text{ below the horizontal to the right}}$.

6.18 We shall choose southward as the positive direction.

The mass of the man is $m = \dfrac{w}{g} = \dfrac{730\ \text{N}}{9.80\ \text{m/s}^2} = 74.5\ \text{kg}$. Then, from conservation of momentum, we find

$$\left(m_{man}v_{man} + m_{book}v_{book}\right)_f = \left(m_{man}v_{man} + m_{book}v_{book}\right)_i \text{ or}$$

$$\left(74.5\ \text{kg}\right)v_{man} + \left(1.2\ \text{kg}\right)\left(-5.0\ \text{m/s}\right) = 0 + 0 \text{ and } v_{man} = 8.1\times10^{-2}\ \text{m/s}.$$

Therefore, the time required to travel the 5.0 m to shore is

$$t = \frac{\Delta x}{v_{man}} = \frac{5.0\ \text{m}}{8.1\times10^{-2}\ \text{m/s}} = \boxed{62\ \text{s}}.$$

6.19 Requiring that total momentum be conserved gives

$$\left(m_{club}v_{club} + m_{ball}v_{ball}\right)_f = \left(m_{club}v_{club} + m_{ball}v_{ball}\right)_i$$

or $\left(200\ \text{g}\right)\left(40\ \text{m/s}\right) + \left(46\ \text{g}\right)v_{ball} = \left(200\ \text{g}\right)\left(55\ \text{m/s}\right) + 0$,

and $v_{ball} = \boxed{65\ \text{m/s}}$.

6.20 (a) The mass of the rifle is $m = \dfrac{w}{g} = \dfrac{30\ \text{N}}{9.80\ \text{m/s}^2} = 3.1\ \text{kg}$. We choose the direction of the bullet's motion to be negative. Then, conservation of momentum gives

$$\left(m_{rifle}v_{rifle} + m_{bullet}v_{bullet}\right)_f = \left(m_{rifle}v_{rifle} + m_{bullet}v_{bullet}\right)_i$$

or $\left(3.1\ \text{kg}\right)v_{rifle} + \left(5.0\times10^{-3}\ \text{kg}\right)\left(-300\ \text{m/s}\right) = 0 + 0$ and $v_{rifle} = \boxed{0.49\ \text{m/s}}$.

(b) The mass of the man plus rifle is $m = \dfrac{730\ \text{N}}{9.80\ \text{m/s}^2} = 74.5\ \text{kg}$. We use the same approach as in (a), to find $v = \left(\dfrac{5.0\times10^{-3}\ \text{kg}}{74.5\ \text{kg}}\right)\left(300\ \text{m/s}\right) = \boxed{2.0\times10^{-2}\ \text{m/s}}$.

6.21 The velocity of the girl relative to the ice, v_{gi}, is $v_{gi} = v_{gp} + v_{pi}$ where
$v_{gp} = \text{velocity of girl relative to plank}$, and
$v_{pi} = \text{velocity of plank relative to ice}$. Since we are given that
$v_{gp} = 1.50 \text{ m/s}$, this becomes $v_{gi} = 1.50 \text{ m/s} + v_{pi}$. (1)

(a) Conservation of momentum gives $m_g v_{gi} + m_p v_{pi} = 0$, or $v_{pi} = -\left(\frac{m_g}{m_p}\right) v_{gi}$. (2)

Then, Equation (1) becomes $\left(1 + \frac{m_g}{m_p}\right) v_{gi} = 1.50 \text{ m/s}$

or $v_{gi} = \dfrac{1.50 \text{ m/s}}{1 + \left(\dfrac{45.0 \text{ kg}}{150 \text{ kg}}\right)} = \boxed{1.15 \text{ m/s}}$.

(b) Then, using (2) above, $v_{pi} = -\left(\dfrac{45.0 \text{ kg}}{150 \text{ kg}}\right)(1.15 \text{ m/s}) = -0.346 \text{ m/s}$

or $v_{pi} = \boxed{0.346 \text{ m/s directed opposite to the girl's motion}}$.

6.22 Consider the thrower first, with velocity after the throw of $v_{thrower}$. Applying conservation of momentum yields

$$(65.0 \text{ kg})v_{thrower} + (0.0450 \text{ kg})(30.0 \text{ m/s}) = (65.0 \text{ kg} + 0.0450 \text{ kg})(2.50 \text{ m/s}),$$

or $v_{thrower} = \boxed{2.48 \text{ m/s}}$.

Now, consider the (catcher + ball), with velocity of $v_{catcher}$ after the catch. From momentum conservation,

$$(60.0 \text{ kg} + 0.0450 \text{ kg})v_{catcher} = (0.0450 \text{ kg})(30.0 \text{ m/s}) + (60.0 \text{ kg})(0),$$

or $v_{catcher} = \boxed{2.25 \times 10^{-2} \text{ m/s}}$.

6.23 The ratio of the kinetic energy of the Earth to that of the ball is

$$\frac{KE_E}{KE_b} = \frac{\frac{1}{2}m_E v_E^2}{\frac{1}{2}m_b v_b^2} = \left(\frac{m_E}{m_b}\right)\left(\frac{v_E}{v_b}\right)^2, \qquad (1)$$

From conservation of momentum,

$$p_f = p_i = 0\text{, giving } m_E v_E + m_b v_b = 0 \text{ or } \frac{v_E}{v_b} = \boxed{-\frac{m_b}{m_E}}.$$

Equation (1) then becomes $\frac{KE_E}{KE_b} = \left(\frac{m_E}{m_b}\right)\left(-\frac{m_b}{m_E}\right)^2 = \boxed{\frac{m_b}{m_E}}$.

Using order of magnitude numbers, $\frac{KE_E}{KE_b} = \frac{m_b}{m_E} \sim \frac{1 \text{ kg}}{10^{25} \text{ kg}} \boxed{\sim 10^{-25}}$.

6.24 (a) Find the velocity of the amoeba after 1.0 s (i.e., after it has ejected 1.0×10^{-13} kg of water). Using conservation of momentum,

$$\left(1.0 \times 10^{-12} \text{ kg}\right)v_f + \left(1.0 \times 10^{-13} \text{ kg}\right)\left(-1.0 \times 10^{-4} \text{ m/s}\right) = 0 + 0$$

yielding $v_f = 1.0 \times 10^{-5}$ m/s .

The acceleration has been,

$$a = \frac{v_f - v_i}{\Delta t} = \frac{1.0 \times 10^{-5} \text{ m/s} - 0}{1.0 \text{ s}} = \boxed{1.0 \times 10^{-5} \text{ m/s}^2}.$$

(b) The reaction force exerted on the amoeba by the emerging jet is

$$F_{reaction} = ma = \left(1.0 \times 10^{-12} \text{ kg}\right)\left(1.0 \times 10^{-5} \text{ m/s}^2\right) = 1.0 \times 10^{-17} \text{ N}.$$

If the amoeba is to have constant velocity, the net force acting on it must be zero. Thus, the water must exert a resistance force with magnitude given by $F_{reaction} - F_{resistance} = 0$, or

$$F_{resistance} = F_{reaction} = \boxed{1.0 \times 10^{-17} \text{ N}}.$$

6.25 From conservation of momentum,

$$m_{ball}\left(v_{ball}\right)_f + m_{pin}\left(v_{pin}\right)_f = m_{ball}\left(v_{ball}\right)_i + m_{pin}\left(v_{pin}\right)_i,$$

or $$(7.00\text{ kg})(1.80\text{ m/s}) + (2.00\text{ kg})(3.00\text{ m/s}) = (7.00\text{ kg})\left(v_{ball}\right)_i + 0$$

which gives $\left(v_{ball}\right)_i = \boxed{2.66\text{ m/s}}$.

6.26 For each skater, the impulse-momentum theorem gives

$$\overline{F} = \frac{\Delta p}{\Delta t} = \frac{m(\Delta v)}{\Delta t} = \frac{(75.0\text{ kg})(5.00\text{ m/s})}{0.100\text{ s}} = \boxed{3.75\times 10^3\text{ N}}.$$

Since $\overline{F} < 4500\text{ N}$, there are $\boxed{\text{no broken bones}}$.

6.27 (a) If M is the mass of a single car, conservation of momentum gives

$$(3M)v_f = M(3.00\text{ m/s}) + (2M)(1.20\text{ m/s}),\text{ or } v_f = \boxed{1.80\text{ m/s}}$$

(b) The kinetic energy lost is $KE_{lost} = KE_i - KE_f$, or

$$KE_{lost} = \frac{1}{2}M(3.00\text{ m/s})^2 + \frac{1}{2}(2M)(1.20\text{ m/s})^2 - \frac{1}{2}(3M)(1.80\text{ m/s})^2$$

With $M = 2.00\times 10^4\text{ kg}$, this yields $KE_{lost} = \boxed{2.16\times 10^4\text{ J}}$.

6.28 Let us apply conservation of energy to the block from the time just after the bullet has passed through until it reaches maximum height in order to find its speed V just after the collision.

$$\frac{1}{2}mv_i^2 + mgy_i = \frac{1}{2}mv_f^2 + mgy_f \text{ becomes } \frac{1}{2}mV^2 + 0 = 0 + mgy_f$$

or $$V = \sqrt{2gy_f} = \sqrt{2\left(9.80\ \text{m/s}^2\right)\left(0.120\ \text{m}\right)} = 1.53\ \text{m/s}$$

Now use conservation of momentum from before until just after the collision in order to find the initial speed of the bullet, v.

$$\left(7.0\times 10^{-3}\ \text{kg}\right)v + 0 = \left(1.5\ \text{kg}\right)\left(1.53\ \text{m/s}\right) + \left(7.0\times 10^{-3}\ \text{kg}\right)\left(200\ \text{m/s}\right),$$

from which $v = \boxed{5.3\times 10^2\ \text{m/s}}$.

6.29 Let M = mass of ball, m = mass of bullet, v = velocity of bullet, and V = the initial velocity of the ball-bullet combination. Then, using conservation of momentum from just before to just after collision gives

$$\left(M+m\right)V = mv + 0 \quad \text{or} \quad V = \left(\frac{m}{M+m}\right)v.$$

Now, we use conservation of mechanical energy from just after the collision until the ball reaches maximum height to find

$$0 + \left(M+m\right)g\,h_{max} = \frac{1}{2}\left(M+m\right)V^2 + 0 \quad \text{or} \quad h_{max} = \frac{V^2}{2g} = \frac{1}{2g}\left(\frac{m}{M+m}\right)^2 v^2.$$

With the data values provided, this becomes

$$h_{max} = \frac{1}{2\left(9.80\ \text{m/s}^2\right)}\left(\frac{0.030\ \text{kg}}{0.15\ \text{kg}+0.030\ \text{kg}}\right)^2\left(200\ \text{m/s}\right)^2 = \boxed{57\ \text{m}}.$$

6.30 First, we will find the horizontal speed, v_{ix}, of the block and embedded bullet just after impact. After this instant, the block-bullet combination is a projectile, and we find the time to reach the floor by use of $\Delta y = v_{iy}t + \frac{1}{2}a_y t^2$, which becomes

$$-1.00\text{ m} = 0 + \frac{1}{2}\left(-9.80\text{ m/s}^2\right)t^2\text{, giving} \qquad t = 0.452\text{ s.}$$

Thus, $v_{ix} = \dfrac{\Delta x}{t} = \dfrac{2.00\text{ m}}{0.452\text{ s}} = 4.43\text{ m/s}$.

Now use conservation of momentum for the collision, with v_b = speed of incoming bullet:

$$\left(8.00\times10^{-3}\text{ kg}\right)v_b + 0 = \left(258\times10^{-3}\text{ kg}\right)\left(4.43\text{ m/s}\right)\text{, so}$$

$$v_b = \boxed{143\text{ m/s}}. \qquad \text{(about 320 mph)}$$

6.31 When Gayle jumps on the sled, conservation of momentum gives

$$\left(50.0\text{ kg} + 5.00\text{ kg}\right)v_2 = \left(50.0\text{ kg}\right)\left(4.00\text{ m/s}\right) + 0\text{, or } v_2 = 3.64\text{ m/s}.$$

After Gayle and the sled glide down 5.00 m, conservation of mechanical energy gives

$$\frac{1}{2}\left(55.0\text{ kg}\right)v_3^2 + 0 = \frac{1}{2}\left(55.0\text{ kg}\right)\left(3.64\text{ m/s}\right)^2 + \left(55.0\text{ kg}\right)\left(9.80\text{ m/s}^2\right)\left(5.00\text{ m}\right),$$

so $\quad v_3 = 10.5\text{ m/s}$.

After her Brother jumps on, conservation of momentum yields

$$\left(55.0\text{ kg} + 30.0\text{ kg}\right)v_4 = \left(55.0\text{ kg}\right)\left(10.50\text{ m/s}\right) + 0\text{, and } v_4 = 6.82\text{ m/s}.$$

After all slide an additional 10.0 m down, conservation of mechanical energy gives the final speed as

$$\frac{1}{2}\left(85.0\text{ kg}\right)v_5^2 + 0 = \frac{1}{2}\left(85.0\text{ kg}\right)\left(6.82\text{ m/s}\right)^2 + \left(85.0\text{ kg}\right)\left(9.80\text{ m/s}^2\right)\left(10.0\text{ m}\right)$$

or $\quad v_5 = \boxed{15.6\text{ m/s}}$.

6.32 (a) Conservation of momentum gives $m_T v_{fT} + m_c v_{fc} = m_T v_{iT} + m_c v_{ic}$, or

$$v_{fT} = \frac{m_T v_{iT} + m_c\left(v_{ic} - v_{fc}\right)}{m_T}$$

$$= \frac{(9000\text{ kg})(20.0\text{ m/s}) + (1200\text{ kg})\left[(25.0 - 18.0)\text{ m/s}\right]}{9000\text{ kg}}$$

$$v_{fT} = \boxed{20.9\text{ m/s East}}$$

(b) $$KE_{lost} = KE_i - KE_f = \left[\frac{1}{2}m_c v_{ic}^2 + \frac{1}{2}m_T v_{iT}^2\right] - \left[\frac{1}{2}m_c v_{fc}^2 + \frac{1}{2}m_T v_{fT}^2\right]$$

$$= \frac{1}{2}\left[m_c\left(v_{ic}^2 - v_{fc}^2\right) + m_T\left(v_{iT}^2 - v_{fT}^2\right)\right]$$

$$= \frac{1}{2}\left[(1200\text{ kg})(625 - 324)\left(\text{m}^2/\text{s}^2\right) + (9000\text{ kg})(400 - 438.2)\left(\text{m}^2/\text{s}^2\right)\right]$$

$$KE_{lost} = \boxed{8.68 \times 10^3\text{ J, which becomes internal energy}}.$$

Note: If 20.9 m/s were used to determine the energy lost instead of 20.9333, the answer would be very different. We keep extra digits in all intermediate answers until the problem is complete.

6.33 First, we use conservation of mechanical energy to find the speed of the block and embedded bullet just after impact:

$$\left(KE + PE_s\right)_f = \left(KE + PE_s\right)_i \text{ becomes } \frac{1}{2}(m + M)V^2 + 0 = 0 + \frac{1}{2}kx^2,$$

and yields $$V = \sqrt{\frac{kx^2}{m+M}} = \sqrt{\frac{(150\text{ N/m})(0.800\text{ m})^2}{(0.0120 + 0.100)\text{ kg}}} = 29.3\text{ m/s}$$

Now, employ conservation of momentum to find the speed of the bullet just before impact: $mv + M(0) = (m + M)V$,

or $$v = \left(\frac{m+M}{m}\right)V = \left(\frac{0.112\text{ kg}}{0.0120\text{ kg}}\right)(29.3\text{ m/s}) = \boxed{273\text{ m/s}}.$$

6.34 (a) Using conservation of momentum, $(\Sigma \mathbf{p})_{after} = (\Sigma \mathbf{p})_{before}$, gives

$$[(4.0 + 10 + 3.0)\ \text{kg}]v = (4.0\ \text{kg})(5.0\ \text{m/s}) + (10\ \text{kg})(3.0\ \text{m/s}) + (3.0\ \text{kg})(-4.0\ \text{m/s})$$

Therefore, $v = +2.2\ \text{m/s}$, or $\boxed{2.2\ \text{m/s toward the right}}$.

(b) $\boxed{\text{No}}$. For example, if the 10-kg and 3.0-kg mass were to stick together first, they would move with a speed given by solving

$$(13\ \text{kg})v_1 = (10\ \text{kg})(3.0\ \text{m/s}) + (3.0\ \text{kg})(-4.0\ \text{m/s}),\ \text{or}\ v_1 = +1.38\ \text{m/s}.$$

Then when this 13 kg combined mass collides with the 4.0 kg mass, we have

$$(17\ \text{kg})v = (13\ \text{kg})(1.38\ \text{m/s}) + (4.0\ \text{kg})(5.0\ \text{m/s}),\ \text{and}\ v = +2.2\ \text{m/s}$$

just as in part (a).

6.35 (a) From conservation of momentum,

$$(5.00\ \text{g})v_{1f} + (10.0\ \text{g})v_{2f} = (5.00\ \text{g})(20.0\ \text{cm/s}) + 0 \quad (1)$$

Also for an elastic, head-on, collision, we have $v_{1i} + v_{1f} = v_{2i} + v_{2f}$, which becomes $20.0\ \text{cm/s} + v_{1f} = v_{2f}$. (2)

Solving (1) and (2) simultaneously yields

$$v_{1f} = \boxed{-6.67\ \text{cm/s}},\ \text{and}\ v_{2f} = \boxed{13.3\ \text{cm/s}}.$$

(b) $KE_i = KE_{1i} + KE_{2i} = \frac{1}{2}(5.00 \times 10^{-3}\ \text{kg})(0.200\ \text{m/s})^2 + 0 = 1.00 \times 10^{-4}\ \text{J}$

$$KE_{2f} = \frac{1}{2}m_2 v_{2f}^2 = \frac{1}{2}(10.0 \times 10^{-3}\ \text{kg})(13.3 \times 10^{-2}\ \text{m/s})^2 = 8.89 \times 10^{-5}\ \text{J},\ \text{so}$$

$$\frac{KE_{2f}}{KE_i} = \frac{8.89 \times 10^{-5}\ \text{J}}{1.00 \times 10^{-4}\ \text{J}} = \boxed{0.889}$$

6.36 Using conservation of momentum gives

$$(10.0\text{ g})v_{1f} + (15.0\text{ g})v_{2f} = (10.0\text{ g})(20.0\text{ cm/s}) + (15.0\text{ g})(-30.0\text{ cm/s}) \quad (1)$$

For elastic, head on collisions, $v_{1i} + v_{1f} = v_{2i} + v_{2f}$ which becomes

$$20.0\text{ cm/s} + v_{1f} = -30.0\text{ cm/s} + v_{2f}. \quad (2)$$

Solving (1) and (2) simultaneously gives $v_{1f} = \boxed{-40.0\text{ cm/s}}$,

and $v_{2f} = \boxed{10.0\text{ cm/s}}$.

6.37 Conservation of momentum gives

$$(25.0\text{ g})v_{1f} + (10.0\text{ g})v_{2f} = (25.0\text{ g})(20.0\text{ cm/s}) + (10.0\text{ g})(15.0\text{ cm/s}) \quad (1)$$

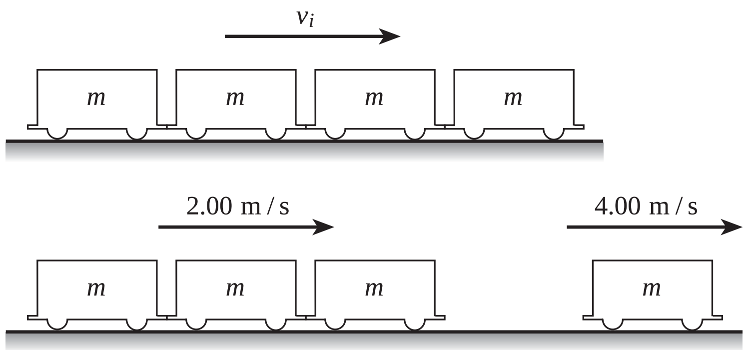
For head-on, elastic collisions, we know that $v_{1i} + v_{1f} = v_{2i} + v_{2f}$.

Thus, $20.0\text{ cm/s} + v_{1f} = 15.0\text{ cm/s} + v_{2f}$. (2)

Solving (1) and (2) simultaneously yields

$$v_{1f} = \boxed{17.1\text{ cm/s}},\text{ and } v_{2f} = \boxed{22.1\text{ cm/s}}.$$

6.38 (a) The internal forces exerted by the actor do not change total momentum.



From conservation of momentum

$$(4m)v_i = (3m)(2.00\ \text{m/s}) + m(4.00\ \text{m/s})$$

$$v_i = \frac{6.00\ \text{m/s} + 4.00\ \text{m/s}}{4} = \boxed{2.50\ \text{m/s}}$$

(b) $$W_{actor} = K_f - K_i = \frac{1}{2}\left[(3m)(2.00\ \text{m/s})^2 + m(4.00\ \text{m/s})^2\right] - \frac{1}{2}(4m)(2.50\ \text{m/s})^2$$

$$W_{actor} = \frac{(2.50\times 10^4\ \text{kg})}{2}\left[12.0 + 16.0 - 25.0\right](\text{m/s})^2 = \boxed{3.75\times 10^4\ \text{J}}$$

6.39 We assume equal firing speeds v and equal forces F required for the two bullets to push wood fibers apart. These forces are directed opposite to the bullets displacements through the fibers.

When the block is held in the vise, $W_{net} = KE_f - KE_i$ gives

$$F\left(8.00\times10^{-2}\ \text{m}\right)\cos 180° = 0 - \frac{1}{2}\left(7.00\times10^{-3}\ \text{kg}\right)v^2,$$

or $$\frac{1}{2}\left(7.00\times10^{-3}\ \text{kg}\right)v^2 = \left(8.00\times10^{-2}\ \text{m}\right)F \qquad (1)$$

When a second 7.00-g bullet is fired into the block, now on a frictionless surface, conservation of momentum yields

$$\left(1.014\ \text{kg}\right)v_f = \left(7.00\times10^{-3}\ \text{kg}\right)v + 0\text{, or } v_f = \left(\frac{7.00\times10^{-3}}{1.014}\right)v \qquad (2)$$

Also, applying the work-kinetic energy theorem to the second impact,

$$Fd\cos 180° = \frac{1}{2}\left(1.014\ \text{kg}\right)v_f^2 - \frac{1}{2}\left(7.00\times10^{-3}\ \text{kg}\right)v^2 \qquad (3)$$

Substituting (2) into (3), we obtain

$$-Fd = \frac{1}{2}\left(1.014\ \text{kg}\right)\left(\frac{7.00\times10^{-3}}{1.014}\right)^2 v^2 - \frac{1}{2}\left(7.00\times10^{-3}\ \text{kg}\right)v^2,$$

or $$Fd = \left[\frac{1}{2}\left(7.00\times10^{-3}\ \text{kg}\right)v^2\right]\left(1 - \frac{7.00\times10^{-3}}{1.014}\right) \qquad (4)$$

Finally, substituting (1) into (4) gives

$$Fd = \left[\left(8.00\times10^{-2}\ \text{m}\right)F\right]\left(1 - \frac{7.00\times10^{-3}}{1.014}\right)\text{, or } d = 7.94\times10^{-2}\ \text{m} = \boxed{7.94\ \text{cm}}$$

6.40 First, consider conservation of momentum and write

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$$

Since $m_1 = m_2$, this becomes $v_{1i} + v_{2i} = v_{1f} + v_{2f}$. (1)

For an elastic head-on collision, we also have $v_{1i} - v_{2i} = -\left(v_{1f} - v_{2f}\right)$,

which may be written as $v_{1i} + v_{2i} = v_{1f} + v_{2f}$ (2)

Subtracting Equation (2) from (1) gives $v_{2f} = v_{1i}$ (3)

Adding Equations (1) and (2) yields $v_{1f} = v_{2i}$ (4)

Equations (3) and (4) show us that, under the conditions of equal mass objects striking one another in a head-on elastic collision, the two objects simply exchange velocities. Thus, we may write the results of the various collisions as

(a) $v_{1f} = \boxed{0}$, $v_{2f} = \boxed{1.50\ \text{m/s}}$

(b) $v_{1f} = \boxed{-1.00\ \text{m/s}}$, $v_{2f} = \boxed{1.50\ \text{m/s}}$

(c) $v_{1f} = \boxed{1.00\ \text{m/s}}$, $v_{2f} = \boxed{1.50\ \text{m/s}}$

6.41 Choose the +*x*-axis to be eastward and the +*y*-axis northward.

(a) First, we conserve momentum in the *x* direction to find

$$(185\ \text{kg})V\cos\theta = (90\ \text{kg})(5.0\ \text{m/s}),\ \text{or}\ V\cos\theta = \left(\frac{90}{185}\right)(5.0\ \text{m/s}) \quad (1)$$

Conservation of momentum in the *y* direction gives

$$(185\ \text{kg})V\sin\theta = (95\ \text{kg})(3.0\ \text{m/s}),\ \text{or}\ V\sin\theta = \left(\frac{95}{185}\right)(3.0\ \text{m/s}) \quad (2)$$

Divide equation (2) by (1) to obtain $\tan\theta = \dfrac{(95)(3.0)}{(90)(5.0)}$, and $\theta = \boxed{32°}$

Then, either (1) or (2) gives $V = 2.88\ \text{m/s}$, which rounds to $V = \boxed{2.9\ \text{m/s}}$.

(b) $KE_{lost} = KE_i - KE_f$

$$= \frac{1}{2}\left[(90\text{ kg})(5.0\text{ m/s})^2 + (95\text{ kg})(3.0\text{ m/s})^2 - (185\text{ kg})(2.88\text{ m/s})^2\right]$$

$= \boxed{7.9\times10^2\text{ J}}$ converted into internal energy

6.42 Choose the +x-axis to be eastward and the +y-axis northward.

(a) Conserving momentum in the x direction gives

$$0 + (10.0\text{ kg})v_{2x} = (8.00\text{ kg})(15.0\text{ m/s}) + 0\text{, or } v_{2x} = 12.0\text{ m/s}.$$

Momentum conservation in the y direction yields

$$(8.00\text{ kg})(-4.00\text{ m/s}) + (10.0\text{ kg})v_{2y} = 0 + 0\text{, or } v_{2y} = 3.20\text{ m/s}.$$

After collision, $v_2 = \sqrt{v_{2x}^2 + v_{2y}^2} = \sqrt{154}\text{ m/s} = 12.4\text{ m/s}$

and $\theta = \tan^{-1}\left(\frac{v_{2y}}{v_{2x}}\right) = \tan^{-1}\left(\frac{3.20}{12.0}\right) = 14.9°$. Thus, the final velocity of the 10.0-kg mass is $\mathbf{v}_2 = \boxed{12.4\text{ m/s at }14.9°\text{ N of E}}$.

(b) $\frac{KE_{lost}}{KE_i} = \frac{KE_i - KE_f}{KE_i} = 1 - \frac{KE_f}{KE_i}$

$$= 1 - \left[\frac{(8.00)(-4.00)^2 + (10.0)\left(\sqrt{154}\right)^2}{(8.00)(15.0)^2 + 0}\right] = 0.0720$$

or $\boxed{7.20\%}$ of the original kinetic energy is lost in the collision.

6.43 Choose the +x-axis to be eastward and the +y-axis northward.

If v_i is the initial northward speed of the 3000-kg car, conservation of momentum in the y direction gives

$$0 + (3000\text{ kg})v_i = (5000\text{ kg})\left[(5.22\text{ m/s})\sin 40.0°\right]\text{, or } v_i = \boxed{5.59\text{ m/s}}$$

Observe that knowledge of the initial speed of the 2000-kg car was unnecessary for this solution.

6.44 We use conservation of momentum for both northward and eastward components.

For the eastward direction: $M(13.0 \text{ m/s}) = 2MV_f \cos 55.0°$

For the northward direction: $Mv_{2i} = 2MV_f \sin 55.0°$

Divide the northward equation by the eastward equation to find:

$$v_{2i} = (13.0 \text{ m/s})\tan 55.0°$$

$$= \left[(13.0 \text{ m/s})\left(\frac{2.237 \text{ mi/h}}{1 \text{ m/s}}\right)\right]\tan 55.0° = \boxed{41.5 \text{ mi/h}}$$

Thus, the driver of the north bound car was untruthful.

6.45 Choose the x-axis to be along the original line of motion.

(a) From conservation of momentum in the x direction,

$$m(5.00 \text{ m/s}) + 0 = m(4.33 \text{ m/s})\cos 30.0° + mv_{2f}\cos\theta,$$

or $v_{2f}\cos\theta = 1.25 \text{ m/s}$ (1)

Conservation of momentum in the y direction gives

$0 = m(4.33 \text{ m/s})\sin 30.0° + mv_{2f}\sin\theta$, or $v_{2f}\sin\theta = -2.16 \text{ m/s}$ (2)

Dividing (2) by (1) gives $\tan\theta = \dfrac{-2.16}{1.25} = -1.73$ and $\theta = -60.0°$.

Then, either (1) or (2) gives $v_{2f} = 2.50 \text{ m/s}$, so the final velocity of the second ball is $\mathbf{v}_{2f} = \boxed{2.50 \text{ m/s at -60.0°}}$.

(b) $KE_i = \frac{1}{2}mv_{1i}^2 + 0 = \frac{1}{2}m(5.00 \text{ m/s})^2 = m(12.5 \text{ m}^2/\text{s}^2)$

$$KE_f = \frac{1}{2}mv_{1f}^2 + \frac{1}{2}mv_{2f}^2$$
$$= \frac{1}{2}m(4.33 \text{ m/s})^2 + \frac{1}{2}m(2.50 \text{ m/s})^2 = m(12.5 \text{ m}^2/\text{s}^2)$$

Since $KE_f = KE_i$, this is an $\boxed{\text{elastic collision}}$.

6.46 The recoil speed of the subject plus pallet after a heartbeat is

$$V = \frac{\Delta x}{\Delta t} = \frac{6.00 \times 10^{-5}\ \text{m}}{0.160\ \text{s}} = 3.75 \times 10^{-4}\ \text{m/s}.$$

From conservation of momentum, $mv - MV = 0 + 0$, so the mass of blood leaving the heart is

$$m = M\left(\frac{V}{v}\right) = (54.0\ \text{kg})\left(\frac{3.75 \times 10^{-4}\ \text{m/s}}{0.500\ \text{m/s}}\right) = 4.05 \times 10^{-2}\ \text{kg} = \boxed{40.5\ \text{g}}.$$

6.47 $Impulse = \overline{\mathbf{F}}(\Delta t) = \Delta\mathbf{p} = m\left(\mathbf{v}_f - \mathbf{v}_i\right)$

$$= (0.400\ \text{kg})\left[(-22.0\ \text{m/s}) - 15.0\ \text{m/s}\right] = -14.8\ \text{kg}\cdot\text{m/s}$$

Impulse = $\boxed{14.6\ \text{kg}\cdot\text{m/s}\ \text{ in the direction of the final velocity of the ball}}$

6.48 First, we use conservation of mechanical energy to find the speed of m_1 at B just before collision. This gives $\frac{1}{2}m_1 v_1^2 + 0 = 0 + m_1 g h_i$,

or $v_1^2 = \sqrt{2gh_i} = \sqrt{2(9.80\ \text{m/s}^2)(5.00\ \text{m})} = 9.90\ \text{m/s}$.

Next, we apply conservation of momentum and knowledge of elastic collisions to find the velocity of m_1 at B just after collision.

From conservation of momentum, with the second object initially at rest,

we have $m_1 v_{1f} + m_2 v_{2f} = m_1 v_{1i} + 0$, or $v_{2f} = \frac{m_1}{m_2}\left(v_{1i} - v_{1f}\right)$. (1)

For head-on elastic collisions, $v_{1f} + v_{1i} = v_{2f} + v_{2i}$. Since $v_{2i} = 0$ in this case, this becomes $v_{2f} = v_{1f} + v_{1i}$ and combining this with (1) above we obtain

$$v_{1f} = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)v_{1i} = \left(\frac{5.00 - 10.0}{5.00 + 10.0}\right)(9.90\ \text{m/s}) = -3.30\ \text{m/s}.$$

Finally, use conservation of mechanical energy for m_1 after the collision to find the maximum rebound height. This gives $0 + m_1 g h_{max} = \frac{1}{2} m_1 v_{1f}^2 + 0$,

or $$h_{max} = \frac{v_{1f}^2}{2g} = \frac{(-3.30 \text{ m/s})^2}{2(9.80 \text{ m/s}^2)} = \boxed{0.556 \text{ m}}.$$

6.49 Choose the positive direction to be the direction of the truck's initial velocity.

Apply conservation of momentum to find the velocity of the combined vehicles after collision:

$$(4000 \text{ kg} + 800 \text{ kg})V = (4000 \text{ kg})(+8.00 \text{ m/s}) + (800 \text{ kg})(-8.00 \text{ m/s}),$$

which yields $V = +5.33 \text{ m/s}$.

Use the impulse-momentum theorem, $Impulse = \overline{F}(\Delta t) = \Delta p = m(v_f - v_i)$, to find the magnitude of the average force exerted on each driver during the collision.

Truck Driver:

$$\left|\overline{F}\right| = \frac{m\left|v_f - v_i\right|_{truck}}{\Delta t} = \frac{(80.0 \text{ kg})\left|5.33 \text{ m/s} - 8.00 \text{ m/s}\right|}{0.120 \text{ s}} = \boxed{1.78 \times 10^3 \text{ N}}$$

Car Driver:

$$\left|\overline{F}\right| = \frac{m\left|v_f - v_i\right|_{car}}{\Delta t} = \frac{(80.0 \text{ kg})\left|5.33 \text{ m/s} - (-8.00 \text{ m/s})\right|}{0.120 \text{ s}} = \boxed{8.89 \times 10^3 \text{ N}}$$

6.50 If the pendulum bob barely swings through a complete circle, it arrives at the top of the arc (having risen a vertical distance of $2l$) with essentially zero velocity.

From conservation of mechanical energy, we find the minimum velocity of the bob at the bottom of the arc as $(KE + PE_g)_{bottom} = (KE + PE_g)_{top}$, or $\frac{1}{2} M V^2 = 0 + M g (2l)$. This gives $V = 2\sqrt{g l}$ as the needed velocity of the bob just after the collision.

Conserving momentum through the collision then gives the minimum initial velocity of the bullet as

$$m\left(\frac{v}{2}\right) + M\left(2\sqrt{g l}\right) = mv + 0, \text{ or } v = \boxed{\frac{4M}{m}\sqrt{g l}}.$$

6.51 Note that the initial velocity of the target particle is zero (i.e., $v_{2i} = 0$).

From conservation of momentum, $m_1 v_{1f} + m_2 v_{2f} = m_1 v_{1i} + 0$. (1)

For head-on elastic collisions, $v_{1f} + v_{1i} = v_{2f} + 0$. (2)

Solving (1) and (2) simultaneously yields the final velocities as

$$v_{1f} = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) v_{1i} \text{ and } v_{2f} = \left(\frac{2m_1}{m_1 + m_2}\right) v_{1i}$$

(a) If $m_1 = 2.0 \text{ g}$, $m_2 = 1.0 \text{ g}$, and $v_{1i} = 8.0 \text{ m/s}$, then

$$v_{1f} = \boxed{\frac{8}{3} \text{ m/s}} \text{ and } v_{2f} = \boxed{\frac{32}{3} \text{ m/s}}.$$

(b) If $m_1 = 2.0 \text{ g}$, $m_2 = 10 \text{ g}$, and $v_{1i} = 8.0 \text{ m/s}$, we find

$$v_{1f} = \boxed{-\frac{16}{3} \text{ m/s}} \text{ and } v_{2f} = \boxed{\frac{8}{3} \text{ m/s}}.$$

(c) The final kinetic energy of the 2.0 g particle in each case is:

Case (a): $KE_{1f} = \frac{1}{2} m_1 v_{1f}^2 = \frac{1}{2}\left(2.0 \times 10^{-3} \text{ kg}\right)\left(\frac{8}{3} \text{ m/s}\right)^2 = \boxed{7.1 \times 10^{-3} \text{ J}}$

Case (b): $KE_{1f} = \frac{1}{2} m_1 v_{1f}^2 = \frac{1}{2}\left(2.0 \times 10^{-3} \text{ kg}\right)\left(-\frac{16}{3} \text{ m/s}\right)^2 = \boxed{2.8 \times 10^{-2} \text{ J}}$

Since the incident kinetic energy is the same in cases (a) and (b), we observe that the incident particle loses more kinetic energy in case (a)

6.52 Use conservation of mechanical energy, $\left(KE+PE_g\right)_B=\left(KE+PE_g\right)_A$, to find the speed of the bead at point B just before it collides with the ball. This gives $\frac{1}{2}mv_{1i}^2+0=0+mgy_A$, or $v_{1i}=\sqrt{2gy_A}=\sqrt{2\left(9.80\ \text{m/s}^2\right)\left(1.50\ \text{m}\right)}=5.42\ \text{m/s}$.

Conservation of momentum during the collision gives

$$\left(0.400\ \text{kg}\right)v_{1f}+\left(0.600\ \text{kg}\right)v_{2f}=\left(0.400\ \text{kg}\right)\left(5.42\ \text{m/s}\right)+0,$$

or $$v_{1f}+1.50v_{2f}=5.42\ \text{m/s}. \qquad (1)$$

For a head-on elastic collision, we have $v_{2f}+v_{2i}=v_{1f}+v_{1i}$, which gives

$$v_{2f}=v_{1f}+5.42\ \text{m/s}. \qquad (2)$$

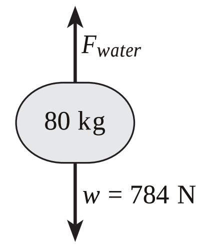
Solving (1) and (2) simultaneously, the velocities just after collision are

$$v_{1f}=-1.08\ \text{m/s} \text{ and } v_{2f}=4.34\ \text{m/s}.$$

Now, we use conservation of the mechanical energy of the ball after collision to find the maximum height the ball will reach. This gives

$$0+Mgy_{max}=\frac{1}{2}Mv_{2f}^2+0, \text{ or } y_{max}=\frac{v_{2f}^2}{2g}=\frac{\left(4.34\ \text{m/s}\right)^2}{2\left(9.80\ \text{m/s}^2\right)}=\boxed{0.960\ \text{m}}$$

6.53 We first find the speed of the diver when he reaches the water by using $v^2 = v_i^2 + 2a_y(\Delta y)$. This becomes



$$v^2 = 0 + 2\left(-9.80\ \text{m/s}^2\right)\left(-3.0\ \text{m}\right), \text{ and yields } v = -\sqrt{59}\ \text{m/s}$$

The negative sign indicates the downward direction.

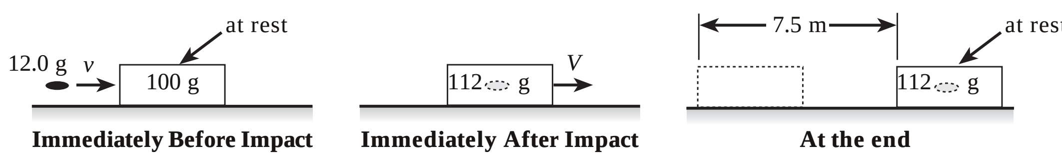
Next, we use the impulse-momentum theorem to find the resistive force exerted by the water as the diver comes to rest.

$$Impulse = F_{net}(\Delta t) = \Delta p = m\left(v_f - v_i\right), \text{ or}$$

$$\left(F_{water} - 784\ \text{N}\right)(2.0\ \text{s}) = (80\ \text{kg})\left[0 - \left(-\sqrt{59}\ \text{m/s}\right)\right], \text{ which gives}$$

$$F_{water} = 784\ \text{N} + \left(\frac{80\sqrt{59}}{2}\right)\text{N} = \boxed{1.1\times 10^3\ \text{N}\ \ (\text{upward})}.$$

6.54



Using the work-kinetic energy theorem from immediately after impact to the end gives:

$$W_{net} = F_{friction}\ s\cos 180° = KE_{end} - KE_{after},$$

or, $$-\left[\mu_k (M+m)\, g\right]s = 0 - \frac{1}{2}(M+m)V^2 \text{ and } V = \sqrt{2\mu_k\, g\, s}.$$

Then, using conservation of momentum from immediately before to immediately after impact gives $mv + 0 = (M+m)V$, or

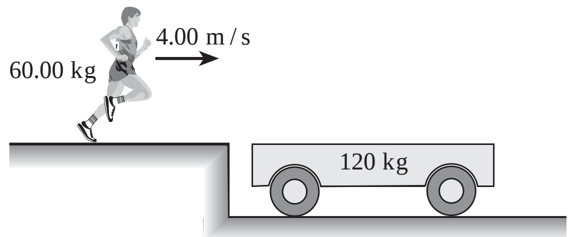
$$v = \left(\frac{M+m}{m}\right)V = \left(\frac{M+m}{m}\right)\sqrt{2\mu_k\, g\, s} = \left(\frac{112\ \text{g}}{12.0\ \text{g}}\right)\sqrt{2(0.650)\left(9.80\ \text{m/s}^2\right)(7.5\ \text{m})}$$

$$v = \boxed{91\ \text{m/s}}$$

6.55 (a) Using conservation of momentum,

$$(60.0\text{ kg}+120\text{ kg})v_f=(60.0\text{ kg})(4.00\text{ m/s})+0,$$

or $$v_f=\boxed{1.33\text{ m/s}}$$



(b) $\Sigma F_y=n-(60.0\text{ kg})(9.80\text{ m/s}^2)=0$

so the normal force is $n=588\text{ N}$

and $f_k=\mu_k n=(0.400)(588\text{ N})=\boxed{235\text{ N}}$

(c) Apply the impulse-momentum theorem to the person:

$$Impulse=\overline{F}_{net}(\Delta t)=\Delta p=m(v_f-v_i)$$

so $$\Delta t=\frac{m(v_f-v_i)}{-f_k}=\frac{(60.0\text{ kg})(1.33\text{ m/s}-4.00\text{ m/s})}{-235\text{ N}}=\boxed{0.681\text{ s}}$$

(d) $$\Delta p_{person}=m(v_f-v_i)=(60.0\text{ kg})(1.33\text{ m/s}-4.00\text{ m/s})=-160\text{ N}\cdot\text{s}$$

$$\Delta p_{cart}=M(v_f-0)=(120\text{ kg})(1.33\text{ m/s}-0)=\boxed{+160\text{ N}\cdot\text{s}}$$

(e) $$\Delta x_{person}=\overline{v}(\Delta t)=\left(\frac{v_f+v_i}{2}\right)(\Delta t)$$

$$=\left(\frac{1.33\text{ m/s}+4.00\text{ m/s}}{2}\right)(0.681\text{ s})=1.82\text{ m}$$

(f) $$\Delta x_{cart}=\overline{v}(\Delta t)=\left(\frac{v_f+0}{2}\right)(\Delta t)=\left(\frac{1.33\text{ m/s}}{2}\right)(0.681\text{ s})=\boxed{0.454\text{ m}}$$

(g) $$\Delta KE_{person}=\frac{1}{2}m(v_f^2-v_i^2)$$

$$=\frac{(60.0\text{ kg})}{2}\left[(1.33\text{ m/s})^2-(4.00\text{ m/s})^2\right]=\boxed{-427\text{ J}}$$

(h) $$\Delta KE_{cart}=\frac{1}{2}M(v_f^2-0)=\frac{(120\text{ kg})}{2}\left[(1.33\text{ m/s})^2-0\right]=\boxed{107\text{ J}}$$

(i) Equal friction forces act through different distances on person and cart to do different amounts of work on them. This is a perfectly inelastic collision in which the total work on both person and cart together is –320 J, which becomes +320 J of internal energy.

6.56 (a) Let v_{1i} and v_{2i} be the velocities of m_1 and m_2 just before the collision. Then conservation of energy gives:

$$v_{1i} = -v_{2i} = \sqrt{2gh} = \sqrt{2\left(9.80\ \text{m/s}^2\right)\left(5.00\ \text{m}\right)} = \boxed{9.90\ \text{m/s}}.$$

(b) From conservation of momentum:

$$(2.00)v_{1f} + (4.00)\,v_{2f} = (2.00)(9.90\ \text{m/s}) + (4.00)(-9.90\ \text{m/s}),$$

or $(2.00)v_{1f} + (4.00)\,v_{2f} = -19.8\ \text{m/s}$. (1)

For an elastic head-on collision, $v_{1f} + v_{1i} = v_{2f} + v_{2i}$, giving

$v_{1f} + 9.90\ \text{m/s} = v_{2f} - 9.90\ \text{m/s}$, or $v_{2f} = v_{1f} + 19.8\ \text{m/s}$ (2)

Solving (1) and (2) simultaneously gives

$$v_{1f} = \boxed{-16.5\ \text{m/s}},\ \text{and}\ v_{2f} = \boxed{3.30\ \text{m/s}}.$$

(c) Applying conservation of energy to each block after the collision gives:

$$h_{1f} = \frac{v_{1f}^2}{2g} = \frac{(-16.5\ \text{m/s})^2}{2\left(9.80\ \text{m/s}^2\right)} = \boxed{13.9\ \text{m}}$$

and $$h_{2f} = \frac{v_{2f}^2}{2g} = \frac{(3.30\ \text{m/s})^2}{2\left(9.80\ \text{m/s}^2\right)} = \boxed{0.556\ \text{m}}$$

6.57 (a) Use conservation of mechanical energy to find the speed of m_1 just before collision. This gives

$$v_{1i} = \sqrt{2gh_1} = \sqrt{2\left(9.80\text{ m/s}^2\right)\left(2.50\text{ m}\right)} = 7.00\text{ m/s}.$$

Apply conservation of momentum from just before to just after the collision:

$$\left(0.500\text{ kg}\right)v_{1f} + \left(1.00\text{ kg}\right)v_{2f} = \left(0.500\text{ kg}\right)\left(7.00\text{ m/s}\right) + 0,$$

or $\quad v_{1f} + 2v_{2f} = 7.00\text{ m/s}$ (1)

For a head-on elastic collision, $v_{1f} + v_{1i} = v_{2f} + v_{2i}$,

which becomes $v_{1f} - v_{2f} = -7.00\text{ m/s}$. (2)

Solving (1) and (2) simultaneously yields

$$v_{1f} = \boxed{-2.33\text{ m/s}}, \text{ and } v_{2f} = \boxed{4.67\text{ m/s}}.$$

(b) Apply conservation of mechanical energy to m_1 after the collision to find

$$h_1' = \frac{v_{1f}^2}{2g} = \frac{\left(-2.33\text{ m/s}\right)^2}{2\left(9.80\text{ m/s}^2\right)} = \boxed{0.277\text{ m}}. \text{ (rebound height)}$$

(c) From $\Delta y = v_{iy}t + \frac{1}{2}a_y t^2$, with $v_{iy} = 0$, the time for m_2 to reach the floor after it flies horizontally off the table is found to be

$$t = \sqrt{\frac{2(\Delta y)}{a_y}} = \sqrt{\frac{2\left(-2.00\text{ m}\right)}{-9.80\text{ m/s}^2}} = 0.639\text{ s}.$$

The horizontal distance traveled in this time is

$$\Delta x = v_{ix}t = \left(4.67\text{ m/s}\right)\left(0.639\text{ s}\right) = \boxed{2.98\text{ m}}.$$

(d) After the 0.500 kg mass comes back down the incline, it flies off the table with a horizontal velocity of 2.33 m/s. The time of the flight to the floor is 0.639 s as found above and the horizontal distance traveled is

$$\Delta x = v_{ix}t = \left(2.33\text{ m/s}\right)\left(0.639\text{ s}\right) = \boxed{1.49\text{ m}}.$$

6.58 Use conservation of mechanical energy to find the velocity, v, of Tarzan just as he reaches Jane. This gives $v = \sqrt{2gh_i} = \sqrt{2(9.80\ \text{m/s}^2)(3.00\ \text{m})} = 7.67\ \text{m/s}$.

Now, use conservation of momentum to find the velocity, V, of Tarzan + Jane just after the collision. This becomes $(M+m)V = Mv + 0$, or

$$V = \left(\frac{M}{M+m}\right)v = \left(\frac{80.0\ \text{kg}}{140\ \text{kg}}\right)(7.67\ \text{m/s}) = 4.38\ \text{m/s}.$$

Finally, use conservation of mechanical energy from just after he picks her up to the end of their swing to determine the maximum height, H, reached. This yields

$$H = \frac{V^2}{2g} = \frac{(4.38\ \text{m/s})^2}{2(9.80\ \text{m/s}^2)} = \boxed{0.980\ \text{m}}$$

6.59 (a) The momentum of the system is initially zero and remains constant throughout the motion. Therefore, when m_1 leaves the wedge, we must have $m_2 v_{wedge} + m_1 v_{block} = 0$, or

$$v_{wedge} = -\left(\frac{m_1}{m_2}\right)v_{block} = -\left(\frac{0.500}{3.00}\right)(4.00\ \text{m/s}) = \boxed{-0.667\ \text{m/s}}.$$

(b) Using conservation of energy as the block slides down the wedge, we have $(KE + PE_g)_i = (KE + PE_g)_f$ or

$$0 + m_1 gh = \frac{1}{2}m_1 v_{block}^2 + \frac{1}{2}m_2 v_{wedge}^2 + 0.$$

Thus, $h = \frac{1}{2g}\left[v_{block}^2 + \left(\frac{m_2}{m_1}\right)v_{wedge}^2\right]$

$$= \frac{1}{19.6\ \text{m/s}^2}\left[(4.00\ \text{m/s})^2 + \left(\frac{3.00}{0.500}\right)(-0.667\ \text{m/s})^2\right] = \boxed{0.952\ \text{m}}.$$

6.60 (a) Let m be the mass of each cart. Then, if v_0 is the initial velocity of the red cart, applying conservation of momentum to the collision gives

$$mv_b + mv_r = mv_0 + 0\text{, or } v_b + v_r = v_0 \quad (1)$$

where v_b and v_r are the velocities of the blue and red carts after collision.

In a head-on elastic collision, we have $v_{2f} + v_{2i} = v_{1f} + v_{1i}$ which reduces to

$$v_b - v_r = v_0 . \quad (2)$$

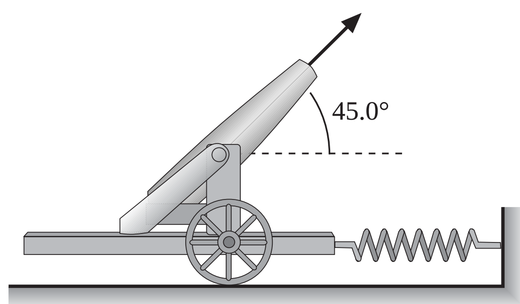
Solving (1) and (2) simultaneously gives $v_r = \boxed{0}$, and $v_b = \boxed{3.00\ \text{m/s}}$.

(b) Using conservation of mechanical energy for the blue cart-spring system, $(KE + PE_s)_f = (KE + PE_s)_i$ becomes

$$0 + \frac{1}{2}kx^2 = \frac{1}{2}mv_b^2 + 0$$

or $$x = \sqrt{\frac{m}{k}}\,v_b = \sqrt{\frac{0.250\ \text{kg}}{50.0\ \text{N/m}}}\,(3.00\ \text{m/s}) = \boxed{0.212\ \text{m}}.$$

6.61 (a) Use conservation of the component of momentum in the horizontal direction from just before to just after the cannon firing.



$(\Sigma p_x)_f = (\Sigma p_x)_i$ gives

$$m_{shell}(v_{shell}\cos 45.0°) + m_{cannon}v_{recoil} = 0\text{, or}$$

$$v_{recoil} = -\left(\frac{m_{shell}}{m_{cannon}}\right)v_{shell}\cos 45.0°$$

$$= -\left(\frac{200\ \text{kg}}{5000\ \text{kg}}\right)(125\ \text{m/s})\cos 45.0° = \boxed{-3.54\ \text{m/s}}$$

(b) Use conservation of mechanical energy for the cannon-spring system from right after the cannon is fired to the instant when the cannon comes to rest.

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

$$0 + 0 + \frac{1}{2}kx_{max}^2 = \frac{1}{2}m_{cannon}\,v_{recoil}^2 + 0 + 0$$

$$x_{max} = \sqrt{\frac{m_{cannon}\,v_{recoil}^2}{k}} = \sqrt{\frac{(5000\text{ kg})(\text{-}3.54\text{ m/s})^2}{2.00\times10^4\text{ N/m}}} = \boxed{1.77\text{ m}}$$

(c) $|F_{max}| = k\,x_{max} = \left(2.00\times10^4\text{ N/m}\right)(1.77\text{ m}) = \boxed{3.54\times10^4\text{ N}}$

(d) No. The rail exerts a vertical external force (the normal force) on the cannon and prevents it from recoiling vertically. Momentum is not conserved in the vertical direction. The spring does not have time to stretch during the cannon firing. Thus, no external horizontal force is exerted on the system (cannon plus shell) from just before to just after firing. Momentum is conserved in the horizontal direction during this interval.

6.62 Conservation of the *x*-component of momentum gives

$$(3m)v_{2x} + 0 = -mv_0 + (3m)v_0\text{, or } v_{2x} = \frac{2}{3}v_0. \tag{1}$$

Likewise, conservation of the *y*-component of momentum gives

$$-mv_{1y} + (3m)v_{2y} = 0\text{, and } v_{1y} = 3v_{2y}. \tag{2}$$

Since the collision is elastic, $(KE)_f = (KE)_i$, or

$$\frac{1}{2}mv_{1y}^2 + \frac{1}{2}(3m)\left(v_{2x}^2 + v_{2y}^2\right) = \frac{1}{2}mv_0^2 + \frac{1}{2}(3m)v_0^2 \tag{3}$$

Substituting (1) and (2) into (3) yields

$$9v_{2y}^2 + 3\left(\frac{4}{9}v_0^2 + v_{2y}^2\right) = 4v_0^2\text{, or } v_{2y} = v_0\frac{\sqrt{2}}{3}.$$

(a) The particle of mass m has final speed $v_{1y} = 3\,v_{2y} = \boxed{v_0\sqrt{2}}$,

and the particle of mass 3m moves at

$$v_2 = \sqrt{v_{2x}^2 + v_{2y}^2} = \sqrt{\frac{4}{9}v_0^2 + \frac{2}{9}v_0^2} = \boxed{v_0\sqrt{\frac{2}{3}}}.$$

(b) $\theta = \tan^{-1}\left(\frac{v_{2y}}{v_{2x}}\right) = \tan^{-1}\left(\frac{1}{\sqrt{2}}\right) = \boxed{35.3°}$.

6.63 Let particle 1 be the neutron and particle 2 be the carbon nucleus. Then, we are given that $m_2 = 12m_1$.

(a) From conservation of momentum $m_2 v_{2f} + m_1 v_{1f} = m_1 v_{1i} + 0$. Since $m_2 = 12m_1$, this reduces to $12v_{2f} + v_{1f} = v_{1i}$. (1)

For a head-on elastic collision, $v_{2f} + v_{2i} = v_{1f} + v_{1i}$.

Since $v_{2i} = 0$, this becomes $v_{2f} - v_{1f} = v_{1i}$. (2)

Solve (1) and (2) simultaneously to find

$$v_{1f} = -\frac{11}{13}v_{1i}, \text{ and } v_{2f} = \frac{2}{13}v_{1i}.$$

The initial kinetic energy of the neutron is $KE_{1i} = \frac{1}{2}m_1 v_{1i}^2$, and the final kinetic energy of the carbon nucleus is

$$KE_{2f} = \frac{1}{2}m_2 v_{2f}^2 = \frac{1}{2}(12m_1)\left(\frac{4}{169}v_{1i}^2\right) = \frac{48}{169}\left(\frac{1}{2}m_1 v_{1i}^2\right) = \frac{48}{169}KE_{1i}.$$

The fraction of kinetic energy transferred is $\frac{KE_{2f}}{KE_{1i}} = \frac{48}{169} = \boxed{0.28}$.

(b) If $KE_{1i} = 1.6\times10^{-13}$ J, then

$$KE_{2f} = \frac{48}{169}KE_{1i} = \frac{48}{169}\left(1.6\times10^{-13}\text{ J}\right) = \boxed{4.5\times10^{-14}\text{ J}}.$$

The remaining energy 1.6×10^{-13} J – 4.5×10^{-14} J= $\boxed{1.1\times10^{-13}\text{ J}}$ stays with the neutron.

6.64 Choose the positive x-axis in the direction of the initial velocity of the cue ball. Let v_i be the initial speed of the cue ball, v_c be the final speed of the cue ball, v_T be the final speed of the target, and θ be the angle the target's final velocity makes with the x-axis.

Conservation of momentum in the x-direction gives

$$m v_T \cos\theta + m v_c \cos 30.0° = 0 + m v_i \text{, or } v_T \cos\theta = v_i - v_c \cos 30.0° \quad (1)$$

From conservation of momentum in the y-direction,

$$m v_T \sin\theta - m v_c \sin 30.0° = 0 + 0 \text{, or } v_T \sin\theta = v_c \sin 30.0° \quad (2)$$

Since this is an elastic collision, kinetic energy is conserved, giving

$$\frac{1}{2} m v_T^2 + \frac{1}{2} m v_c^2 = \frac{1}{2} m v_i^2 \text{, or } v_T^2 = v_i^2 - v_c^2 \quad (3)$$

(b) To solve, square equations (1) and (2). Then add the results to obtain $v_T^2 = v_i^2 - 2v_i v_c \cos 30.0° + v_c^2$. Substitute this into equation (3) and simplify to find

$$v_c = v_i \cos 30.0° = (4.00 \text{ m/s}) \cos 30.0° = \boxed{3.46 \text{ m/s}}.$$

Then, equation (3) yields $v_T = \sqrt{v_i^2 - v_c^2}$, or

$$v_T = \sqrt{(4.00 \text{ m/s})^2 - (3.46 \text{ m/s})^2} = \boxed{2.00 \text{ m/s}}.$$

(a) With the results found above, equation (2) gives

$$\sin\theta = \left(\frac{v_c}{v_T}\right) \sin 30.0° = \left(\frac{3.46}{2.00}\right) \sin 30.0° = 0.866 \text{, or } \theta = 60.0° .$$

Thus, the angle between the velocity vectors after collision is

$$\phi = 60.0° + 30.0° = \boxed{90.0°}.$$

6.65 The deceleration of the incident block is $a = -\frac{f_k}{m} = -\frac{\mu_k(mg)}{m} = -\mu_k g$.

Therefore, $v^2 = v_i^2 + 2a(\Delta x)$ gives the speed of the incident block just before collision as $v = \sqrt{v_0^2 - 2\,\mu_k g\,d}$.

Conservation of momentum from just before to just after collision gives

$$m v_1 + (2m) v_2 = m v \text{, or } 2 v_2 + v_1 = v \,. \qquad (1)$$

where v_1 and v_2 are the speeds of the two blocks just after collision.

Since this is a head-on elastic collision, $v_{2f} + v_{2i} = v_{1f} + v_{1i}$,

which becomes $v_2 - v_1 = v$. (2)

Adding equations (1) and (2) yields $v_2 = \frac{2}{3} v = \frac{2}{3}\sqrt{v_0^2 - 2\,\mu_k g\,d}$.

Note that the mass canceled in the calculation of the deceleration above. Thus, the second block will have the same deceleration after collision as the incident block had before. Then, $v_f^2 = v_i^2 + 2a(\Delta x)$ with $v_f = 0$ gives the stopping distance for the second block as $0 = v_2^2 + 2(-\mu_k g)D$, or

$$D = \frac{v_2^2}{2\mu_k g} = \frac{2}{9\mu_k g}\left(v_0^2 - 2\,\mu_k g\,d\right) = \boxed{\frac{2v_0^2}{9\mu_k g} - \frac{4d}{9}} .$$

Answers to Even Numbered Conceptual Questions

2. Only if the collision is perfectly head-on. If the two objects collide even slightly off center, a glancing collision will occur and the final velocities will be along lines other than that of the initial motion.

4. No. Only in a precise head-on collision with equal and opposite momentum can both balls wind up at rest. Yes. In the second case, assuming equal masses for each ball, if Ball 2, originally at rest, is struck squarely by Ball 1, then Ball 2 takes off with the velocity of Ball 1. Then Ball 1 is at rest.

6. The skater gains the most momentum by catching and then throwing the frisbee.

8. Kinetic energy can be written as $\frac{p^2}{2m}$. Thus, even through the particles have the same kinetic energies their momenta may be different due to a difference in mass.

10. The resulting collision is intermediate between an elastic and a completely inelastic collision. Some energy of motion is transformed as the pieces buckle, crumple, and heat up during the collision. Also, a small amount is lost as sound. The most kinetic energy is lost in a head-on collision, so the expectation of damage to the passengers is greatest.

12. The less massive object loses the most kinetic energy in the collision.

14. The superhero is at rest before the toss and the net momentum of the system is zero. When he tosses the piano, say toward the right, something must get an equal amount of momentum to the left to keep the momentum at zero. This something recoiling to the left must be Superman. He cannot stay at rest.

16. The passenger must undergo a certain momentum change in the collision. This means that a certain impulse must be exerted on the passenger by the steering wheel, the window, an air bag, or something. By increasing the time during which this momentum change occurs, the resulting force on the passenger can be decreased.

18. A certain impulse is required to stop the egg. But, if the time during which the momentum change of the egg occurs is increased, the resulting force on the egg is reduced. The time is increased as the sheet billows out as the egg is brought to a stop. The force is reduced low enough so that the egg will not break.

Answers to Even Numbered Problems

2. (a) $5.40 \text{ N} \cdot \text{s}$ (b) -27.0 J

4. (a) 0 (b) $1.1 \text{ kg} \cdot \text{m/s}$

6. 1.7 kN

8. $7.00 \times 10^3 \text{ N}$ upward

10. An average force of $6.4 \times 10^3 \text{ N}$ (≈ 1400 lbs) would be required to hold the child.

12. (a) $12.0 \text{ N} \cdot \text{s}$ (b) 6.00 m/s (c) 4.00 m/s

14. (a) -333 N (b) 333 N directed opposite to water flow
(c) 333 N in direction of water flow

16. (a) $6.3 \text{ kg} \cdot \text{m/s}$ toward the pitcher
(b) $3.2 \times 10^3 \text{ N}$ toward the pitcher

18. 62 s

20. (a) 0.49 m/s (b) $2.0 \times 10^{-2} \text{ m/s}$

22. $v_{thrower} = 2.48 \text{ m/s}$, $v_{catcher} = 2.25 \times 10^{-2} \text{ m/s}$

24. (a) $1.0 \times 10^{-5} \text{ m/s}^2$
(b) $1.0 \times 10^{-17} \text{ N}$

26. $\overline{F} = 3.75 \times 10^3 \text{ N}$, no broken bones

28. $5.3 \times 10^2 \text{ m/s}$

30. 143 m/s

32. (a) 20.9 m/s East (b) $8.68 \times 10^3 \text{ J}$ into internal energy

34. (a) 2.2 m/s toward the right (b) No

36. -40.0 cm/s (10.0-g object), $+10.0 \text{ cm/s}$ (15.0-g object)

38. (a) 2.50 m/s (b) $3.75 \times 10^4 \text{ J}$

40. (a) $0,\ 1.50\ \text{m/s}$ (b) $-1.00\ \text{m/s},\ 1.50\ \text{m/s}$
(c) $1.00\ \text{m/s},\ 1.50\ \text{m/s}$

42. (a) $12.4\ \text{m/s}$ at 14.9° N of E (b) 7.20 %

44. No, his speed was $41.5\ \text{mi/h}$.

46. 40.5 g

48. 0.556 m

50. $v_{min} = \left(\dfrac{4M}{m}\right)\sqrt{g l}$

52. 0.960 m above the level of point B

54. $91\ \text{m/s}$

56. (a) $9.90\ \text{m/s},\ -9.90\ \text{m/s}$ (b) $-16.5\ \text{m/s},\ 3.30\ \text{m/s}$
(c) 13.9 m, 0.556 m

58. 0.980 m

60. (a) $v_{red} = 0,\ v_{blue} = 3.00\ \text{m/s}$ (b) 0.212 m

62. (a) $v_m = v_0\sqrt{2},\ v_{3m} = v_0\sqrt{\dfrac{2}{3}}$ (b) 35.3°

64. (a) 90.0° (b) $3.46\ \text{m/s}\ (\text{cue ball}),\ 2.00\ \text{m/s}\ (\text{target})$