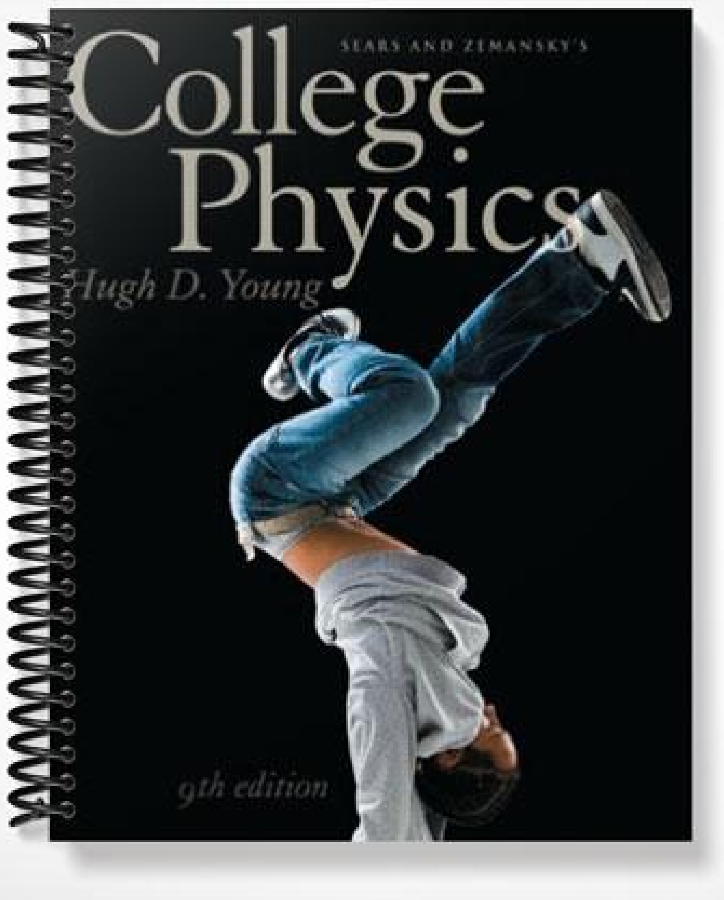
SOLUTIONS MANUAL



2

MOTION ALONG A STRAIGHT LINE

Answers to Multiple-Choice Problems

1. C, D **2.** C **3.** C, D **4.** A, B **5.** D **6.** C **7.** A, D **8.** A **9.** D **10.** C **11.** A **12.** A, C, D
13. B, D **14.** B **15.** C

Solutions to Problems

***2.1. Set Up:** Let the $+x$ direction be to the right in the figure.
Solve: (a) The lengths of the segments determine the distance of each point from O:

$$x_A = -5\text{ cm},\ \ x_B = +45\text{ cm},\ \ x_C = +15\text{ cm},\ \text{and}\ \ x_D = -5\text{ cm}.$$

(b) The displacement is Δx; the sign of Δx indicates its direction. The distance is always positive.

(i) A to B: $\Delta x = x_B - x_A = +45\text{ cm} - (-5\text{ cm}) = +50\text{ cm}$. Distance is 50 cm.

(ii) B to C: $\Delta x = x_C - x_B = +15\text{ cm} - 45\text{ cm} = -30\text{ cm}$. Distance is 30 cm.

(iii) C to D: $\Delta x = x_D - x_C = -5\text{ cm} - 15\text{ cm} = -20\text{ cm}$. Distance is 20 cm.

(iv) A to D: $\Delta x = x_D - x_A = 0$. Distance $= 2(AB) = 100\text{ cm}$.

Reflect: When the motion is always in the same direction during the interval the magnitude of the displacement and the distance traveled are the same. In (iv) the ant travels to the right and then to the left and the magnitude of the displacement is less than the distance traveled.

2.2. Set Up: From the graph the position x_t at each time t is: $x_1 = 1.0\text{ m}$, $x_2 = 0$, $x_3 = -1.0\text{ m}$, $x_4 = 0$, $x_8 = 6.0\text{ m}$, and $x_{10} = 6.0\text{ m}$.
Solve: (a) The displacement is Δx. (i) $\Delta x = x_{10} - x_1 = +5.0\text{ m}$; (ii) $\Delta x = x_{10} - x_3 = +7.0\text{ m}$; (iii) $\Delta x = x_3 - x_2 = -1.0\text{ m}$; (iv) $\Delta x = x_4 - x_2 = 0$.
(b) (i) $3.0\text{ m} + 1.0\text{ m} = 4.0\text{ m}$; 90° (ii) $1.0\text{ m} + 1.0\text{ m} = 2.0\text{ m}$; (iii) zero (stays at $x = 6.0\text{ m}$)

2.3. Set Up: Let the $+x$ direction be to the right. $x_A = 2.0\text{ m}$, $x_B = 7.0\text{ m}$, $x_C = 6.0\text{ m}$.
Solve: Average velocity is

$$v_{\text{av-}x} = \frac{\Delta x}{\Delta t} = \frac{x_C - x_A}{\Delta t} = \frac{+6.0\text{ m} - 2.0\text{ m}}{3.0\text{ s}} = 1.3\text{ m/s}.$$

$$\text{Average speed} = \frac{\text{distance}}{\text{time}} = \frac{4.0\text{ m} + 1.0\text{ m} + 1.0\text{ m}}{3.0\text{ s}} = 2.0\text{ m/s}$$

Reflect: The average speed is greater than the magnitude of the average velocity.

2.4. Set Up: The average velocity is $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t}$, 13.5 days $= 1.166\times10^6$ s, and at the release point $x = +5.150\times10^6$ m.

Solve: (a) $v_{\text{av-}x} = \dfrac{x_2 - x_1}{\Delta t} = \dfrac{0 - 5.150 \times 10^6 \text{ m}}{1.166 \times 10^6 \text{ s}} = -4.42 \text{ m/s}$

(b) For the round-trip, $x_2 = x_1$ and $\Delta x = 0$. The average velocity is zero.

Reflect: The average velocity for the trip from the nest to the release point is positive.

***2.5. Set Up:** $x_A = 0$, $x_B = 3.0$ m, $x_C = 9.0$ m. $t_A = 0$, $t_B = 1.0$ s, $t_C = 5.0$ s.

Solve: (a) $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t}$

$$A \text{ to } B\text{: } v_{\text{av-}x} = \frac{\Delta x}{\Delta t} = \frac{x_B - x_A}{t_B - t_A} = \frac{3.0 \text{ m}}{1.0 \text{ s}} = 3.0 \text{ m/s}$$

$$B \text{ to } C\text{: } v_{\text{av-}x} = \frac{x_C - x_B}{t_C - t_B} = \frac{6.0 \text{ m}}{4.0 \text{ s}} = 1.5 \text{ m/s}$$

$$A \text{ to } C\text{: } v_{\text{av-}x} = \frac{x_C - x_A}{t_C - t_A} = \frac{9.0 \text{ m}}{5.0 \text{ s}} = 1.8 \text{ m/s}$$

(b) The velocity is always in the same direction (+x-direction), so the distance traveled is equal to the displacement in each case, and the average speed is the same as the magnitude of the average velocity.

Reflect: The average speed is different for different time intervals.

2.6. Set Up: $t_A = 0$, $t_B = 3.0$ s, $t_C = 6.0$ s. $x_A = 0$, $x_B = 25.0$ m, $x_C = 0$.

Solve: (a) $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t}$

$$A \text{ to } B\text{: } v_{\text{av-}x} = \frac{\Delta x}{\Delta t} = \frac{x_B - x_A}{t_B - t_A} = \frac{25.0 \text{ m}}{3.0 \text{ s}} = 8.3 \text{ m/s}$$

$$B \text{ to } C\text{: } v_{\text{av-}x} = \frac{x_C - x_B}{t_C - t_B} = \frac{-25.0 \text{ m}}{3.0 \text{ s}} = -8.3 \text{ m/s}$$

$$A \text{ to } C\text{: } v_{\text{av-}x} = \frac{x_C - x_A}{t_C - t_A} = 0$$

(b) For A to B and for B to C the distance traveled equals the magnitude of the displacement and the average speed equals the magnitude of the average velocity. For A to C the displacement is zero. Thus, the average velocity is zero but the distance traveled is not zero so the average speed is not zero. For the motion A to B and for B to C the velocity is always in the same direction but during A to C the motion changes direction.

***2.7. Set Up:** The positions x_t at time t are: $x_0 = 0$, $x_1 = 1.0$ m, $x_2 = 4.0$ m, $x_3 = 9.0$ m, $x_4 = 16.0$ m.

Solve: (a) The distance is $x_3 - x_1 = 8.0$ m.

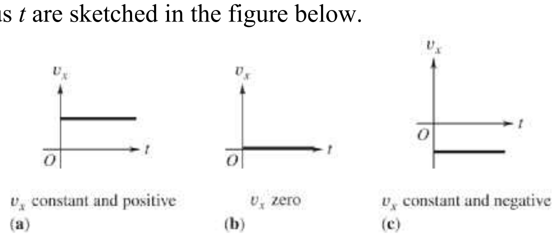
(b) $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t}$. (i) $v_{\text{av},x} = \dfrac{x_1 - x_0}{1.0 \text{ s}} = 1.0 \text{ m/s}$; (ii) $v_{\text{av},x} = \dfrac{x_2 - x_1}{1.0 \text{ s}} = 3.0 \text{ m/s}$; (iii) $v_{\text{av},x} = \dfrac{x_3 - x_2}{1.0 \text{ s}} = 5.0 \text{ m/s}$;

(iv) $v_{\text{av},x} = \dfrac{x_4 - x_3}{1.0 \text{ s}} = 7.0 \text{ m/s}$; (v) $v_{\text{av},x} = \dfrac{x_4 - x_0}{4.0 \text{ s}} = 4.0 \text{ m/s}$

Reflect: In successive 1 s time intervals the boulder travels greater distances and the average velocity for the intervals increases from one interval to the next.

2.8. Set Up: $v_x(t)$ is the slope of the x versus t graph. In each case this slope is constant, so v_x is constant.

Solve: The graphs of v_x versus t are sketched in the figure below.



2.9. Set Up: Let $+x$ be the direction the runner travels. $v_{\text{av},x} = \dfrac{\Delta x}{\Delta t}$. $1 \text{ mi/h} = 1.466 \text{ ft/s} = 0.4470 \text{ m/s}$

Solve: (a) $v_{\text{av},x} = \dfrac{1.00 \text{ mi}}{(4.00 \text{ min})(1 \text{ h}/60 \text{ min})} = 15.0 \text{ mi/h}$

(b) $(15.0 \text{ mi/h})\left(\dfrac{1.466 \text{ ft/s}}{1 \text{ mi/h}}\right) = 22.0 \text{ ft/s}$

(c) $(15.0 \text{ mi/h})\left(\dfrac{0.4470 \text{ m/s}}{1 \text{ mi/h}}\right) = 6.70 \text{ m/s}$

2.10. Set Up: Assume constant speed v, so $d = vt$.

Solve: (a) $t = \dfrac{d}{t} = \dfrac{5.0\times 10^6 \text{ m}}{7(331 \text{ m/s})} = (2158 \text{ s})\left(\dfrac{1 \text{ min}}{60 \text{ s}}\right) = 36 \text{ min}$

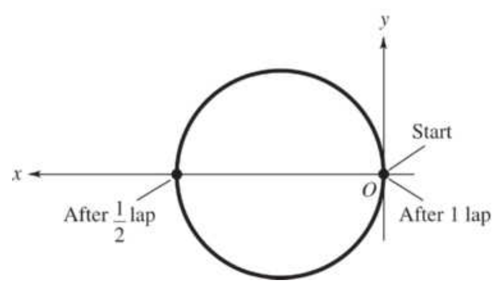
(b) $d = vt = 7(331 \text{ m/s})(11 \text{ s}) = 2.5\times 10^4 \text{ m} = 25 \text{ km}$

***2.11. Set Up:** $1.0 \text{ century} = 100 \text{ yr}$. $1 \text{ km} = 10^5 \text{ cm}$.

Solve: (a) $d = vt = (5.0 \text{ cm/yr})(100 \text{ yr}) = 500 \text{ cm} = 5.0 \text{ m}$

(b) $t = \dfrac{d}{t} = \dfrac{550\times 10^5 \text{ cm}}{5.0 \text{ cm/yr}} = 1.1\times 10^7 \text{ yr}$

2.12. Set Up: The distance around the circular track is $d = \pi(40.0 \text{ m}) = 126 \text{ m}$. For a half-lap, $d = 63 \text{ m}$. Use coordinates for which the origin is at her starting point and the x-axis is along a diameter, as shown in the figure below.



Solve: (a) After one lap she has returned to her starting point. Thus, $\Delta x = 0$ and $v_{\text{av},x} = 0$.

$$\text{average speed} = \frac{d}{t} = \frac{126 \text{ m}}{62.5 \text{ s}} = 2.01 \text{ m/s}$$

(b) $\Delta x = 40.0 \text{ m}$ and $v_{\text{av},x} = \dfrac{\Delta x}{\Delta t} = \dfrac{40.0 \text{ m}}{28.7 \text{ s}} = 1.39 \text{ m/s}$; average speed $= \dfrac{d}{t} = \dfrac{63 \text{ m}}{28.7 \text{ s}} = 2.20 \text{ m/s}$

2.13. Set Up: Since sound travels at a constant speed, $\Delta x = v_x \Delta t$; also, from the appendix we find that 1 mile is 1.609 km.

Solve: $\Delta x = (344 \text{ m/s})(7.5 \text{ s})\left(\dfrac{1 \text{ mi}}{1.609\times 10^3 \text{ m}}\right) = 1.6 \text{ mi}$

Reflect: The speed of sound is $(344 \text{ m/s})\left(\dfrac{1 \text{ mi}}{1.609\times 10^3 \text{ m}}\right) \approx \dfrac{1}{5} \text{ mi/s}$

2.14. Solve: (a) $t = \dfrac{d}{v}$. touch: $t = \dfrac{1.85 \text{ m}}{76.2 \text{ m/s}} = 0.0243 \text{ s}$; pain: $t = \dfrac{1.85 \text{ m}}{0.610 \text{ m/s}} = 3.03 \text{ s}$

(b) The difference between the two times in (a) is 3.01 s.

***2.15. Set Up:** The velocity of the truck relative to the road is equal to the velocity of the truck relative to me plus my velocity relative to the road: $v_{\text{T/R}} = v_{\text{T/M}} + v_{\text{M/R}}$. Assume that all numbers are good to two significant figures.

Solve: (a) As seen by me, the truck moves *backwards* 25 meters during 5.5 seconds. Thus, the truck's velocity relative to me is $v_{\text{T/M}} = \dfrac{-25\text{ m}}{5.5\text{ s}} = -\underline{4.5}5\text{ m/s}$. My velocity relative to the road is $v_{\text{M/R}} = (110\text{ km/h})(1000\text{ m/km})(1\text{ h}/3600\text{ s}) = \underline{30}.6\text{ m/s}$.

Thus, the velocity of the truck relative to the road is $v_{\text{T/R}} = v_{\text{T/M}} + v_{\text{M/R}} = -\underline{4.5}5\text{ m/s} + \underline{30}.6\text{ m/s} = 26\text{ m/s}$.

(b) The distance the truck moves (relative to the road) is $\Delta x = (26\text{ m/s})(5.5\text{ s}) = \underline{14}3\text{ m} = 1.4\times10^2\text{ m}$.

Reflect: Note that the distance that I move is $(30.6\text{ m/s})(5.5\text{ s}) = \underline{16}8\text{ m}$, which is 25 meters further than the distance that the truck travels.

2.16. Set Up: Since we know the position of the mouse as a function of time, we can compute its average velocity from $\upsilon_{\text{av},x} = \dfrac{\Delta x}{\Delta t}$.

Solve: Calculate the position of the mouse at $t = 0$ s; $t = 1.0$ s; and $t = 4.0$ s:

$$x(0\text{ s}) = 0$$

$$x(1.0\text{ s}) = (8.5\text{ cm}\cdot\text{s}^{-1})(1.0\text{ s}) - (2.5\text{ cm}\cdot\text{s}^{-2})(1.0\text{ s})^2 = 6.0\text{ cm}$$

$$x(4.0\text{ s}) = (8.5\text{ cm}\cdot\text{s}^{-1})(4.0\text{ s}) - (2.5\text{ cm}\cdot\text{s}^{-2})(4.0\text{ s})^2 = -6.0\text{ cm}$$

The average velocities of the mouse from 0 to 1 second and from 0 to 4 seconds are (respectively)

$$\upsilon_{\text{av},x} = \frac{\Delta x}{\Delta t} = \frac{6.0\text{ cm} - 0}{1.0\text{ s}} = 6.0\text{ cm/s};\quad \upsilon_{\text{av},x} = \frac{\Delta x}{\Delta t} = \frac{-6.0\text{ cm} - 0}{4.0\text{ s}} = -1.5\text{ cm/s}.$$

Reflect: Since the average velocity of the mouse changes sign, the mouse must have turned around. The x versus t graph for the mouse, which is an inverted parabola, also shows that the mouse reverses direction.

***2.17. Set Up:** Use the normal driving time to find the distance. Use this distance to find the time on Friday.

Solve: $\Delta x = \upsilon_{\text{av},x}\,\Delta t = (105\text{ km/h})(1.33\text{ h}) = 140\text{ km}$. Then on Friday $\Delta t = \dfrac{\Delta x}{\upsilon_{\text{av},x}} = \dfrac{140\text{ km}}{70\text{ km/h}} = 2.00\text{ h}$. The increase in time is $2.00\text{ h} - 1.33\text{ h} = 0.67\text{ h} = 40\text{ min}$.

Reflect: A smaller average speed corresponds to a longer travel time when the distance is the same.

2.18. Set Up: Let d be the distance A runs in time t. Then B runs a distance $200.0\text{ m} - d$ in the same time t.

Solve: $d = \upsilon_A t$ and $200.0\text{ m} - d = \upsilon_B t$. Combine these two equations to eliminate d. $200.0\text{ m} - \upsilon_A t = \upsilon_B t$ and $t = \dfrac{200.0\text{ m}}{8.0\text{ m/s} + 7.0\text{ m/s}} = 13.3\text{ s}$. Then $d = (8.0\text{ m/s})(13.3\text{ s}) = 106\text{ m}$; they will meet 106 m from where A starts.

***2.19. Set Up:** The instantaneous velocity is the slope of the tangent to the x versus t graph.

Solve: (a) The velocity is zero where the graph is horizontal; point IV.

(b) The velocity is constant and positive where the graph is a straight line with positive slope; point I.

(c) The velocity is constant and negative where the graph is a straight line with negative slope; point V.

(d) The slope is positive and increasing at point II.

(e) The slope is positive and decreasing at point III.

2.20. Set Up: The instantaneous velocity at any point is the slope of the x versus t graph at that point. Estimate the slope from the graph.

Solve: A: $\upsilon_x = 6.7$ m/s; B: $\upsilon_x = 6.7$ m/s; C: $\upsilon_x = 0$; D: $\upsilon_x = -40.0$ m/s; E: $\upsilon_x = -40.0$ m/s; F: $\upsilon_x = -40.0$ m/s; G: $\upsilon_x = 0$.

Reflect: The sign of υ_x shows the direction the car is moving. υ_x is constant when x versus t is a straight line.

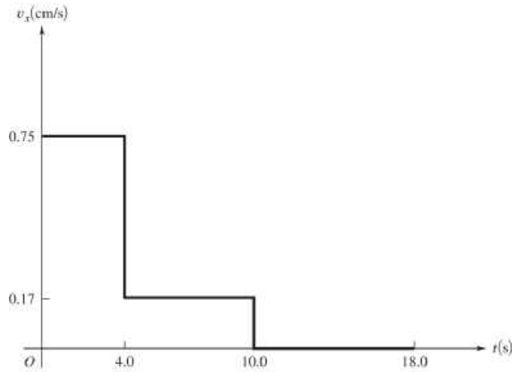
2.21. Set Up: Values of x_t at time t can be read from the graph: $x_0 = 0$, $x_4 = 3.0$ cm, $x_{10} = 4.0$ cm, and $x_{18} = 4.0$ cm. υ_x is constant when x versus t is a straight line.

Solve: The motion consists of constant velocity segments.

$$t=0 \text{ to } 4.0\text{ s: } \upsilon_x=\frac{3.0\text{ cm}-0}{4.0\text{ s}}=0.75\text{ cm/s;}$$

$$t=4.0\text{ s to } 10.0\text{ s: } \upsilon_x=\frac{4.0\text{ cm}-3.0\text{ cm}}{6.0\text{ s}}=0.17\text{ cm/s; } t=10.0\text{ s to } 18.0\text{ s: } \upsilon_x=0.$$

The graph of υ_x versus t is shown in the figure below.



Reflect: υ_x is the slope of x versus t.

2.22. Set Up: The instantaneous acceleration is the slope of the υ_x versus t graph.

Solve: $t=3$ s: The graph is horizontal, so $a_x=0$.

$t=7$ s: The graph is a straight line with slope $\dfrac{44\text{ m/s}-20\text{ m/s}}{4\text{ s}}=6.0\text{ m/s}^2$; $a_x=6.0\text{ m/s}^2$.

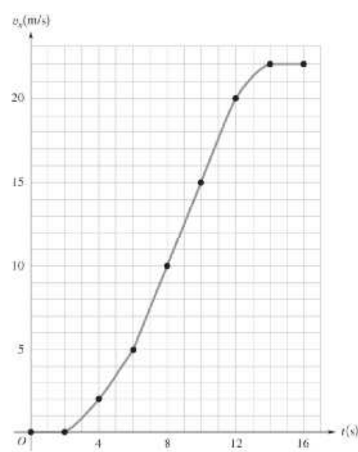
$t=11$ s: The graph is a straight line with slope $\dfrac{0-44\text{ m/s}}{4\text{ s}}=-11\text{ m/s}^2$; $a_x=-11\text{ m/s}^2$.

2.23. Set Up: $a_{\text{av},x}=\dfrac{\Delta\upsilon_x}{\Delta t}$

Solve: (a) 0 s to 2 s: $a_{\text{av},x}=0$; 2 s to 4 s: $a_{\text{av},x}=1.0\text{ m/s}^2$; 4 s to 6 s: $a_{\text{av},x}=1.5\text{ m/s}^2$; 6 s to 8 s: $a_{\text{av},x}=2.5\text{ m/s}^2$; 8 s to 10 s: $a_{\text{av},x}=2.5\text{ m/s}^2$; 10 s to 12 s: $a_{\text{av},x}=2.5\text{ m/s}^2$; 12 s to 14 s: $a_{\text{av},x}=1.0\text{ m/s}^2$; 14 s to 16 s: $a_{\text{av},x}=0$.

The acceleration is not constant over the entire 16 s time interval. The acceleration is constant between 6 s and 12 s.

(b) The graph of υ_x versus t is given in the figure below. $t=9$ s: $a_x=2.5\text{ m/s}^2$; $t=13$ s: $a_x=1.0\text{ m/s}^2$; $t=15$ s: $a_x=0$.



Reflect: The acceleration is constant when the velocity changes at a constant rate. When the velocity is constant, the acceleration is zero.

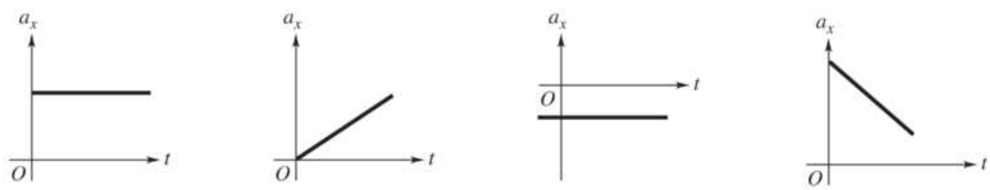
2.24. Set Up: 1 ft = 0.3048 m. $g = 9.8\ \text{m/s}^2$.

Solve: (a) $5g = 49\ \text{m/s}^2$ and $5g = (49\ \text{m/s}^2)\left(\dfrac{1\ \text{ft}}{0.3048\ \text{m}}\right) = 160\ \text{ft/s}^2$

(b) $60g = 590\ \text{m/s}^2$ and $60g = (590\ \text{m/s}^2)\left(\dfrac{1\ \text{ft}}{0.3048\ \text{m}}\right) = 1900\ \text{ft/s}^2$

(c) $(1.67\ \text{m/s}^2)\left(\dfrac{1g}{9.8\ \text{m/s}^2}\right) = 0.17g$ **(d)** $\left(24.3\ \text{m/s}^2\right)\left(\dfrac{1g}{9.8\ \text{m/s}^2}\right) = 2.5g$

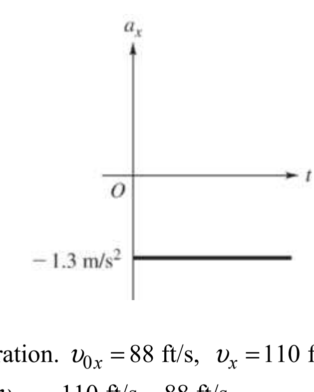
***2.25. Set Up:** The acceleration a_x equals the slope of the v_x versus t curve.
Solve: The qualitative graphs of acceleration as a function of time are given in the figure below.



(a) (b) (c) (d)

The acceleration can be described as follows: (**a**) positive and constant, (**b**) positive and increasing, (**c**) negative and constant, (**d**) positive and decreasing.
Reflect: When $\boldsymbol{v}_x$ and a_x have the same sign then the speed is increasing. In **(c)** the velocity and acceleration have opposite signs and the speed is decreasing.

2.26. Set Up: The acceleration a_x is the slope of the graph of v_x versus t.
Solve: (a) Reading from the graph, at $t = 4.0$ s, $v_x = 2.7$ cm/s, to the right and at $t = 7.0$ s, $v_x = 1.3$ cm/s, to the left.
(b) v_x versus t is a straight line with slope $-\dfrac{8.0\ \text{cm/s}}{6.0\ \text{s}} = -1.3\ \text{cm/s}^2$. The acceleration is constant and equal to $1.3\ \text{cm/s}^2$, to the left.
(c) The graph of a_x versus t is given in the figure below.



***2.27. Set Up:** Assume constant acceleration. $v_{0x} = 88$ ft/s, $v_x = 110$ ft/s, and $t = 3.50$ s. Let $x_0 = 0$.

Solve: (a) $v_x = v_{0x} + a_x t$ and $a_x = \dfrac{v_x - v_{0x}}{t} = \dfrac{110\ \text{ft/s} - 88\ \text{ft/s}}{3.50\ \text{s}} = 6.3\ \text{ft/s}^2$.

(b) $x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2 = (88\ \text{ft/s})(3.50\ \text{s}) + \frac{1}{2}(6.3\ \text{ft/s}^2)(3.50\ \text{s})^2 = 347\ \text{ft}$

2.28. Set Up: 1 mph = 0.4470 m/s and 1 m = 3.281 ft. Let $x_0 = 0$. $\upsilon_{0x} = 0$, $t = 2.0$ s, and $\upsilon_x = 45$ mph = 20.1 m/s.

(a) $\upsilon_x = \upsilon_{0x} + a_x t$ and $a_x = \dfrac{\upsilon_x - \upsilon_{0x}}{t} = \dfrac{20.1\text{ m/s} - 0}{2.0\text{ s}} = 10\text{ m/s}^2$

$$a_x = (10\text{ m/s}^2)\left(\frac{3.281\text{ ft}}{1\text{ m}}\right) = 33\text{ ft/s}^2$$

(b) $x = x_0 + \upsilon_{0x}t + \frac{1}{2}a_x t^2 = \frac{1}{2}(10\text{ m/s}^2)(2.0\text{ s})^2 = 20$ m, or $x = \frac{1}{2}(33\text{ ft/s}^2)(2.0\text{ s})^2 = 66$ ft

***2.29. Set Up:** Take the $+y$ direction to be upward. For part (a) we assume that the cat is in freefall with $a_y = -\text{g}$. Since the cat falls a known distance, we can find its final velocity using $v_y{}^2 = v_{0y}{}^2 + 2a_y(y - y_0)$. For parts (b) and (c) we assume that the cat has a constant (but unknown) acceleration due to its interaction with the floor. We may use the equations for constant acceleration.

Solve: (a) Solving for v_y we obtain

$$v_y = \pm\sqrt{v_{0y}{}^2 + 2a_y(y - y_0)}$$

Here we set $\Delta y = (-4.0\text{ ft})(1\text{ m}/3.28\text{ ft}) = -1.\underline{22}$ m, $a_y = -\text{g}$, and $v_y = 0$.

$$\begin{aligned} v_y &= -\sqrt{v_{0y}{}^2 + 2a_y(y - y_0)} \\ &= -\sqrt{-2\text{g}(-1.\underline{22}\text{ m})} = -4.\underline{89}\text{ m/s} = -4.9\text{ m/s}. \end{aligned}$$

Where we choose the negative root since the cat is falling. The *speed* of the cat just before impact is the magnitude of its velocity, which is 4.9 m/s.

(b) During its impact with the floor, the cat is brought to rest over a distance of 12 cm. Thus, we have $v_{0y} = -4.\underline{89}$ m/s, $v_y = 0$, and $\Delta y = -0.12$ m. Solving $\Delta y = \frac{1}{2}(v_y + v_{0y})t$ for time we obtain:

$$t = \frac{2\Delta y}{(v_y + v_{0y})} = \frac{2(-0.12\text{ m})}{(0 + -4.\underline{89}\text{ m/s})} = 0.049\text{ s}.$$

(c) Solving $v_y{}^2 = v_{0y}{}^2 + 2a_y(y - y_0)$ for a_y we obtain $a_y = \dfrac{(v_y{}^2 - v_{0y}{}^2)}{2\Delta y} = \dfrac{0^2 - (-4.\underline{89}\text{ m/s})^2}{2(-0.12\text{ m})} = \underline{99}.6\text{ m/s}^2$. Since this answer is only accurate to two significant figures, we can write it as $1.0\times10^2\text{ m/s}^2$ or approximately 10 g's.

Reflect: During freefall the cat has a negative velocity and a negative acceleration—so it is speeding up. In contrast, during impact with the ground the cat has a negative velocity and a positive acceleration—so it is slowing down.

2.30. Set Up: Let $+x$ be in his direction of motion. Assume constant acceleration. **(a)** $\upsilon_x = 3(331\text{ m/s}) = 993$ m/s, $\upsilon_{0x} = 0$, and $a_x = 5g = 49.0\text{ m/s}^2$. **(b)** $t = 5.0$ s

Solve: (a) $\upsilon_x = \upsilon_{0x} + a_x t$ and $t = \dfrac{\upsilon_x - \upsilon_{0x}}{a_x} = \dfrac{993\text{ m/s} - 0}{49.0\text{ m/s}^2} = 20.3$ s

Yes, the time required is larger than 5.0 s.

(b) $\upsilon_x = \upsilon_{0x} + a_x t = 0 + (49.0\text{ m/s}^2)(5.0\text{ s}) = 245$ m/s

2.31. Set Up: Assume the ball starts from rest and moves in the $+x$-direction. We may use the equations for constant acceleration.

Solve: (a) $x - x_0 = 1.50$ m, $v_x = 45.0$ m/s and $v_{0x} = 0$. Using $v_x{}^2 = v_{0x}{}^2 + 2a_x(x - x_0)$ gives

$a_x = \dfrac{v_x{}^2 - v_{0x}{}^2}{2(x - x_0)} = \dfrac{(45.0\text{ m/s})^2}{2(1.50\text{ m})} = 675\text{ m/s}^2.$

(b) Using $x - x_0 = \left(\dfrac{v_{0x} + v_x}{2}\right)t$ gives $t = \dfrac{2(x - x_0)}{v_{0x} + v_x} = \dfrac{2(1.50\text{ m})}{45.0\text{ m/s}} = 0.0667$ s

Reflect: We could also use $v_x = v_{0x} + a_x t$ to find $t = \frac{v_x}{a_x} = \frac{45.0 \text{ m/s}}{675 \text{ m/s}^2} = 0.0667 \text{ s}$, which agrees with our previous result. The acceleration of the ball is very large.

2.32. Set Up: Let $+x$ be the direction the jet travels and take $x_0 = 0$. $a_x = 4g = 39.2 \text{ m/s}^2$, $\upsilon_x = 4(331 \text{ m/s}) = 1324 \text{ m/s}$, and $v_{0x} = 0$.

Solve: (a) $\upsilon_x = \upsilon_{0x} + a_x t$ and $t = \frac{\upsilon_x - \upsilon_{0x}}{a_x} = \frac{1324 \text{ m/s} - 0}{39.2 \text{ m/s}^2} = 33.8 \text{ s}$

(b) $x = x_0 + \upsilon_{0x}t + \frac{1}{2}a_x t^2 = \frac{1}{2}(39.2 \text{ m/s}^2)(33.8 \text{ s})^2 = 2.24 \times 10^4 \text{ m} = 22.4 \text{ km}$

2.33. Set Up: Let $+x$ be the direction the person travels. $\upsilon_x = 0$ (stops), $t = 36 \text{ ms} = 3.6 \times 10^{-2} \text{ s}$, $a_x = -60g = -588 \text{ m/s}^2$. a_x is negative since it is opposite to the direction of the motion.

Solve: $\upsilon_x = \upsilon_{0x} + a_x t$ so $\upsilon_{0x} = -a_x t$. Then $x = x_0 + \upsilon_{0x}t + \frac{1}{2}a_x t^2$ gives $x = -\frac{1}{2}a_x t^2$.

$$x = -\tfrac{1}{2}(-588 \text{ m/s}^2)(3.6 \times 10^{-2} \text{ s})^2 = 38 \text{ cm}$$

Reflect: We could also find the initial speed: $\upsilon_{0x} = -a_x t = -(-588 \text{ m/s}^2)(36 \times 10^{-3} \text{ s}) = 21 \text{ m/s} = 47 \text{ mph}$

2.34. Set Up: Take the $+x$ direction to be the direction of motion of the boulder.

Solve: (a) Use the motion during the first second to find the acceleration. $\upsilon_{0x} = 0$, $x_0 = 0$, $x = 2.00 \text{ m}$, and $t = 1.00 \text{ s}$.

$$x = x_0 + \upsilon_{0x}t + \tfrac{1}{2}a_x t^2 \text{ and } a_x = \frac{2x}{t^2} = \frac{2(2.00 \text{ m})}{(1.00 \text{ s})^2} = 4.00 \text{ m/s}^2$$

$$\upsilon_x = \upsilon_{0x} + a_x t = (4.00 \text{ m/s}^2)(1.00 \text{ s}) = 4.00 \text{ m/s}$$

For the second second, $\upsilon_{0x} = 4.00 \text{ m/s}$, $a_x = 4.00 \text{ m/s}^2$, and $t = 1.00 \text{ s}$.

$$x = x_0 + \upsilon_{0x}t + \tfrac{1}{2}a_x t^2 = (4.00 \text{ m/s})(1.00 \text{ s}) + \tfrac{1}{2}(4.00 \text{ m/s}^2)(1.00 \text{ s})^2 = 6.00 \text{ m}$$

We can also solve for the location at $t = 2.00 \text{ s}$, starting at $t = 0$:

$$x = x_0 + \upsilon_{0x}t + \tfrac{1}{2}a_x t^2 = \tfrac{1}{2}(4.00 \text{ m/s}^2)(2.00 \text{ s})^2 = 8.00 \text{ m},$$

which agrees with 2.00 m in the first second and 6.00 m in the second second. The boulder speeds up so it travels farther in each successive second.

(b) We have already found $\upsilon_x = 4.00 \text{ m/s}$ after the first second. After the second second,

$$\upsilon_x = \upsilon_{0x} + a_x t = 4.00 \text{ m/s} + (4.00 \text{ m/s}^2)(1.00 \text{ s}) = 8.00 \text{ m/s}$$

***2.35. Set Up:** Let $+x$ be in the direction of motion of the bullet. $\upsilon_{0x} = 0$, $x_0 = 0$, $\upsilon_x = 335 \text{ m/s}$, and $x = 0.127 \text{ m}$.

Solve: (a) $\upsilon_x^2 = \upsilon_{0x}^2 + 2a_x(x - x_0)$ and

$$a_x = \frac{\upsilon_x^2 - \upsilon_{0x}^2}{2(x - x_0)} = \frac{(335 \text{ m/s})^2 - 0}{2(0.127 \text{ m})} = 4.42 \times 10^5 \text{ m/s}^2 = 4.51 \times 10^4 g$$

(b) $\upsilon_x = \upsilon_{0x} + a_x t$ so $t = \frac{\upsilon_x - \upsilon_{0x}}{a_x} = \frac{335 \text{ m/s} - 0}{4.42 \times 10^5 \text{ m/s}^2} = 0.758 \text{ ms}$

Reflect: The acceleration is very large compared to g. In **(b)** we could also use $(x - x_0) = \left(\frac{\upsilon_{0x} + \upsilon_x}{2}\right)t$ to calculate $t = \frac{2(x - x_0)}{\upsilon_x} = \frac{2(0.127 \text{ m})}{335 \text{ m/s}} = 0.758 \text{ ms}$

2.36. Set Up: Take $+x$ in the direction to be in the direction the airplane travels. $\upsilon_{0x} = 0$. $(x - x_0) = 280 \text{ m}$.

Solve: $(x - x_0) = \left(\frac{\upsilon_{0x} + \upsilon_x}{2}\right)t$ gives $v_x = \frac{2(x - x_0)}{t} = \frac{2(280 \text{ m})}{8.00 \text{ s}} = 70.0 \text{ m/s}$

***2.37. Set Up:** Let $+x$ be the direction the car is moving. We can use the equations for constant acceleration.

Solve: (a) From Eq. (2.13), with $v_{0x} = 0$, $a_x = \frac{v_x^2}{2(x - x_0)} = \frac{(20 \text{ m/s})^2}{2(120 \text{ m})} = 1.67 \text{ m/s}^2$.

(b) Using Eq. (2.14), $t = 2(x - x_0)/v_x = 2(120 \text{ m})/(20 \text{ m/s}) = 12 \text{ s}$.

(c) $(12 \text{ s})(20 \text{ m/s}) = 240 \text{ m}$.

Reflect: The average velocity of the car is half the constant speed of the traffic, so the traffic travels twice as far.

2.38. Set Up: $1 \text{ mi/h} = 1.466 \text{ ft/s}$. The car travels at constant speed during the reaction time. Let $+x$ be the direction the car is traveling, so $a_x = -12.0 \text{ ft/s}^2$ after the brakes are applied.

Solve: (a) $\upsilon_{0x} = (15.0 \text{ mi/h})\left(\frac{1.466 \text{ ft/s}}{1 \text{ mi/h}}\right) = 22.0 \text{ ft/s}$. During the reaction time the car travels a distance of (22.0 ft/s) $(0.7 \text{ s}) = 15.4 \text{ ft}$.

For the motion after the brakes are applied, $\upsilon_{0x} = 22.0 \text{ ft/s}$, $a_x = -12.0 \text{ ft/s}^2$, and $\upsilon_x = 0$. $\upsilon_x^2 = \upsilon_{0x}^2 + 2a_x(x - x_0)$ gives $(x - x_0) = \frac{\upsilon_x^2 - \upsilon_{0x}^2}{2a_x} = \frac{0 - (22.0 \text{ ft/s})^2}{2(-12.0 \text{ ft/s}^2)} = 20.2 \text{ ft}$.

The total distance is $15.4 \text{ ft} + 20.2 \text{ ft} = 35.6 \text{ ft}$.

(b) $\upsilon_{0x} = (55.0 \text{ mi/h})\left(\frac{1.466 \text{ ft/s}}{1 \text{ mi/h}}\right) = 80.6 \text{ ft/s}$. A calculation similar to that of part **(a)** gives a total stopping distance of $(x - x_0) = 56.4 \text{ ft} + 270.7 \text{ ft} = 327 \text{ ft}$.

***2.39. Set Up:** $0.250 \text{ mi} = 1320 \text{ ft}$. $60.0 \text{ mph} = 88.0 \text{ ft/s}$. Let $+x$ be the direction the car is traveling.

Solve: (a) braking: $\upsilon_{0x} = 88.0 \text{ ft/s}$, $x - x_0 = 146 \text{ ft}$, $\upsilon_x = 0$. $\upsilon_x^2 = \upsilon_{0x}^2 + 2a_x(x - x_0)$ gives

$$a_x = \frac{\upsilon_x^2 - \upsilon_{0x}^2}{2(x - x_0)} = \frac{0 - (88.0 \text{ ft/s})^2}{2(146 \text{ ft})} = -26.5 \text{ ft/s}^2$$

Speeding up: $\upsilon_{0x} = 0$, $x - x_0 = 1320 \text{ ft}$, $t = 19.9 \text{ s}$. $x - x_0 = \upsilon_{0x}t + \frac{1}{2}a_x t^2$ gives

$$a_x = \frac{2(x - x_0)}{t^2} = \frac{2(1320 \text{ ft})}{(19.9 \text{ s})^2} = 6.67 \text{ ft/s}^2$$

(b) $\upsilon_x = \upsilon_{0x} + a_x t = 0 + (6.67 \text{ ft/s}^2)(19.9 \text{ s}) = 133 \text{ ft/s} = 90.5 \text{ mph}$

(c) $t = \frac{\upsilon_x - \upsilon_{0x}}{a_x} = \frac{0 - 88.0 \text{ ft/s}}{-26.5 \text{ ft/s}^2} = 3.32 \text{ s}$

Reflect: The magnitude of the acceleration while braking is much larger than when speeding up. That is why it takes much longer to go from 0 to 60 mph than to go from 60 mph to 0.

2.40. Set Up: Let $+x$ be the direction the train is traveling. Find $x - x_0$ for each segment of the motion.

Solve: $t = 0$ to 14.0 s: $x - x_0 = \upsilon_{0x}t + \frac{1}{2}a_x t^2 = \frac{1}{2}(1.60 \text{ m/s}^2)(14.0 \text{ s})^2 = 157 \text{ m}$. At $t = 14.0 \text{ s}$, the speed is

$$\upsilon_x = \upsilon_{0x} + a_x = (1.60 \text{ m/s}^2)(14.0 \text{ s}) = 22.4 \text{ m/s}.$$

In the next 70.0 s, $a_x = 0$ and $x - x_0 = \upsilon_{0x}t = (22.4 \text{ m/s})(70.0 \text{ s}) = 1568 \text{ m}$. For the interval during which the train is slowing down, $\upsilon_{0x} = 22.4 \text{ m/s}$, $a_x = -3.50 \text{ m/s}^2$ and $\upsilon_x = 0$. $\upsilon_x^2 = \upsilon_{0x}^2 + 2a_x(x - x_0)$ gives

$$x - x_0 = \frac{\upsilon_x^2 - \upsilon_{0x}^2}{2a_x} = \frac{0 - (22.4 \text{ m/s})^2}{2(-3.50 \text{ m/s}^2)} = 72 \text{ m}.$$

The total distance traveled is $157 \text{ m} + 1568 \text{ m} + 72 \text{ m} = 1800 \text{ m}$.

2.41. Set Up: $A = \pi r^2$ and $C = 2\pi r$, where r is the radius.

Solve: $\dfrac{A_1}{r_1^2} = \dfrac{A_2}{r_2^2}$ and $A_2 = \left(\dfrac{r_2}{r_1}\right)^2 A_1 = \left(\dfrac{2r_1}{r_1}\right)^2 A = 4A$

$$\frac{C_1}{r_1} = \frac{C_2}{r_2} \text{ and } C_2 = \left(\frac{r_2}{r_1}\right)C_1 = \left(\frac{2r_1}{r_1}\right)C = 2C$$

2.42. Set Up: Let L be the length of each side of the cube. The cube has 6 faces of area L^2, so $A = 6L^2$. $V = L^3$.

Solve: $\dfrac{A_1}{L_1^2} = \dfrac{A_2}{L_2^2}$ and $A_2 = \left(\dfrac{L_2}{L_1}\right)^2 A_1 = \left(\dfrac{3L_1}{L_1}\right)^2 A_1 = 9A_1$; surface area increases by a factor of 9.

$\dfrac{V_1}{L_1^3} = \dfrac{V_2}{L_2^3}$ and $V_2 = \left(\dfrac{L_2}{L_1}\right)^3 V_1 = \left(\dfrac{3L_1}{L_1}\right)^3 V_1 = 27V_1$; volume increases by a factor of 27.

***2.43. Set Up:** The volume of a cylinder of radius R and height H is given by $V = \pi R^2 H$. We know the ratio of the heights of the two tanks and their volumes. From this information we can determine the ratio of their radii.

Solve: We take the ratio of the volumes of the two tanks: $\dfrac{V_{\text{large}}}{V_{\text{small}}} = \dfrac{218}{150} = \dfrac{\pi R_{\text{large}}^2 H_{\text{large}}}{\pi R_{\text{small}}^2 H_{\text{small}}} = 1.20\left(\dfrac{R_{\text{large}}}{R_{\text{small}}}\right)^2$, where we have used $\dfrac{H_{\text{large}}}{H_{\text{small}}} = 1.20$. Solving for the ratio of the radii we obtain $\dfrac{R_{\text{large}}}{R_{\text{small}}} = \sqrt{\left(\dfrac{1}{1.20}\right)\left(\dfrac{218}{150}\right)} = 1.10$. Thus, the larger radius is 10% larger than the smaller radius.

Reflect: All of the ratios used are dimensionless, and independent of the units used for measurement.

2.44. Set Up: Assuming that the point guard and center have the same density, the ratio of their masses will be the ratio of their volumes. The volume of a rectangular solid of length l, height h, and width w is given by $V = lhw$. If each linear dimension of the solid is increased by a factor of k, its volume will be increased by a factor of k^3 since $(kl)(kh)(kw) = k^3 lhw$. This result is general and applies to objects of any shape, provided that all of its linear dimensions are increased by the same factor k.

Solve: First convert the height of each player to inches: the height of the point guard is 70 inches and the height of the center is 86 inches. Assume that each dimension is increased by a factor of $\left(\dfrac{86}{70}\right)$. Thus we have

$$\frac{\text{mass of center}}{175 \text{ lbs}} = \frac{\text{volume of center}}{\text{volume of point guard}} = \left(\frac{86}{70}\right)^3$$

Solving for the mass of the center we obtain

$$\text{mass of center} = (175 \text{ lbs})\left(\frac{86}{70}\right)^3 = 325 \text{ lbs.}$$

Reflect: If we double all of the dimensions of an object, its volume is increased by a factor of $2^3 = 8$ and its surface area is increased by a factor of $2^2 = 4$. If the density of the object remains fixed, its mass will also increase by a factor of 8.

***2.45. Set Up:** $a_A = a_B$, $x_{0A} = x_{0B} = 0$, $v_{0x,A} = v_{0x,B} = 0$, and $t_A = 2t_B$.

Solve: **(a)** $x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2$ gives $x_A = \frac{1}{2}a_A t_A^2$ and $x_B = \frac{1}{2}a_B t_B^2$. $a_A = a_B$ gives $\dfrac{x_A}{t_A^2} = \dfrac{x_B}{t_B^2}$ and

$$x_B = \left(\frac{t_B}{t_A}\right)^2 x_A = \left(\tfrac{1}{2}\right)^2 (250 \text{ km}) = 62.5 \text{ km}$$

(b) $v_x = v_{0x} + a_x t$ gives $a_A = \dfrac{v_A}{t_A}$ and $a_B = \dfrac{v_B}{t_B}$. Since $a_A = a_B$, $\dfrac{v_A}{t_A} = \dfrac{v_B}{t_B}$ and

$$v_B = \left(\frac{t_B}{t_A}\right) v_A = \left(\tfrac{1}{2}\right)(350\ \text{m/s}) = 175\ \text{m/s}.$$

Reflect: v_x is proportional to t and for $v_{0x} = 0$, x is proportional to t^2.

2.46. Set Up: $a_A = 3a_B$ and $v_{0A} = v_{0B}$. Let $x_{0A} = x_{0B} = 0$. Since cars stop, $v_A = v_B = 0$.

Solve: (a) $v_x{}^2 = v_{0x}{}^2 + 2a_x(x - x_0)$ gives $a_A x_A = a_B x_B$, and $x_B = \left(\dfrac{a_A}{a_B}\right) x_A = 3D$

(b) $v_x = v_{0x} + a_x t$ gives $a_A t_A = a_B t_B$, so $t_A = \left(\dfrac{a_B}{a_A}\right) t_B = \tfrac{1}{3}T$

2.47. Set Up: $v_{0A} = v_{0B} = 0$. Let $x_{0A} = x_{0B} = 0$. $a_A = a_B$ and $v_B = 2v_A$.

Solve: (a) $v_x{}^2 = v_{0x}{}^2 + 2a_x(x - x_0)$ gives $a_x = \dfrac{v_x{}^2 - v_{0x}{}^2}{2(x - x_0)}$ and $\dfrac{v_A{}^2}{x_A} = \dfrac{v_B{}^2}{x_B}$.

$$x_B = \left(\frac{v_B}{v_A}\right)^2 x_A = 4(500\ \text{m}) = 2000\ \text{m}$$

(b) $v_x = v_{0x} + a_x t$ gives $a_x = \dfrac{v_x}{t}$. $\dfrac{v_A}{t_A} = \dfrac{v_B}{t_B}$ and $t_B = \left(\dfrac{v_B}{v_A}\right) t_A = 2T$.

Reflect: x is proportional to $v_x{}^2$ and t is proportional to v_x.

2.48. Set Up: Let $+y$ be upward. $a_y = -9.80\ \text{m/s}^2$. $v_y = 0$ at the maximum height.

Solve: (a) $y - y_0 = 0.220$ m, $a_y = -9.80\ \text{m/s}^2$, $v_y = 0$. $v_y{}^2 = v_{0y}{}^2 + 2a_y(y - y_0)$ gives

$$v_{0y} = \sqrt{-2a_y(y - y_0)} = \sqrt{-2(-9.80\ \text{m/s}^2)(0.220\ \text{m})} = 2.08\ \text{m/s}.$$

(b) When the flea returns to ground, $v_y = -v_{0y}$. $v_y = v_{0y} + a_y t$ gives

$$t = \frac{v_y - v_{0y}}{a_y} = \frac{-2.08\ \text{m/s} - 2.08\ \text{m/s}}{-9.80\ \text{m/s}^2} = 0.424\ \text{s}$$

(c) $a = 9.80\ \text{m/s}^2$, downward, at all points in the motion.

2.49. Set Up: Let $+y$ be downward. $a_y = 9.80\ \text{m/s}^2$

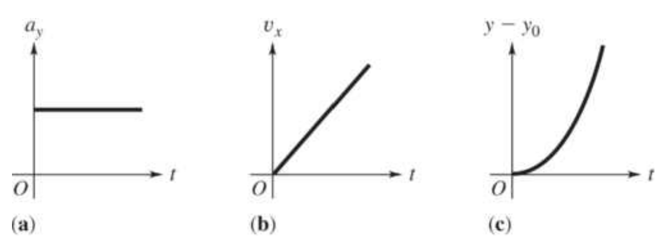
Solve: (a) $v_{0y} = 0$, $t = 2.50$ s, $a_y = 9.80\ \text{m/s}^2$.

$$y - y_0 = v_{0y}t + \tfrac{1}{2}a_y t^2 = \tfrac{1}{2}(9.80\ \text{m/s}^2)(2.50\ \text{s})^2 = 30.6\ \text{m}.$$

The building is 30.6 m tall.

(b) $v_y = v_{0y} + a_y t = 0 + (9.80\ \text{m/s}^2)(2.50\ \text{s}) = 24.5\ \text{m/s}$

(c) The graphs of a_y, v_y, and y versus t are given in the figure below. Take $y = 0$ at the ground.



2.50. Set Up: Take $+y$ to be downward and $y_0 = 0$. $y = 14{,}600$ ft, $v_{0y} = 0$, and $a_y = 32$ ft/s^2.

Solve: (a) $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$ and $t = \sqrt{\frac{2y}{a_y}} = \sqrt{\frac{2(14{,}600 \text{ ft})}{32 \text{ ft/s}^2}} = 30.2$ s

(b) $v_y = v_{0y} + a_y t = (32 \text{ ft/s}^2)(30.2 \text{ s}) = 966 \text{ ft/s} = 659$ mph

(c) It is a poor assumption to neglect air resistance and aerodynamic lift.

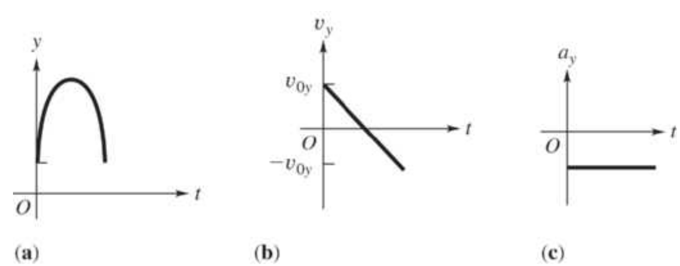
***2.51. Set Up:** Take $+y$ upward. $v_y = 0$ at the maximum height. $a_y = -0.379g = -3.71$ m/s^2.

Solve: Consider the motion from the maximum height back to the initial level. For this motion $v_{0y} = 0$ and $t = 4.25$ s. $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2 = \frac{1}{2}(-3.71 \text{ m/s}^2)(4.25 \text{ s})^2 = -33.5$ m

The ball went 33.5 m above its original position.

(b) Consider the motion from just after it was hit to the maximum height. For this motion $v_y = 0$ and $t = 4.25$ s. $v_y = v_{0y} + a_y t$ gives $v_{0y} = -a_y t = -(-3.71 \text{ m/s}^2)(4.25 \text{ s}) = 15.8$ m/s.

(c) The graphs are sketched in the figure below.



Reflect: The answers can be checked several ways. For example, $v_y = 0$, $v_{0y} = 15.8$ m/s, and $a_y = -3.7$ m/s^2 in $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

$$y - y_0 = \frac{v_y^2 - v_{0y}^2}{2a_y} = \frac{0 - (15.8 \text{ m/s})^2}{2(-3.71 \text{ m/s}^2)} = 33.6 \text{ m},$$

which agrees with the height calculated in **(a)**.

2.52. Set Up: Take $+y$ to be downward. $v_{0y} = 0$ and let $y_0 = 0$.

Solve: (a) $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$ gives $a_y = \frac{2y}{t^2} = \frac{2(11.26 \text{ m})}{(3.17 \text{ s})^2} = 2.24 \text{ m/s}^2 = 0.229g$

(b) $v_y = v_{0y} + a_y t = (2.24 \text{ m/s}^2)(3.17 \text{ s}) = 7.10$ m/s

***2.53. Set Up:** Take $+y$ upward. $a_y = -9.80$ m/s^2. The initial velocity of the sandbag equals the velocity of the balloon, so $v_{0y} = +5.00$ m/s. When the balloon reaches the ground, $y - y_0 = -40.0$ m. At its maximum height the sandbag has $v_y = 0$.

Solve: (a) $t = 0.250$ s:

$$y - y_0 = v_{0y}t + \tfrac{1}{2}a_y t^2 = (5.00 \text{ m/s})(0.250 \text{ s}) + \tfrac{1}{2}(-9.80 \text{ m/s}^2)(0.250 \text{ s})^2 = 0.94 \text{ m}.$$

The sandbag is 40.9 m above the ground.

$$v_y = v_{0y} + a_y t = +5.00 \text{ m/s} + (-9.80 \text{ m/s}^2)(0.250 \text{ s}) = 2.55 \text{ m/s}.$$

$t = 1.00$ s:

$$y - y_0 = (5.00 \text{ m/s})(1.00 \text{ s}) + \tfrac{1}{2}(-9.80 \text{ m/s}^2)(1.00 \text{ s})^2 = 0.10 \text{ m}.$$

The sandbag is 40.1 m above the ground.

$$v_y = v_{0y} + a_y t = +5.00\text{ m/s} + (-9.80\text{ m/s}^2)(1.00\text{ s}) = -4.80\text{ m/s}.$$

(b) $y - y_0 = -40.0$ m, $v_{0y} = 5.00$ m/s, $a_y = -9.80\text{ m/s}^2$. $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ gives $-40.0\text{ m} = (5.00\text{ m/s})\ t - (4.90\text{ m/s}^2)t^2$. $(4.90\text{ m/s}^2)t^2 - (5.00\text{ m/s})t - 40.0\text{ m} = 0$ and

$$t = \frac{1}{9.80}\left(5.00 \pm \sqrt{(-5.00)^2 - 4(4.90)(-40.0)}\right)\text{ s} = (0.51 \pm 2.90)\text{ s}.$$

t must be positive, so $t = 3.41$ s.

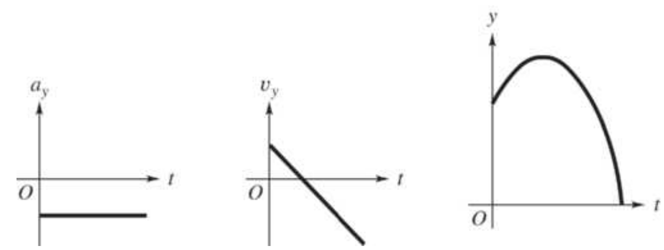
(c) $v_y = v_{0y} + a_y t = +5.00\text{ m/s} + (-9.80\text{ m/s}^2)(3.41\text{ s}) = -28.4\text{ m/s}$

(d) $v_{0y} = 5.00$ m/s, $a_y = -9.80\text{ m/s}^2$, $v_y = 0$. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

$$y - y_0 = \frac{v_y^2 - v_{0y}^2}{2a_y} = \frac{0 - (5.00\text{ m/s})^2}{2(-9.80\text{ m/s}^2)} = 1.28\text{ m}.$$

The maximum height is 41.3 m above the ground.

(e) The graphs of a_y, v_y, and y versus t are given in the figure below. Take $y = 0$ at the ground.



2.54. Set Up: Take $+y$ upward.

(a) Set Up: Consider the motion from when he applies the acceleration to when the shot leaves his hand: $v_{0y} = 0$, $v_y = ?$, $a_y = 45.0\text{ m/s}^2$, $y - y_0 = 0.640$ m. Use $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$.

Solve: $v_y = \sqrt{2a_y(y - y_0)} = \sqrt{2(45.0\text{ m/s}^2)(0.640\text{ m})} = 7.59\text{ m/s}$

(b) Set Up: Consider the motion of the shot from the point where he releases it to its maximum height, where $v = 0$. Take $y = 0$ at the ground. $y_0 = 2.20$ m, $y = ?$, $a_y = -9.80\text{ m/s}^2$ (free fall), $v_{0y} = 7.59$ m/s [from part **(a)**], and $v_y = 0$ at maximum height. Use $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$.

Solve: $y - y_0 = \dfrac{v_y^2 - v_{0y}^2}{2a_y} = \dfrac{0 - (7.59\text{ m/s})^2}{2(-9.80\text{ m/s}^2)} = 2.94\text{ m}$

Thus, $y = 2.20\text{ m} + 2.94\text{ m} = 5.14\text{ m}$.

(c) Set Up: Consider the motion of the shot from the point where he releases it to when it returns to the height of his head. Take $y = 0$ at the ground. $y_0 = 2.20$ m, $y = 1.83$ m, $a_y = -9.80\text{ m/s}^2$, $v_{0y} = +7.59$ m/s, $t = ?$. Use $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$.

Solve: $1.83\text{ m} - 2.20\text{ m} = (7.59\text{ m/s})t + \frac{1}{2}(-9.80\text{ m/s}^2)t^2 = (7.59\text{ m/s})t - (4.90\text{ m/s}^2)t^2$

$4.90t^2 - 7.59t - 0.37 = 0$, with t in seconds.

Use the quadratic formula to solve for t:

$$t = \frac{1}{9.80}\left(7.59 \pm \sqrt{(7.59)^2 - 4(4.90)(-0.37)}\right) = 0.774 \pm 0.822$$

Note that t must be positive, so $t = 0.774\text{ s} + 0.822\text{ s} = 1.60\text{ s}$

Reflect: Calculate the time to the maximum height: $v_y = v_{0y} + a_y t$, so $t = (v_y - v_{0y})/a_y = -(7.59\text{ m/s})/(-9.80\text{ m/s}^2) =$ 0.77 s. It also takes 0.77 s to return to 2.2 m above the ground, for a total time of 1.54 s. His head is a little lower than 2.20 m, so it is reasonable for the shot to reach the level of his head a little later than 1.54 s after being thrown; the answer of 1.60 s in part **(c)** makes sense.

***2.55. Set Up:** $a_M = 0.170 a_E$. Take $+y$ to be upward and $y_0 = 0$.

Solve: (a) $\upsilon_{0E} = \upsilon_{0M}$. $\upsilon_y^2 = \upsilon_{0y}^2 + 2a_y(y - y_0)$ with $\upsilon_y = 0$ at the maximum height gives $2a_y y = -\upsilon_{0y}^2$, so $a_M y_M = a_E y_E$.

$$y_M = \left(\frac{a_E}{a_M}\right) y_E = \left(\frac{1}{0.170}\right)(12.0\text{ m}) = 70.6\text{ m}$$

(b) Consider the time to the maximum height on the earth. The total travel time is twice this. First solve for υ_{0y}, with $\upsilon_y = 0$ and $y = 12.0$ m. $\upsilon_y^2 = \upsilon_{0y}^2 + 2a_y(y - y_0)$ gives

$$\upsilon_{0y} = \sqrt{-2(-a_E)y} = \sqrt{-2(-9.8\text{ m/s}^2)(12.0\text{ m})} = 15.3\text{ m/s}.$$

Then $\upsilon_y = \upsilon_{0y} + a_y t$ gives

$$t = \frac{\upsilon_y - \upsilon_{0y}}{a_y} = \frac{0 - 15.3\text{ m/s}}{-9.8\text{ m/s}^2} = 1.56\text{ s}.$$

The total time is $2(1.56\text{ s}) = 3.12$ s. Then, on the moon $\upsilon_y = \upsilon_{0y} + a_y t$ with $\upsilon_{0y} = 15.3$ m/s, $\upsilon_y = 0$, and $a = -1.666\text{ m/s}^2$ gives

$$t = \frac{\upsilon_y - \upsilon_{0y}}{a_y} = \frac{0 - 15.3\text{ m/s}}{-1.666\text{ m/s}^2} = 9.18\text{ s}.$$

The total time is 18.4 s. It takes 15.3 s longer on the moon.

Reflect: The maximum height is proportional to $1/a$, so the height on the moon is greater. Since the acceleration is the rate of change of the speed, the wrench loses speed at a slower rate on the moon and it takes more time for its speed to reach $\upsilon = 0$ at the maximum height. In fact, $t_M/t_E = a_E/a_M = 1/0.170 = 5.9$, which agrees with our calculated times. But to find the difference in the times we had to solve for the actual times, not just their ratios.

2.56. Set Up: Take $+y$ downward. $a_y = +9.80\text{ m/s}^2$.

Solve: (a) $\upsilon_y = \upsilon_{0y} + a_y t = 15.0\text{ m/s} + (9.80\text{ m/s}^2)(2.00\text{ s}) = 34.6\text{ m/s}$

(b) $y - y_0 = \upsilon_{0y} t + \frac{1}{2} a_y t^2 = (15.0\text{ m/s})(2.00\text{ s}) + \frac{1}{2}(9.80\text{ m/s}^2)(2.00\text{ s})^2 = 49.6\text{ m}$

(c) $\upsilon_y^2 = \upsilon_{0y}^2 + 2a_y(y - y_0)$ gives $\upsilon_y = \sqrt{(15.0\text{ m/s})^2 + 2(9.80\text{ m/s}^2)(10.0\text{ m})} = 20.5\text{ m/s}$

2.57. Set Up: Take $+y$ upward. $a_y = -9.80\text{ m/s}^2$. When the rock reaches the ground, $y - y_0 = -60.0$ m.

Solve: (a) $y - y_0 = \upsilon_{0y} t + \frac{1}{2} a_y t^2$ gives $-60.0\text{ m} = (12.0\text{ m/s})t - (4.9\text{ m/s}^2)t^2$. $(4.90\text{ m/s}^2)t^2 - (12.0\text{ m/s})t - 60.0\text{ m} = 0$ and

$$t = \frac{1}{9.80}\left(12.0 \pm \sqrt{(-12.0)^2 - 4(4.90)(-60.0)}\right)\text{ s} = (1.22 \pm 3.71)\text{ s}.$$

t must be positive, so $t = 4.93$ s.

(b) $\upsilon_y^2 = \upsilon_{0y}^2 + 2a_y(y - y_0)$ gives $\upsilon_y = -\sqrt{(12.0\text{ m/s})^2 + 2(-9.80\text{ m/s}^2)(-60.0\text{ m})} = -36.3\text{ m/s}$.

Reflect: We could have taken downward to be $+y$. Then $y - y_0$, υ_y, and a_y are all positive, but υ_{0y} is negative. The same results are obtained with this alternative choice of coordinates.

2.58. Set Up: Take $+x$ to be in the direction the sled travels. 1610 km/h = 447 m/s. 1020 km/h = 283 m/s. Assume the acceleration is constant.

Solve: (a) $v_{0x} = 0$. $v_x = v_{0x} + a_x t$ gives $a_x = \frac{v_x - v_{0x}}{t} = \frac{447\text{ m/s} - 0}{1.80\text{ s}} = 248\text{ m/s}^2 = 25.3g$

(b) $(x - x_0) = \left(\frac{v_{0x} + v_x}{2}\right)t = \left(\frac{447\text{ m/s}}{2}\right)(1.80\text{ s}) = 402\text{ m}$

(c) Solve for a_x and compare to 40g. $v_x = 0$.

$$a_x = \frac{v_x - v_{0x}}{t} = \frac{0 - 283\text{ m/s}}{1.40\text{ s}} = -202\text{ m/s}^2 = -20.6g.$$

The figures are inconsistent, if the acceleration while stopping is constant. The acceleration while stopping could reach 40*g* if the acceleration wasn't constant.

***2.59. Set Up:** Use subscripts f and s to refer to the faster and slower stones, respectively. Take $+y$ to be upward and $y_0 = 0$ for both stones. $v_{0\text{f}} = 3v_{0\text{s}}$. When a stone reaches the ground, $y = 0$.

Solve: (a) $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$ gives $a_y = -\frac{2v_{0y}}{t}$. Since both stones have the same a_y, $\frac{v_{0\text{f}}}{t_\text{f}} = \frac{v_{0\text{s}}}{t_\text{s}}$ and

$$t_\text{s} = t_\text{f}\left(\frac{v_{0\text{s}}}{v_{0\text{f}}}\right) = \left(\tfrac{1}{3}\right)10\text{ s} = 3.3\text{ s}$$

(b) Since $v_y = 0$ at the maximum height, then $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $a_y = -\frac{v_{0y}^2}{2y}$. Since both have the same a_y, $\frac{v_{0\text{f}}^2}{y_\text{f}} = \frac{v_{0\text{s}}^2}{y_\text{s}}$ and $y_\text{f} = y_\text{s}\left(\frac{v_{0\text{f}}}{v_{0\text{s}}}\right)^2 = 9H$.

Reflect: The faster stone reaches a greater height so it travels a greater distance than the slower stone and takes more time to return to the ground.

2.60. Set Up: Take $+y$ to be downward and $y_0 = 0$. Both coconuts have the same acceleration, $a_y = g$. Let *A* be the coconut that falls from the greater height and let *B* be the other coconut. $y_A = 2y_B$. $v_{0A} = v_{0B} = 0$.

Solve: (a) $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $a_y = \frac{v_y^2}{2y}$ and $\frac{v_A^2}{y_A} = \frac{v_B^2}{y_B}$. $v_B = v_A\sqrt{\frac{y_B}{y_A}} = V\sqrt{\frac{1}{2}} = V/\sqrt{2}$

(b) $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$ gives $a_y = \frac{2y}{t^2}$ and $\frac{y_A}{t_A^2} = \frac{y_B}{t_B^2}$. $t_A = t_B\sqrt{\frac{y_A}{y_B}} = \sqrt{2}T$

***2.61. Set Up:** $\vec{v}_{\text{T/E}} = 65$ mph, north. $\vec{v}_{\text{VW/E}} = 42$ mph, south. Let $+y$ be north.

Solve: $\vec{v}_{\text{T/E}} = \vec{v}_{\text{T/VW}} + \vec{v}_{\text{VW/E}}$ and $\vec{v}_{\text{T/VW}} = \vec{v}_{\text{T/E}} - \vec{v}_{\text{VW/E}}$

(a) $(v_{\text{T/VW}})_y = (v_{\text{T/E}})_y - (v_{\text{VW/E}})_y = 65\text{ mph} - (-42\text{ mph}) = 107\text{ mph}$. Relative to the VW, the Toyota is traveling north at 107 mph. $\vec{v}_{\text{VW/T}} = -\vec{v}_{\text{T/VW}}$. Relative to the Toyota the VW is traveling south at 107 mph.

(b) The answers are the same as in **(**a**)**.

2.62. Set Up: A = air, E = eagle, G = ground. $\vec{v}_{\text{A/G}} = 35$ mph, east.

Solve: $\vec{v}_{\text{E/G}} = \vec{v}_{\text{E/A}} + \vec{v}_{\text{A/G}}$

(a) $\vec{v}_{\text{E/A}} = 22$ mph, east. $\vec{v}_{\text{E/A}}$ and $\vec{v}_{\text{A/G}}$ are both east and $v_{\text{E/G}} = v_{\text{E/A}} + v_{\text{A/G}} = 57$ mph. $\vec{v}_{\text{E/G}}$ is east.

(b) $\vec{v}_{\text{E/A}} = 22$ mph, west. $\vec{v}_{\text{E/A}}$ and $\vec{v}_{\text{A/G}}$ are in opposite directions and $v_{\text{E/G}} = v_{\text{A/G}} - v_{\text{E/A}} = 13$ mph. $\vec{v}_{\text{E/G}}$ is east.

2.63. Set Up: Use coordinates with $+y$ downward. Relative to the earth the package has $v_{0y} = +3.50\text{ m/s}$ and $a_y = 9.80\text{ m/s}^2$.

Solve: The velocity of the package relative to the ground just before it hits is

$$v_y = \sqrt{v_{0y}^2 + 2a_y(y - y_0)} = \sqrt{(3.50\text{ m/s})^2 + 2(9.80\text{ m/s}^2)(8.50\text{ m})} = 13.4\text{ m/s}$$

(a) $\vec{v}_{\text{P/G}} = 13.4\text{ m/s},$ downward. $\vec{v}_{\text{H/G}} = 3.50\text{ m/s},$ downward. $\vec{v}_{\text{P/G}} = \vec{v}_{\text{P/H}} + \vec{v}_{\text{H/G}}$ and $\vec{v}_{\text{P/H}} = \vec{v}_{\text{P/G}} - \vec{v}_{\text{H/G}}$.
$\vec{v}_{\text{P/H}} = 9.9\text{ m/s},$ downward.

(b) $\vec{v}_{\text{H/P}} = -\vec{v}_{\text{P/H}},$ so $\vec{v}_{\text{H/P}} = 9.9\text{ m/s},$ upward.

Reflect: Since the helicopter is traveling downward, the package is moving slower relative to the helicopter than its speed relative to the ground.

2.64. Set Up: $\vec{v}_{\text{P/A}} = 600\text{ mph}$ and is east for the first 200 mi and west for the return 200 mi. The time is the distance relative to the ground divided by the speed relative to the ground.

Solve: $\vec{v}_{\text{P/E}} = \vec{v}_{\text{P/A}} + \vec{v}_{\text{A/E}}$

(a) $v_{\text{A/E}} = 0$ and $v_{\text{P/E}} = 600\text{ mph}.$ $t = \dfrac{4000\text{ mi}}{600\text{ mi/h}} = 6.67\text{ h}$

(b) San Francisco to Chicago: $\vec{v}_{\text{A/E}} = 150\text{ mph},$ east. $\vec{v}_{\text{P/A}} = 600\text{ mph},$ east.

$$v_{\text{P/E}} = v_{\text{P/A}} + v_{\text{A/E}} = 750\text{ mph}.\quad t = \frac{2000\text{ mi}}{750\text{ mi/h}} = 2.67\text{ h}$$

Chicago to San Francisco: $\vec{v}_{\text{A/E}} = 150\text{ mph},$ east. $\vec{v}_{\text{P/A}} = 600\text{ mph},$ west.

$$v_{\text{P/E}} = v_{\text{P/A}} - v_{\text{A/E}} = 450\text{ mph}.\quad t = \frac{2000\text{ mi}}{450\text{ mi/h}} = 4.44\text{ h}$$

The total time is $2.67\text{ h} + 4.44\text{ h} = 7.11\text{ h}$.

***2.65. Set Up:** 1 light year $= (3.00\times10^8\text{ m/s})(3.156\times10^7\text{ s}) = 9.47\times10^{15}\text{ m}$

Solve: $t = \dfrac{d}{v} = \dfrac{(4.25\text{ light years})(9.47\times10^{15}\text{ m/light year})}{1000\times10^3\text{ m/s}} = 4.02\times10^{10}\text{ s} = 1300\text{ yr}$

2.66. Set Up: At $t = 0$ the auto and truck are at the same position. The auto overtakes the truck when after time T they have both traveled a distance d.

Solve: (a) Apply $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$ to the motion of each vehicle. The auto has $v_{0x} = 0$ and $a_x = 2.50\text{ m/s}^2,$ so $d = \frac{1}{2}(2.50\text{ m/s}^2)T^2$. The truck has $v_{0x} = 15.0\text{ m/s}$ and $a_x = 0,$ so $d = (15.0\text{ m/s})T$. Combining these two equations gives $(1.25\text{ m/s}^2)T^2 = (15.0\text{ m/s})T$ and $T = 12.0\text{ s}$. Then $d = (15.0\text{ m/s})(12.0\text{ s}) = 180\text{ m}$.

(b) $v_x = v_{0x} + a_x t = 0 + (2.50\text{ m/s}^2)(12.0\text{ s}) = 30.0\text{ m/s}$

***2.67. Set Up:** The average speed is the total distance traveled divided by the total time. The elapsed time is the distance traveled divided by the average speed. The total distance traveled is 20 mi. With an average speed of 8 mi/h for 10 mi, the time for that first 10 miles is $\dfrac{10\text{ mi}}{8\text{ mi/h}} = 1.25\text{ h}$.

Solve: (a) An average speed of 4 mi/h for 20 mi gives a total time of $\dfrac{20\text{ mi}}{4\text{ mi/h}} = 5.0\text{ h}$. The second 10 mi must be covered in $5.0\text{ h} - 1.25\text{ h} = 3.75\text{ h}$. This corresponds to an average speed of $\dfrac{10\text{ mi}}{3.75\text{ h}} = 2.7\text{ mi/h}$.

(b) An average speed of 12 mi/h for 20 mi gives a total time of $\frac{20\text{ mi}}{12\text{ mi/h}} = 1.67\text{ h}$. The second 10 mi must be covered in $1.67\text{ h} - 1.25\text{ h} = 0.42\text{ h}$. This corresponds to an average speed of $\frac{10\text{ mi}}{0.42\text{ h}} = 24\text{ mi/h}$.

(c) An average speed of 16 mi/h for 20 mi gives a total time of $\frac{20\text{ mi}}{16\text{ mi/h}} = 1.25\text{ h}$. But 1.25 h was already spent during the first 10 miles and the second 10 miles would have to be covered in zero time. This is not possible and an average speed of 16 mi/h for the 20-mile ride is not possible.

Reflect: The average speed for the total trip is not the average of the average speeds for each 10-mile segment. The rider spends a different amount of time traveling at each of the two average speeds.

2.68. Set Up: Both you and your friend run at a steady pace over the 10 km race so the equation $\Delta x = v_x t$ applies. You can calculate the time that it takes for your friend to complete the race and then subtract 15 minutes (900 seconds) to obtain the time that you need to achieve your goal. The race is 10 km, which is 1.0×10^4 m.

Solve: The time your friend takes to complete the race is $t = \frac{\Delta x}{v_x} = \frac{1.0\times10^4\text{ m}}{2.5\text{ m/s}} = 4.0\times10^3\text{ s}$. Thus, you need to complete the race in $4.0\times10^3\text{ s} - 900\text{ s} = 3.1\times10^3\text{ s}$. The required speed to do this is $v_x = \frac{\Delta x}{t} = \frac{1.0\times10^4\text{ m}}{3.1\times10^3\text{ s}} = 3.2\text{ m/s}$.

Reflect: If your friend had a 15-minute head start, this is also the speed that you would need to just catch up at the end of the race.

***2.69. Set Up:** Let $+y$ to be upward and $y_0 = 0$. $a_M = a_E/6$. At the maximum height $v_y = 0$.

Solve: (a) $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$. Since $v_y = 0$ and v_{0y} is the same for both rocks, $a_M y_M = a_E y_E$ and

$$y_E = \left(\frac{a_M}{a_E}\right) y_M = H/6$$

(b) $v_y = v_{0y} + a_y t$. $a_M t_M = a_E t_E$ and $t_M = \left(\frac{a_E}{a_M}\right) t_E = 6(4.0\text{ s}) = 24.0\text{ s}$

Reflect: On the moon, where the acceleration is less, the rock reaches a greater height and takes more time to reach that maximum height.

2.70. Set Up: Let $+y$ to be downward. $v_{0y} = 2.0\text{ m/s}$, $v_y = 1.3\text{ m/s}$, and $y - y_0 = 0.020\text{ m}$.

Solve: (a) $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

$$a_y = \frac{v_y^2 - v_{0y}^2}{2(y - y_0)} = \frac{(1.3\text{ m/s})^2 - (2.0\text{ m/s})^2}{2(0.020\text{ m})} = -58\text{ m/s}^2 = -5.9g$$

(b) $y - y_0 = \left(\frac{v_{0y} + v_y}{2}\right) t$ gives $t = \frac{2(y - y_0)}{v_{0y} + v_y} = \frac{2(0.020\text{ m})}{2.0\text{ m/s} + 1.3\text{ m/s}} = 12\text{ ms}$

2.71. Set Up: $v_{0x} = 0$, $v_x = 5.0\times10^3\text{ m/s}$, and $x - x_0 = 4.0\text{ m}$

Solve: (a) $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ gives

$$a_x = \frac{v_x^2 - v_{0x}^2}{2(x - x_0)} = \frac{(5.0\times10^3\text{ m/s})^2}{2(4.0\text{ m})} = 3.1\times10^6\text{ m/s}^2 = 3.2\times10^5 g$$

(b) $v_x = v_{0x} + a_x t$ gives $t = \frac{v_x - v_{0x}}{a_x} = \frac{5.0\times10^3\text{ m/s}}{3.1\times10^6\text{ m/s}^2} = 1.6\text{ ms}$

(c) The calculated a is less than $450{,}000g$ so the acceleration required doesn't rule out this hypothesis.

2.72. Set Up: Assume an initial height of 200 m and a constant acceleration of $9.80\ \text{m/s}^2$. Let $+y$ be downward, $1\ \text{km/h} = 0.2778\ \text{m/s}$ and $1\ \text{mi/h} = 0.4470\ \text{m/s}$.

Solve: (a) $y - y_0 = 200\ \text{m}$, $a_y = 9.80\ \text{m/s}^2$, $v_{0y} = 0$. $v_y{}^2 = v_{0y}{}^2 + 2a_y(y - y_0)$ gives $v_y = \sqrt{2(9.80\ \text{m/s}^2)(200\ \text{m})} =$ $60\ \text{m/s} = 200\ \text{km/h} = 140\ \text{mi/h}$.
(b) Raindrops actually have a speed of about 1 m/s as they strike the ground.
(c) The actual speed at the ground is much less than the speed calculated assuming free-fall, so neglect of air resistance is a very poor approximation for falling raindrops.
Reflect: In the absence of air resistance raindrops would land with speeds that would make them very dangerous.

***2.73. Set Up:** Let $+y$ be downward. The egg has $v_{0y} = 0$ and $a_y = 9.80\ \text{m/s}^2$. Find the distance the professor walks during the time t it takes the egg to fall to the height of his head. At this height, the egg has $y - y_0 = 44.2\ \text{m}$.
Solve: $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ gives

$$t = \sqrt{\frac{2(y - y_0)}{a_y}} = \sqrt{\frac{2(44.2\ \text{m})}{9.80\ \text{m/s}^2}} = 3\ .00\ \text{s}.$$

The professor walks a distance $x - x_0 = v_{0x}t = (1.20\ \text{m/s})(3.00\ \text{s}) = 3.60\ \text{m}$. Release the egg when your professor is 3.60 m from the point directly below you.
Reflect: Just before the egg lands its speed is $(9.80\ \text{m/s}^2)(3.00\ \text{s}) = 29.4\ \text{m/s}$. It is traveling much faster than the professor.

2.74. Set Up: Let $+x$ be in the direction down the incline. The final velocity for the first 10.0 s is the initial speed for the second 10.0 s of motion.
Solve: For the first 10.0 s of motion $v_{0x} = 0$ and $v_x = a_x(10.0\ \text{s})$. For the second 10.0 s of motion, $v_{0x} = a_x(10.0\ \text{s})$, $x - x_0 = 150\ \text{m}$ and $t = 10.0\ \text{s}$. $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$ gives $150\ \text{m} = (10.0\ \text{m/s})^2 a_x + \frac{1}{2}a_x(10.0\ \text{m/s})^2 = 150.0a_x$ and $a_x = 1.0\ \text{m/s}^2$. Then for the first 5.0 s, $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2 = 0 + \frac{1}{2}(1.00\ \text{m/s}^2)(5.0\ \text{s})^2 = 12.5\ \text{m}$.

***2.75. Set Up:** Since air resistance is ignored, the boulder is in free-fall and has a constant downward acceleration of magnitude $9.80\ \text{m/s}^2$. Apply the constant acceleration equations to the motion of the boulder. Take $+y$ to be upward.
Solve: (a) $v_{0y} = +40.0\ \text{m/s}$, $v_y = +20.0\ \text{m/s}$, $a_y = -9.80\ \text{m/s}^2$. $v_y = v_{0y} + a_y t$ gives

$$t = \frac{v_y - v_{0y}}{a_y} = \frac{20.0\ \text{m/s} - 40.0\ \text{m/s}}{-9.80\ \text{m/s}^2} = +2.04\ \text{s}.$$

(b) $v_y = -20.0\ \text{m/s}$. $t = \dfrac{v_y - v_{0y}}{a_y} = \dfrac{-20.0\ \text{m/s} - 40.0\ \text{m/s}}{-9.80\ \text{m/s}^2} = +6.12\ \text{s}.$

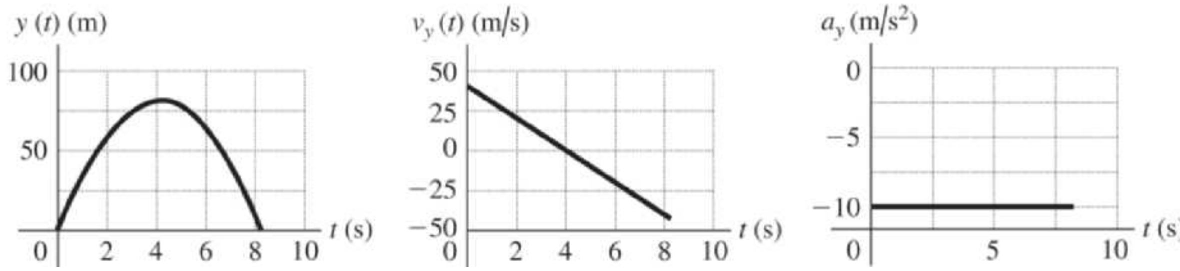
(c) $y - y_0 = 0$, $v_{0y} = +40.0\ \text{m/s}$, $a_y = -9.80\ \text{m/s}^2$. $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ gives $t = 0$ and

$$t = -\frac{2v_{0y}}{a_y} = -\frac{2(40.0\ \text{m/s})}{-9.80\ \text{m/s}^2} = +8.16\ \text{s}.$$

(d) $v_y = 0$, $v_{0y} = +40.0\ \text{m/s}$, $a_y = -9.80\ \text{m/s}^2$. $v_y = v_{0y} + a_y t$ gives $t = \dfrac{v_y - v_{0y}}{a_y} = \dfrac{0 - 40.0\ \text{m/s}}{-9.80\ \text{m/s}^2} = 4.08\ \text{s}.$

(e) The acceleration is $9.80\ \text{m/s}^2$, downward, at all points in the motion.
(f) The graphs are sketched in the following figure.

Reflect: We have $v_y = 0$ at the maximum height. The time to reach the maximum height is half the total time in the air, so the answer in part (d) is half the answer in part **(c)**. Also note that $2.04\text{ s} < 4.08\text{ s} < 6.12\text{ s}$. The boulder is going upward until it reaches its maximum height, and after the maximum height it is traveling downward.



2.76. Set Up: Take $+x$ to be the direction the car moves when speeding up. Use the acceleration and stopping data to find a in each case. $1\text{ mph} = 0.4470\text{ m/s}$. Design the on-ramp for the less powerful car and the off-ramp for the car with bald tires.

Solve: *on-ramp* (speeding up): $v_{0x} = 0$, $v_x = 60\text{ mph} = 26.8\text{ m/s}$, $t = 10.0\text{ s}$ and $v_x = v_{0x} + a_x t$ gives

$$a_x = \frac{v_x - v_{0x}}{t} = 2.68\text{ m/s}^2.$$

Then $v_{0x} = 0$, $v_x = 70\text{ mph} = 31.3\text{ m/s}$ and $a_x = 2.68\text{ m/s}^2$ in $v_x{}^2 = v_{0x}{}^2 + 2a_x(x - x_0)$ gives

$$x - x_0 = \frac{v_x{}^2 - v_{0x}{}^2}{2a_x} = 180\text{ m}.$$

This is the required length of the on-ramp.

off-ramp (slowing down): $v_{0x} = 60\text{ mph} = 26.8\text{ m/s}$, $v_x = 0$, $t = 20.0\text{ s}$ and $v_x = v_{0x} + a_x t$ gives

$$a_x = \frac{v_x - v_{0x}}{t} = -1.34\text{ m/s}^2.$$

Then $v_{0x} = 70\text{ mph} = 31.3\text{ m/s}$, $v_x = 0$ and $a_x = -1.34\text{ m/s}^2$ in $v_x{}^2 = v_{0x}{}^2 + 2a_x(x - x_0)$ gives

$$x - x_0 = \frac{v_x{}^2 - v_{0x}{}^2}{2a_x} = 370\text{ m}.$$

This is the required length of the off-ramp.

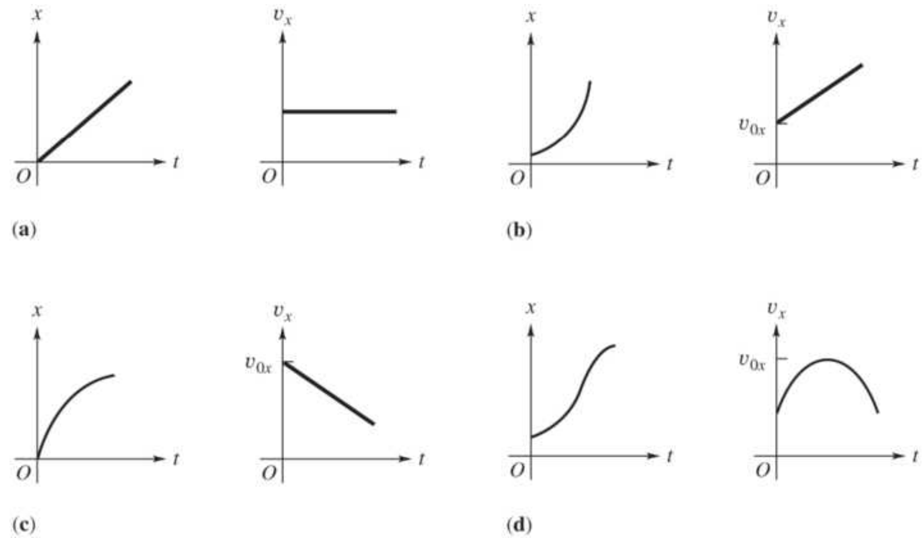
2.77. Set Up: The average acceleration is given by $a_{\text{av},x} = \dfrac{\Delta v_x}{\Delta t}$. The time for each beat is $\dfrac{1}{72}$ minutes, or $\dfrac{60}{72}$ seconds.

Solve: $a_{\text{av},x} = \dfrac{\Delta v_x}{\Delta t} = \dfrac{425\text{ cm/s} - 0}{60/72\text{ seconds}} = 510\text{ cm/s}^2.$

Reflect: This is about $\dfrac{1}{2}$g.

2.78. Set Up: Let $+x$ be to the right. (**a**) Δx is constant so v_x is constant and positive. (**b**) Δx increases so v_x is positive and increasing. (**c**) Δx decreases so v_x is positive and decreasing. (**d**) Δx increases and then decreases so v_x increases and then decreases.

Solve: The graphs are sketched qualitatively in the figures below.



***2.79. Set Up:** Take $+y$ to be upward. There are two periods of constant acceleration: $a_y = +2.50\ \text{m/s}^2$ while the engines fire and $a_y = -9.8\ \text{m/s}^2$ after they shut off. Constant acceleration equations can be applied within each period of constant acceleration.

Solve: (a) Find the speed and height at the end of the first 20.0 s. $a_y = +2.50\ \text{m/s}^2$, $v_{0y} = 0$, and $y_0 = 0$. $v_y = v_{0y} + a_y t = (2.50\ \text{m/s}^2)(20.0\ \text{s}) = 50.0\ \text{m/s}$ and $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2 = \frac{1}{2}(2.50\ \text{m/s}^2)(20.0\ \text{s})^2 = 500\ \text{m}$. Next consider the motion from this point to the maximum height. $y_0 = 500\ \text{m}$, $v_y = 0$, $v_{0y} = 50.0\ \text{m/s}$, and $a_y = -9.8\ \text{m/s}^2$. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

$$y - y_0 = \frac{v_y^2 - v_{0y}^2}{2a_y} = \frac{0 - (50.0\ \text{m/s})^2}{2(-9.8\ \text{m/s}^2)} = +128\ \text{m},$$

so $y = 628\ \text{m}$. The duration of this part of the motion is obtained from $v_y = v_{0y} + a_y t$:

$$t = \frac{v_y - v_{0y}}{a_y} = \frac{-50\ \text{m/s}}{-9.8\ \text{m/s}^2} = 5.10\ \text{s}$$

(b) At the highest point, $v_y = 0$ and $a_y = 9.8\ \text{m/s}^2$, downward.

(c) Consider the motion from the maximum height back to the ground. $a_y = -9.8\ \text{m/s}^2$, $v_{0y} = 0$, $y = 0$, and $y_0 = 628\ \text{m}$. $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$ gives

$$t = \sqrt{\frac{2(y - y_0)}{a_y}} = 11.3\ \text{s}.$$

The total time the rocket is in the air is $20.0\ \text{s} + 5.10\ \text{s} + 11.3\ \text{s} = 36.4\ \text{s}$. $v_y = v_{0y} + a_y t = (-9.8\ \text{m/s}^2)(11.3\ \text{s}) = -111\ \text{m/s}$. Just before it hits the ground the rocket will have speed $111\ \text{m/s}$.

Reflect: We could calculate the time of free fall directly by considering the motion from the point of engine shutoff to the ground: $v_{0y} = 50.0\ \text{m/s}$, $y - y_0 = 500\ \text{m}$ and $a_y = -9.8\ \text{m/s}^2$. $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ gives $t = 16.4\ \text{s}$, which agrees with a total time of 36.4 s.

2.80. Set Up: The velocity is the slope of the x versus t graph. The sign of the slope specifies the direction of the velocity.
Solve: (a) The mouse is to the right of the origin when x is positive. This is for $0 < t < 6.0\text{ s}$ and for $t > 8.5\text{ s}$. The mouse is to the left of the origin when x is negative. This is for $6.0\text{ s} < t < 8.5\text{ s}$. The mouse is at the origin when $t = 0,\ 6.0\text{ s},\ 8.5\text{ s}$.

(b) At $t = 0$, υ_x is positive and has magnitude $\dfrac{\Delta x}{\Delta t} = \dfrac{40.0\text{ cm}}{3.0\text{ s}} = 13.3\text{ cm/s}$.
(c) The acceleration is not constant. For constant a the x-t graph would be a section of a parabola, and it is not.
(d) The speed is greatest when the magnitude of the slope is greatest, and this is between 5.0 s and 6.0 s. The speed in this interval is

$$\frac{40.0\text{ cm}}{1.0\text{ s}} = 40.0\text{ cm/s}.$$

During this part of the motion the velocity is negative and the mouse is moving to the left.
(e) The mouse is moving to the right when x is increasing. This happens for $0 < t < 3.0\text{ s}$ and for $t > 7.0\text{ s}$. The mouse is moving to the left when x is decreasing. This happens for $5.0\text{ s} < t < 7.0\text{ s}$. The mouse is instantaneously at rest when the slope of the tangent to the x versus t graph is zero, when the tangent is horizontal. This happens for $3.0\text{ s} < t < 5.0\text{ s}$ and at $t = 7.0\text{ s}$.
(f) In the first 3 seconds the mouse travels from 0 to 40.0 cm so it travels 40.0 cm. In the first 10 seconds the mouse travels from 0 cm to 40.0 cm, from 40.0 cm to -10.0 cm and from -10.0 cm to 15.0 cm. The total distance traveled is $40.0\text{ cm} + 50.0\text{ cm} + 25.0\text{ cm} = 115\text{ cm}$.
(g) The mouse is speeding up when the slope of x versus t is increasing. This happens at 5.0 s and between 7.0 s and 8.5 s. The mouse is slowing down at 3.0 s, between 6.0 s and 7.0 s and between 8.5 s and 10.0 s.
(h) No, the acceleration is not constant during this entire interval and these formulas apply only for constant acceleration.

2.81. Set Up: In time t_S the S-waves travel a distance $d = \upsilon_S t_S$ and in time t_P the P-waves travel a distance $d = \upsilon_P t_P$.

Solve: (a) $t_S = t_P + 33\text{ s}$. $\dfrac{d}{\upsilon_S} = \dfrac{d}{\upsilon_P} + 33\text{ s}$. $d\left(\dfrac{1}{3.5\text{ km/s}} - \dfrac{1}{6.5\text{ km/s}}\right) = 33\text{ s}$ and $d = 250\text{ km}$.

(b) $t = \dfrac{d}{\upsilon} = \dfrac{375\text{ km}}{3.5\text{ km/s}} = 107\text{ s}$. $t_P = \dfrac{d}{\upsilon_P} = \dfrac{375\text{ km}}{6.5\text{ km/s}} = 58\text{ s}$. $t_S - t_P = 49\text{ s}$

2.82. Set Up: Assume straight line motion along the $+x$-axis. For the starting phase we may use the kinematic equations for constant acceleration: $v_{0x} = 0$, $v_x = 8.00\text{ m/s}$, and $\Delta t = 1.40\text{ s}$; $v_x = \dfrac{\Delta v_x}{\Delta t}$, and $\Delta x = \dfrac{v_x + v_{0x}}{2}\Delta t$.

Solve: (a) $v_x = \dfrac{\Delta v_x}{\Delta t} = \dfrac{8.00\text{ m/s} - 0}{1.40\text{ s}} = 5.71\text{ m/s}^2$.

(b) His acceleration to a top speed of 11.8 m/s occurs over a time of 7.02 s. Thus, $a_{\text{av},x} = \dfrac{\Delta v_x}{\Delta t} = \dfrac{11.8\text{ m/s} - 0}{7.02\text{ s}} = 1.68\text{ m/s}^2$.

(c) The distance traveled during the starting phase is $\Delta x = \left(\dfrac{8.00\text{ m/s} + 0}{2}\right)(1.40\text{ s}) = 5.60\text{ m}$.

Reflect: We cannot calculate the distance that the sprinter travels during the second phase of the race, since we do not know that his acceleration is constant during this phase.

***2.83. Set Up:** Let t_{fall} be the time for the rock to fall to the ground and let t_s be the time it takes the sound to travel from the impact point back to you. $t_{\text{fall}} + t_s = 10.0\text{ s}$. Both the rock and sound travel a distance d that is equal to the height of the cliff. Take $+y$ downward for the motion of the rock. The rock has $\upsilon_{0y} = 0$ and $a_y = 9.80\text{ m/s}^2$.

Solve: (a) For the rock, $y - y_0 = \upsilon_{0y}t + \frac{1}{2}a_y t^2$ gives $t_{\text{fall}} = \sqrt{\dfrac{2d}{9.80\text{ m/s}^2}}$.

For the sound, $t_s = \dfrac{d}{330 \text{ m/s}} = 10.0 \text{ s}$. Let $\alpha^2 = d$. $0.00303\alpha^2 + 0.4518\alpha - 10.0 = 0$. $\alpha = 19.6$ and $d = 384$ m.

(b) You would have calculated $d = \frac{1}{2}(9.80 \text{ m/s}^2)(10.0 \text{ s})^2 = 490$ m. You would have overestimated the height of the cliff. It actually takes the rock less time than 10.0 s to fall to the ground.

Reflect: Once we know d we can calculate that $t_{\text{fall}} = 8.8$ s and $t_s = 1.2$ s. The time for the sound of impact to travel back to you is 12% of the total time and cannot be neglected. The rock has speed 86 m/s just before it strikes the ground.

Solutions to Passage Problems

2.84. Set Up: Since the blood momentarily comes to rest, $v_{0x} = 0$. Also, we know that $v_x = 1.0$ m/s and $\Delta t = 250$ ms.

Solve: $a_{\text{av},x} = \dfrac{\Delta v_x}{\Delta t} = \dfrac{1.0 \text{ m/s} - 0}{0.250 \text{ s}} = 4.0 \text{ m/s}$. Thus, the correct answer is D.

***2.85. Set Up:** Assuming that the aorta and arteries are circular in cross-sectional area, we can use $A = \pi r^2 = \pi\left(\dfrac{d}{2}\right)^2$. Let d_a be the diameter of the aorta and d_b be the diameter of each branch.

Solve: Since the combined area of the two arteries is equal to that of the aorta we have $\pi\left(\dfrac{d_b}{2}\right)^2 + \pi\left(\dfrac{d_b}{2}\right)^2 = \pi\left(\dfrac{d_a}{2}\right)^2$, which reduces to $2{d_b}^2 = {d_a}^2$. Thus, we have $d_b = d_a/\sqrt{2}$. The correct answer is B.

2.86. Set Up: We are asked to find the average velocity (not the average speed): $v_{\text{av},x} = \dfrac{\Delta x}{\Delta t}$.

Solve: For the round-trip, we have $x_f = x_0$ so $\Delta x = 0$ m. Thus, we find $v_{\text{av},x} = \dfrac{\Delta x}{\Delta t} = 0$ m/s.

The correct answer is C.