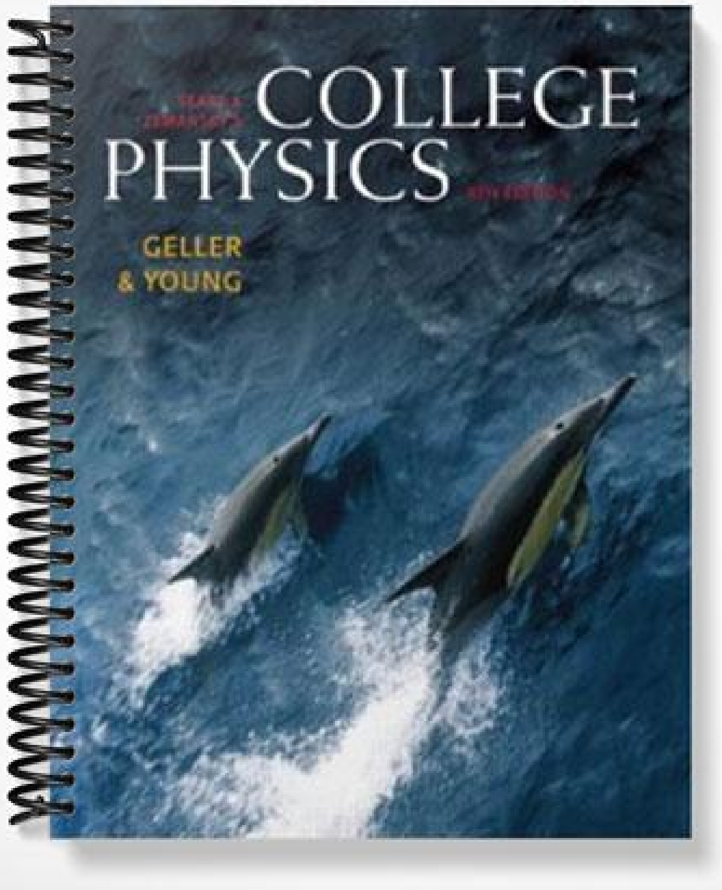
SOLUTIONS MANUAL



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.** B **10.** C **11.** A **12.** A, C, D **13.** B, D **14.** D **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:

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

(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 $= 2(AB) = 100$ 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: $x_1 = 1.0$ m, $x_2 = 0$, $x_3 = -1.0$ m, $x_4 = 0$, $x_8 = 6.0$ m, and $x_{10} = 6.0$ m.
Solve: (a) The displacement is Δx. (i) $\Delta x = x_{10} - x_1 = +5.0$ m; (ii) $\Delta x = x_{10} - x_3 = +7.0$ m; (iii) $\Delta x = x_3 - x_2 = -1.0$ m; (iv) $\Delta x = x_4 - x_2 = 0$.
(b) (i) $3.0\text{ m} + 1.0\text{ m} = 4.0$ m; (ii) $1.0\text{ m} + 1.0\text{ m} = 2.0$ m; (iii) zero (stays at $x = 6.0$ m)

2.3. Set Up: Let the $+x$ direction be to the right. $x_A = 2.0$ m, $x_B = 7.0$ m, $x_C = 6.0$ 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 distance traveled is 2650 miles and the displacement is 1000 miles.
Solve: (a) time $= 12\text{ weeks}\,(168\text{ h/week}) = 2016$ h

$$\text{Average speed} = \frac{\text{distance}}{\text{time}} = \frac{2650\text{ miles}}{2016\text{ h}} = 1.3\text{ mi/h}$$

(b) $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t} = \dfrac{1000\text{ mi}}{2016\text{ h}} = 0.50\text{ mi/h}$

(c) The hiking time is $(12\text{ weeks})(7\text{ days/week})(8\text{ h/day}) = 672\text{ h}$.

$$\text{Average speed} = \frac{2650\text{ miles}}{672\text{ h}} = 3.9\text{ mi/h}$$

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 Figure 2.8.

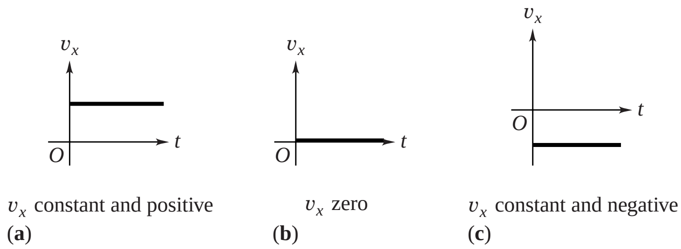


Figure 2.8

2.9. Set Up: Let $+x$ be the direction the runner travels. $v_{\text{av},x} = \dfrac{\Delta x}{\Delta t}$. 1 mi/h = 1.466 ft/s = 0.4470 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 century = 100 yr. 1 km = 10^5 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, $d = 63$ m. Use coordinates for which the origin is at her starting point and the x-axis is along a diameter, as shown in Figure 2.12.

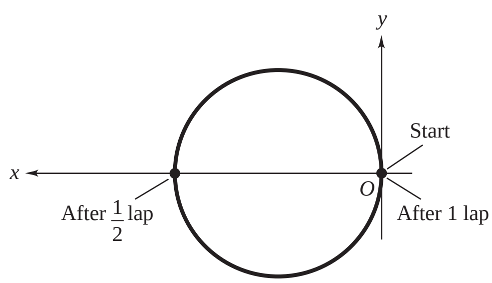


Figure 2.12

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) $\Delta x = 40.0$ 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: 1 attosecond $= 1 \times 10^{-18}$ s. The speed of light is $v = 3.00 \times 10^8$ m/s.
Solve: $d = vt = (3.00 \times 10^8\ \text{m/s})(100 \times 10^{-18}\ \text{s}) = 3.0 \times 10^{-8}\ \text{m} = 30\ \text{nm}$

2.14. Solve: (a) $t = \dfrac{d}{v}$. touch: $t = \dfrac{1.85\ \text{m}}{76.2\ \text{m/s}} = 0.0243$ s; pain: $t = \dfrac{1.85\ \text{m}}{0.610\ \text{m/s}} = 3.03$ s
(b) The difference between the two times in (a) is 3.01 s.

2.15. Set Up: The speed of light is 3.00×10^8 m/s. Light and sound travel at constant speed so $\Delta x = v_{\text{av},x}\Delta t$. The distance from the earth to the sun is 1.50×10^{11} m. The distance from the earth to the moon is 3.48×10^8 m. $1\ \text{y} = 3.156 \times 10^7\ \text{s}$
Solve: (a) $\Delta x = (3.00 \times 10^8\ \text{m/s})(3.156 \times 10^7\ \text{s}) = 9.47 \times 10^{15}\ \text{m}$
(b) Light: $\Delta x = (3.00 \times 10^8\ \text{m/s})(1.0 \times 10^{-9}\ \text{s}) = 0.300\ \text{m}$.
Sound: $\Delta x = (344\ \text{m/s})(1.0 \times 10^{-9}\ \text{s}) = 3.44 \times 10^{-7}\ \text{m}$.
(c) $\Delta t = \dfrac{\Delta x}{v_{\text{av},x}} = \dfrac{1.50 \times 10^{11}\ \text{m}}{3.00 \times 10^8\ \text{m/s}} = 500\ \text{s}$
(d) $\Delta t = \dfrac{\Delta x}{v_{\text{av},x}} = \dfrac{2(3.84 \times 10^8\ \text{m})}{3.00 \times 10^8\ \text{m/s}} = 2.56\ \text{s}$
(e) $\Delta t = \dfrac{\Delta x}{v_{\text{av},x}} = \dfrac{1.80 \times 10^{12}\ \text{m}}{3.00 \times 10^8\ \text{m/s}} = 6000\ \text{s}$

2.16. Set Up: The distance d around a circular path is $d = 2\pi r$. The radius of the earth is 6.38×10^6 m and the earth completes one rotation in 24 h. The radius of the earth's orbit is 1.50×10^{11} m and the earth completes one revolution around the sun in 1 yr $= 3.156 \times 10^7$ s.
Solve: (a) $v = \dfrac{d}{t} = \dfrac{2\pi(6.38 \times 10^6\ \text{m})}{(24\ \text{h})(3600\ \text{s/h})} = 464\ \text{m/s}$
(b) $v = \dfrac{d}{t} = \dfrac{2\pi(1.50 \times 10^{11}\ \text{m})}{3.156 \times 10^7\ \text{s/yr}} = 29.9\ \text{km/s}$

2.17. Set Up: Use the normal driving time to find the distance. Use this distance to find the time on Friday.
Solve: $\Delta x = v_{\text{av},x}\Delta t = (105\ \text{km/h})(1.33\ \text{h}) = 140\ \text{km}$. Then on Friday $\Delta t = \dfrac{\Delta x}{v_{\text{av},x}} = \dfrac{140\ \text{km}}{70\ \text{km/h}} = 2.00\ \text{h}$. 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: $d = v_A t$ and $200.0\ \text{m} - d = v_B t$. Combine these two equations to eliminate d. $200.0\ \text{m} - v_A t = v_B t$ 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: $v_x = 6.7$ m/s; B: $v_x = 6.7$ m/s; C: $v_x = 0$; D: $v_x = -40.0$ m/s; E: $v_x = -40.0$ m/s; F: $v_x = -40.0$ m/s; G: $v_x = 0$.
Reflect: The sign of v_x shows the direction the car is moving. v_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: $x_0 = 0$, $x_4 = 3.0\text{ cm}$, $x_{10} = 4.0\text{ cm}$, and $x_{18} = 4.0\text{ cm}$. v_x is constant when x versus t is a straight line.
Solve: The motion consists of constant velocity segments.

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

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

The graph of v_x versus t is shown in Figure 2.21.

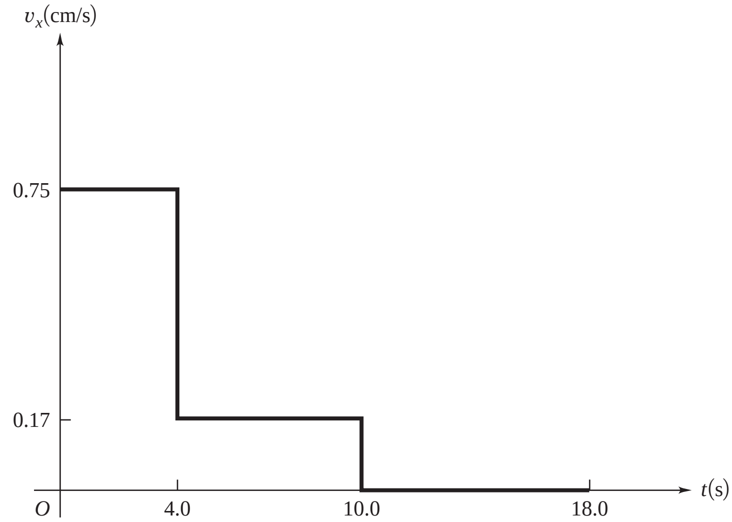


Figure 2.21

Reflect: v_x is the slope of x versus t.

2.22. Set Up: The instantaneous acceleration is the slope of the v_x versus t graph.
Solve: $t = 3\text{ s}$: The graph is horizontal, so $a_x = 0$.

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

$t = 11\text{ s}$: 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: $a_{\text{av},x} = \dfrac{\Delta v_x}{\Delta t}$

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 v_x versus t is given in Figure 2.23. $t = 9$ s: $a_x = 2.5\ \text{m/s}^2$; $t = 13$ s: $a_x = 1.0\ \text{m/s}^2$; $t = 15$ s: $a_x = 0$.

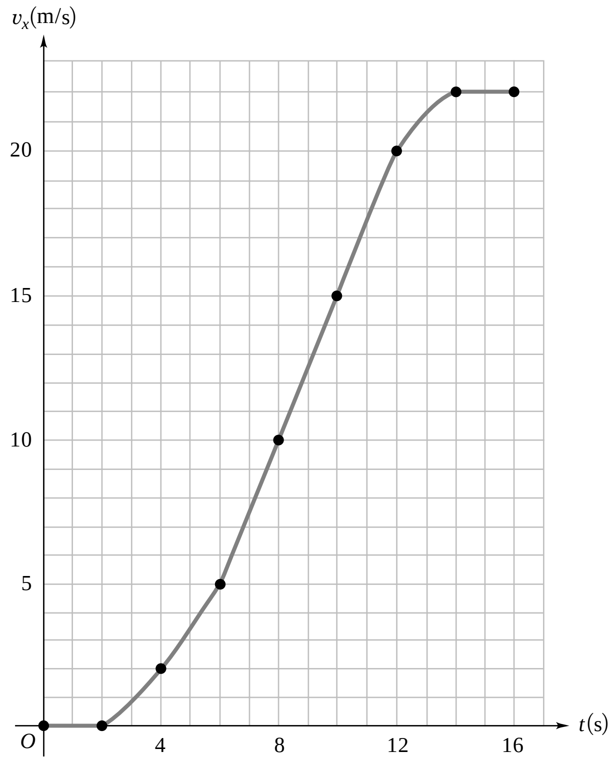


Figure 2.23

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

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 Figure 2.25.

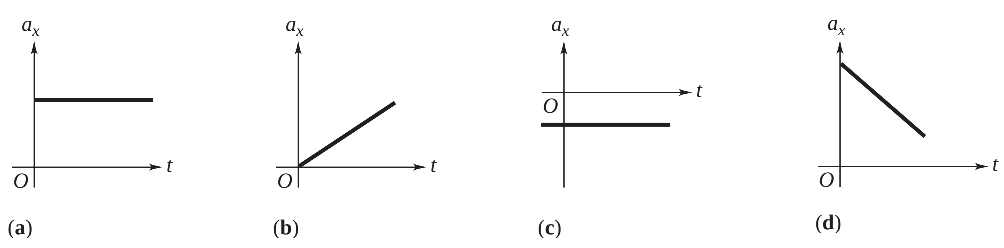


Figure 2.25

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 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 $t = 4.0\ \text{s}$, $v_x = 2.7\ \text{cm/s}$, to the right and at $t = 7.0\ \text{s}$, $v_x = 1.3\ \text{cm/s}$, 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 Figure 2.26.

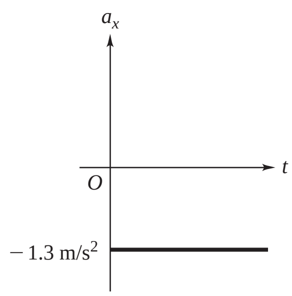


Figure 2.26

2.27. Set Up: Assume constant acceleration. $v_{0x} = 88\ \text{ft/s}$, $v_x = 110\ \text{ft/s}$, and $t = 3.50\ \text{s}$. 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: $1\ \text{mph} = 0.4470\ \text{m/s}$ and $1\ \text{m} = 3.281\ \text{ft}$. Let $x_0 = 0$. $v_{0x} = 0$, $t = 2.0\ \text{s}$, and $v_x = 45\ \text{mph} = 20.1\ \text{m/s}$.

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

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

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

2.29. Set Up: Assume constant acceleration. Take the $+x$ direction to be downward, in the direction of the motion of the capsule. $v_{0x} = 311\ \text{km/h} = 86.4\ \text{m/s}$, $v_x = 0$ (stops), $x_0 = 0$ and $x = 0.81\ \text{m}$.

Solve: (a) $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ and $a_x = \dfrac{v_x^2 - v_{0x}^2}{2(x - x_0)} = \dfrac{0 - (86.4\ \text{m/s})^2}{2(0.81\ \text{m})} = -4.61 \times 10^3\ \text{m/s}^2 = -470g$.

The minus sign tells us that a_x is upward.

(b) $v_x = v_{0x} + a_x t$ so $t = \dfrac{v_x - v_{0x}}{a_x} = \dfrac{0 - 86.4\ \text{m/s}}{-4.6 \times 10^3\ \text{m/s}^2} = 18.7\ \text{ms}$

Reflect: Since the speed decreases, v_x and a_x must be in opposite directions.

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

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

Yes, the time required is larger than 5.0 s.

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

2.31. Set Up: Assume your head accelerates upward 1.0 m in 0.25 s with constant acceleration. Let $+x$ be upward. $v_{0x} = 0$, $x - x_0 = 1.0$ m, and $t = 0.25$ s.

Solve: (a) $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$ and $a_x = \dfrac{2(x - x_0)}{t^2} = \dfrac{2(1.0\text{ m})}{(0.25\text{ s})^2} = 30\text{ m/s}^2 = 3g$

(b) No, different parts of your body travel through different distances in the same time.

Reflect: The shorter the time for you to stand up, the greater the acceleration.

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

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

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

2.33. Set Up: Let $+x$ be the direction the person travels. $v_x = 0$ (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: $v_x = v_{0x} + a_x t$ so $v_{0x} = -a_x t$. Then $x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2$ 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: $v_{0x} = -a_x t = -(-588\text{ m/s}^2)(36 \times 10^{-3}\text{ s}) = 21\text{ m/s} = 47\text{ mph}$

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. $v_{0x} = 0$, $x_0 = 0$, $x = 2.00$ m, and $t = 1.00$ s.

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

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

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

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

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

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

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

(b) We have already found $v_x = 4.00$ m/s after the first second. After the second second,

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

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

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

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

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

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

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

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

2.37. Set Up: Estimate $t = 5.0$ s. $x_0 = 0$, $v_{0x} = 0$, $v_x = 60\text{ mph} = 26.8\text{ m/s}$.

Solve: (a) $v_x = v_{0x} + a_x t$ and $a_x = \dfrac{v_x - v_{0x}}{t} = \dfrac{26.8\text{ m/s} - 0}{5.0\text{ s}} = 5.4\text{ m/s}^2 = 18\text{ ft/s}^2$.

(b) $x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2 = \frac{1}{2}(5.4\text{ m/s}^2)(5.0\text{ s})^2 = 68\text{ m} = 220\text{ ft}$

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

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

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

(b) $v_{0x} = (55.0\text{ mi/h})\left(\dfrac{1.466\text{ ft/s}}{1\text{ mi/h}}\right) = 80.6\text{ ft/s}$. 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: $v_{0x} = 88.0\text{ ft/s}$, $x - x_0 = 146\text{ ft}$, $v_x = 0$. $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ gives

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

Speeding up: $v_{0x} = 0$, $x - x_0 = 1320\text{ ft}$, $t = 19.9$ s. $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$ 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) $v_x = v_{0x} + a_x t = 0 + (6.67\text{ ft/s}^2)(19.9\text{ s}) = 133\text{ ft/s} = 90.5\text{ mph}$

(c) $t = \dfrac{v_x - v_{0x}}{a_x} = \dfrac{0 - 88.0\text{ ft/s}}{-26.5\text{ ft/s}^2} = 3.32\text{ s}$

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

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

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

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

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: For a sphere of radius R the volume is $V = \frac{4}{3}\pi R^3$ and the surface area is $A = 4\pi R^2$.

Solve: (a) $\dfrac{V_1}{R_1^3} = \dfrac{V_2}{R_2^3}$ and $R_2 = R_1\left(\dfrac{V_2}{V_1}\right)^{1/3} = R\left(\dfrac{\frac{1}{2}V_1}{V_1}\right)^{1/3} = R/2^{1/3}$

(b) $\dfrac{A_1}{R_1^2} = \dfrac{A_2}{R_2^2}$ and $A_2 = A_1\left(\dfrac{R_2}{R_1}\right)^2 = A_1\left(\dfrac{R}{2^{1/3}R}\right)^2 = A_1/2^{2/3}$; surface area changes by a factor of $1/2^{2/3}$.

2.44. Set Up: Let a_h and a_l be the accelerations of the rockets, with $a_\text{h} = 2a_\text{l}$. They reach the same final speed, so $v_\text{h} = v_\text{l}$. Since they start from rest, $v_{0\text{h}} = v_{0\text{l}} = 0$.

Solve: (a) $v_x = v_{0x} + a_x t$ gives $a_\text{h}t_\text{h} = a_\text{l}t_\text{l}$ and $t_\text{l} = \left(\dfrac{a_\text{h}}{a_\text{l}}\right)t_\text{h} = 2(50\text{ s}) = 100\text{ s}$.

(b) $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ gives $a_\text{h}x_\text{h} = a_\text{l}x_\text{l}$ and $x_\text{l} = \left(\dfrac{a_\text{h}}{a_\text{l}}\right)x_\text{h} = 2(250\text{ m}) = 500\text{ m}$.

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 $t_A = \left(\dfrac{a_B}{a_A}\right)t_B = \frac{1}{3}T$

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) $y - y_0 = 0.220\ \text{m}$, $a_y = -9.80\ \text{m/s}^2$, $v_y = 0$. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ 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) $v_{0y} = 0$, $t = 2.50\ \text{s}$, $a_y = 9.80\ \text{m/s}^2$.

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

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 Figure 2.49. Take $y = 0$ at the ground.

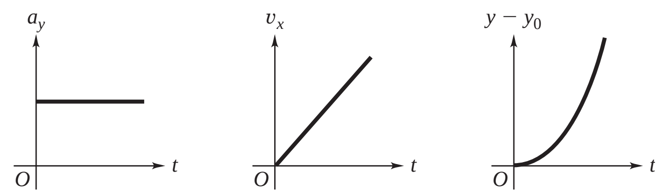


Figure 2.49

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

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

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

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

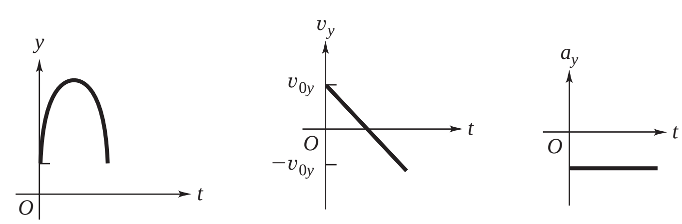
2.51. Set Up: Take $+y$ upward. $v_y = 0$ at the maximum height. $a_y = -0.379g = -3.71\ \text{m/s}^2$.

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

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 $v_{0y} = -a_y t = -(-3.71\ \text{m/s}^2)(4.25\ \text{s}) = 15.8\ \text{m/s}$.

(c) The graphs are sketched in Figure 2.51.



(a) (b) (c)

Figure 2.51

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 $a_y = \dfrac{2y}{t^2} = \dfrac{2(11.26 \text{ m})}{(3.17 \text{ s})^2} = 2.24 \text{ m/s}^2 = 0.229g$

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

(b) $y - y_0 = -40.0$ m, $v_{0y} = 5.00$ m/s, $a_y = -9.80$ 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) $v_y = v_{0y} + a_y t = +5.00 \text{ m/s} + (-9.80 \text{ m/s}^2)(3.41 \text{ s}) = -28.4$ m/s

(d) $v_{0y} = 5.00$ m/s, $a_y = -9.80$ 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 Figure 2.53. Take $y = 0$ at the ground.

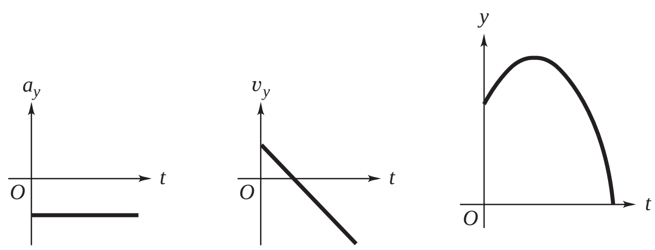


Figure 2.53

2.54. Set Up: Take $+y$ to be downward. The acceleration is the slope of the v_y versus t graph.

Solve: (a) Since v_y is downward, it is positive and equal to the speed v. The v versus t graph has slope $a_y = \dfrac{30.0 \text{ m/s}}{2.0 \text{ s}} = 15 \text{ m/s}^2$.

(b) $v_{0y} = 0$ and let $y_0 = 0$. $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$ gives $t = \sqrt{\frac{2y}{a_y}} = \sqrt{\frac{2(3.5\text{ m})}{15\text{ m/s}^2}} = 0.68\text{ s}$

$$v_y = v_{0y} + a_y t = (15\text{ m/s}^2)(0.68\text{ s}) = 10.2\text{ m/s}$$

(c) At the maximum height, $v_y = 0$. Let $y_0 = 0$. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

$$v_{0y} = \sqrt{-2a_y(y - y_0)} = \sqrt{-2(-15\text{ m/s}^2)(18.0\text{ m})} = 23\text{ m/s}.$$

$v_y = v_y + a_y t$ gives $t = \frac{v_y - v_{0y}}{a_y} = \frac{0 - 23\text{ m/s}}{-15\text{ m/s}^2} = 1.5\text{ s}$

Reflect: The acceleration is 9.80 m/s^2, downward, throughout the motion. The velocity initially is upward, decreases to zero because of the downward acceleration and then is downward and increasing in magnitude because of the downward acceleration.

2.55. Set Up: $a_M = 0.170a_E$. Take $+y$ to be upward and $y_0 = 0$.
Solve: (a) $v_{0E} = v_{0M}$. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ with $v_y = 0$ at the maximum height gives $2a_y y = -v_{0y}^2$, 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 v_{0y}, with $v_y = 0$ and $y = 12.0$ m. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

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

Then $v_y = v_{0y} + a_y t$ gives

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

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

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

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 $v = 0$ 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) $v_y = v_{0y} + a_y t = 15.0\text{ m/s} + (9.80\text{ m/s}^2)(2.00\text{ s}) = 34.6\text{ m/s}$
(b) $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2 = (15.0\text{ m/s})(2.00\text{ s}) + \frac{1}{2}(9.80\text{ m/s}^2)(2.00\text{ s})^2 = 49.6\text{ m}$
(c) $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $v_y = \sqrt{(15.0\text{ m/s})^2 + 2(9.80\text{ m/s}^2)(10.0\text{ m})} = 20.5\text{ m/s}$

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) $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ 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) $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $v_y = -\sqrt{(12.0\text{ m/s})^2 + 2(-9.80\text{ m/s}^2)(-60.0\text{ m})} = -36.3\text{ m/s}.$

Reflect: We could have taken downward to be $+y$. Then $y - y_0$, v_y and a_y are all positive, but v_{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. $1610\text{ km/h} = 447\text{ m/s}$. $1020\text{ km/h} = 283\text{ m/s}$. Assume the acceleration is constant.

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

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

(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 $40g$ 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 $a_y = -\dfrac{2v_{0y}}{t}$. Since both stones have the same a_y, $\dfrac{v_{0\text{f}}}{t_\text{f}} = \dfrac{v_{0\text{s}}}{t_\text{s}}$ 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 $a_y = -\dfrac{v_{0y}^2}{2y}$. Since both have the same a_y, $\dfrac{v_{0\text{f}}^2}{y_\text{f}} = \dfrac{v_{0\text{s}}^2}{y_\text{s}}$ and $y_\text{f} = y_\text{s}\left(\dfrac{v_{0\text{f}}}{v_{0\text{s}}}\right)^2 = 9H$.

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 $a_y = \dfrac{v_y^2}{2y}$ and $\dfrac{v_A^2}{y_A} = \dfrac{v_B^2}{y_B}$. $v_B = v_A\sqrt{\dfrac{y_B}{y_A}} = V\sqrt{\tfrac{1}{2}} = V/\sqrt{2}$

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

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

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

(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: $\vec{v}_{\text{P/A}} = 600$ 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 $v_{\text{P/E}} = 600$ mph. $t = \dfrac{4000\text{ mi}}{600\text{ mi/h}} = 6.67\text{ h}$

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

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

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

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

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

2.65. Set Up: The relative velocities are: $v_{\text{P/G}}$, the plane relative to the ground; $v_{\text{P/A}}$, the plane relative to the air; and $v_{\text{A/G}}$, the air relative to the ground. Let $+x$ be east.

Solve: Use the data for no wind to calculate $v_{\text{P/A}}$:

$$v_{\text{P/A}} = \frac{5310\text{ km}}{6.60\text{ h}} = 804.5\text{ km/h.}$$

$v_{\text{P/G},x} = v_{\text{P/A},x} + v_{\text{A/G},x}$. When flying east from A to B, $v_{\text{P/A}}$ and $v_{\text{A/G}}$ are both east and $v_{\text{P/G}} = 804.5\text{ km/h} + v_{\text{A/G}}$.

$$t_{AB} = \frac{2655\text{ km}}{v_{\text{P/G}}} = \frac{2655\text{ km}}{804.5\text{ km/h} + v_{\text{A/G}}}.$$

When flying west from B to A, $v_{\text{P/A}}$ is west and $v_{\text{A/G}}$ is east and $v_{\text{P/G}} = 804.5\text{ km/h} - v_{\text{A/G}}$.

$$t_{BA} = \frac{2655\text{ km}}{v_{\text{P/G}}} = \frac{2655\text{ km}}{804.5\text{ km/h} - v_{\text{A/G}}}.$$

$t_{AB} + t_{BA} = 6.70\text{ h}$, so

$$\frac{2655\text{ km}}{804.5\text{ km/h} + v_{\text{A/G}}} + \frac{2655\text{ km}}{804.5\text{ km/h} - v_{\text{A/G}}} = 6.70\text{ h}$$

$$[(804.5\text{ km/h})^2 - v_{\text{A/G}}^2][6.70\text{ h}] = (2655\text{ km})(1610\text{ km/h}).$$

$$(804.5\text{ km/h})^2 - v_{\text{A/G}}^2 = 6.376 \times 10^5\text{ km}^2/\text{h}^2 \text{ and } v_{\text{A/G}} = 98.1\text{ km/h}$$

Reflect: When the wind is blowing it increases the speed of the plane relative to the ground for the trip from A to B and decreases this speed for the return trip from B to A. Since the plane spends more time going from B to A than for A to B, the wind decreases the average speed for the roundtrip and therefore increases the total travel time.

2.66. Set Up: At this point Voyager 1 is 2.3×10^{13} m from the sun and the earth is 1.50×10^{11} m from the sun, on the same side as Voyager 1. Thus, Voyager 1 is 2.3×10^{13} m from the earth. The speed of the radio waves is $v = 3.00 \times 10^8$ m/s.

Solve: $t = \dfrac{d}{v} = \dfrac{2.3 \times 10^{13}\text{ m}}{3.00 \times 10^8\text{ m/s}} = 7.6 \times 10^4\text{ s} = 21\text{ h}$

2.67. Set Up: 1 light year $= (3.00 \times 10^8\text{ m/s})(3.156 \times 10^7\text{ s}) = 9.47 \times 10^{15}$ m

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

2.68. 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 $x - x_0 = v_{0x}t + \frac{1}{2}a_xt^2$ 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 $v_{0x} = 15.0$ 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 $T = 12.0$ s. Then $d = (15.0\text{ m/s})(12.0\text{ s}) = 180$ m.

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

2.69. Set Up: Let d be the distance from home to work. average speed $= \dfrac{d}{t}$

Solve: (a) The time to get to work is $t_1 = \dfrac{d}{60\text{ mph}}$. The time to return home is $t_2 = \dfrac{d}{40\text{ mph}}$. The average speed for the round trip is the total distance $2d$ divided by the total time $t_1 + t_2$:

$$\text{average speed} = \frac{2d}{t_1 + t_2} = 2\frac{(60)(40)}{60 + 40}\text{ mph} = 48\text{ mph}$$

(b) The travel times at each speed are not the same. More time is spent traveling at 40 mph so the average speed is less than $(60\text{ mph} + 40\text{ mph})/2$.

Reflect: If the two average speeds for each one-way trip are v_1 and v_2, then the average speed for the roundtrip is $v_{av} = \dfrac{2v_1v_2}{v_1 + v_2}$. If $v_1 = v_2 = v$, then the average speed is this speed v. If the speeds differ a lot, then the average speed for the roundtrip differs greatly from $(v_1 + v_2)/2$. For example, if $v_1 = 90$ mph and $v_2 = 10$ mph, then $v_{av} = 18$ mph. In this case most of the time is spent while traveling at the slower speed.

2.70. Set Up: To catch up the fast runner must run 200.0 m farther than the slow runner in time t.

Solve: (a) Apply $x - x_0 = v_{0x}t$ to each runner: $(x - x_0)_f = (6.20\text{ m/s})t$ and $(x - x_0)_s = (5.50\text{ m/s})t$. $(x - x_0)_f = (x - x_0)_s + 200.0$ m gives $(6.20\text{ m/s})t = (5.50\text{ m/s})t + 200.0$ m and

$$t = \frac{200.0\text{ m}}{6.20\text{ m/s} - 5.50\text{ m/s}} = 286\text{ s}.$$

(b) *fast:* $(x - x_0)_f = (6.20\text{ m/s})(286\text{ s}) = 1770$ m.
slow: $(x - x_0)_s = (5.50\text{ m/s})(286\text{ s}) = 1570$ m

2.71. 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, $a_My_M = a_Ey_E$ and

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

(b) $v_y = v_{0y} + a_yt$. $a_Mt_M = a_Et_E$ and $t_M = \left(\dfrac{a_E}{a_M}\right)t_E = 6(4.0\text{ s}) = 24.0\text{ s}$

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

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

2.73. Set Up: $v_{0x} = 0$, $v_x = 5.0 \times 10^3\ \text{m/s}$, and $x - x_0 = 4.0\ \text{m}$
Solve: (a) $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ gives

$$a_x = \frac{v_x^2 - v_{0x}^2}{2(x - x_0)} = \frac{(5.0 \times 10^3\ \text{m/s})^2}{2(4.0\ \text{m})} = 3.1 \times 10^6\ \text{m/s}^2 = 3.2 \times 10^5 g$$

(b) $v_x = v_{0x} + a_x t$ gives $t = \frac{v_x - v_{0x}}{a_x} = \frac{5.0 \times 10^3\ \text{m/s}}{3.1 \times 10^6\ \text{m/s}^2} = 1.6\ \text{ms}$
(c) The calculated a is less than $450{,}000g$ so the acceleration required doesn't rule out this hypothesis.

2.74. Set Up: Let $+y$ be downward. The meter stick has $v_{0y} = 0$ and $a_y = 9.80\ \text{m/s}^2$. The time the meterstick falls is your reaction time. Let d be the distance the meterstick falls.

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

(b) $t = \sqrt{\frac{0.176\ \text{m}}{4.90\ \text{m/s}^2}} = 0.190\ \text{s}$

2.75. 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.

2.76. 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, $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2 = 0 + \frac{1}{2}(1.00\ \text{m/s}^2)(5.0\ \text{s})^2 = 12.5\ \text{m}$.

2.77. Set Up: Take $+y$ to be upward. **(a)** and **(b)** $v_{0y} = 4973\ \text{km/h} = 1381\ \text{m/s}$, $a_y = -9.8\ \text{m/s}^2$, and $y - y_0 = -45 \times 10^3\ \text{m}$. **(c)** $v_{0y} = 0$, $v_y = 1381\ \text{m/s}$, and $y - y_0 = 45 \times 10^3\ \text{m}$.
Solve: (a) $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ and

$$v_y = -\sqrt{v_{0y}^2 + 2a_y(y - y_0)} = -\sqrt{(1381\ \text{m/s})^2 + 2(-9.8\ \text{m/s}^2)(-45 \times 10^3\ \text{m})}$$
$$v_y = -1670\ \text{m/s} = -6012\ \text{km/h}$$

(b) $v_y = v_{0y} + a_y t$ gives $t = \dfrac{v_y - v_{0y}}{a_y} = \dfrac{-1670\text{ m/s} - 1381\text{ m/s}}{-9.8\text{ m/s}^2} = 310\text{ s}$

(c) $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $a_y = \dfrac{v_y^2 - v_{0y}^2}{2(y - y_0)} = \dfrac{(1381\text{ m/s})^2}{2(45 \times 10^3\text{ m})} = 21\text{ m/s}^2 = 2.2g$

$$y - y_0 = v_{0y}t + \tfrac{1}{2}a_y t^2 \text{ gives } t = \sqrt{\frac{2(y - y_0)}{a_y}} = \sqrt{\frac{2(45 \times 10^3\text{ m})}{21\text{ m/s}^2}} = 65\text{ s}$$

Reflect: The SRBs have greater speed when they return to the ground than they had when released. After release they continue to travel upward. When they return to an altitude of 45 km on their way back down their speed is 4973 km/h, but they gain additional speed as they continue to fall to earth.

2.78. 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 mph $= 0.4470$ 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.

2.79. Set Up: The time interval of 35 years is (35 yr)(365.24 days/yr) $= 1.278 \times 10^4$ days. 1 day $= 8.64 \times 10^4$ s.

Solve: $a_{\text{av}} = \dfrac{\Delta v}{\Delta t} = \dfrac{0.095\text{ mm/day} - 0.123\text{ mm/day}}{1.278 \times 10^4\text{ days}} = -2.2 \times 10^{-6}\text{ mm/day}^2$

$$a_{\text{av}} = (-2.2 \times 10^{-6}\text{ mm/day}^2)\left(\frac{1\text{ day}}{8.64 \times 10^4\text{ s}}\right)^2\left(\frac{1\text{ m}}{10^3\text{ mm}}\right) = -2.9 \times 10^{-19}\text{ m/s}^2$$

The minus sign means that a_{av} is directed opposite to $\vec{v}$; the speed of growth is decreasing in time.

2.80. 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 Figure 2.80.

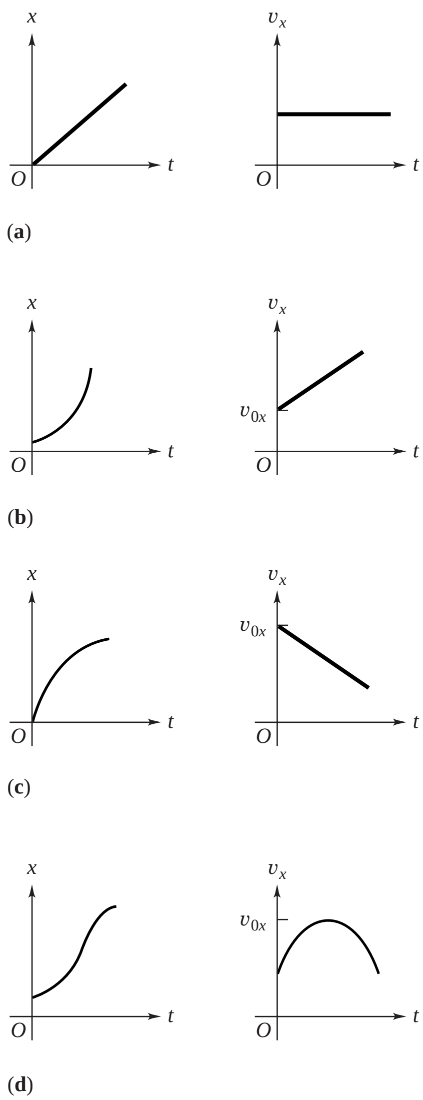


Figure 2.80

2.81. 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 $y = 628$ 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 $y_0 = 628$ 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 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: $v_{0y} = 50.0\ \text{m/s}$, $y - y_0 = 500$ m and $a_y = -9.8\ \text{m/s}^2$. $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ gives $t = 16.4$ s, which agrees with a total time of 36.4 s.

2.82. 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 $0 < t < 6.0$ s and for $t > 8.5$ s. The mouse is to the left of the origin when x is negative. This is for $6.0\ \text{s} < t < 8.5$ s. The mouse is at the origin when $t = 0$, 6.0 s, 8.5 s.

(b) At $t = 0$, v_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 $0 < t < 3.0$ s and for $t > 7.0$ s. The mouse is moving to the left when x is decreasing. This happens for $5.0\ \text{s} < t < 7.0$ 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 $3.0\ \text{s} < t < 5.0$ s and at $t = 7.0$ s.
(f) In the first 3 seconds the mouse travels from 0 to 40.0 cm so 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 cm + 50.0 cm + 25.0 cm = 115 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.

2.83. Set Up: The sign of v_x specifies the direction of motion. The slope of v_x versus t is the acceleration.
Solve: **(a)** The initial velocity is 20.0 cm/s, to the right.
(b) The mouse's greatest speed is 40.0 cm/s. When the mouse has this speed its velocity is positive so it is moving to the right.
(c) The mouse is moving to the right when v_x is positive. This is the case for $0 < t < 6.0$ s and for $9.0\ \text{s} < t < 10.0$ s. The mouse is moving to the left when v_x is negative. This is the case for $6.0\ \text{s} < t < 9.0$ s. The mouse is instantaneously at rest when $t = 6.0$ s and $t = 9.0$ s.
(d) The mouse's largest magnitude of acceleration is between 5.0 s and about 6.3 s. The magnitude of the acceleration is

$$\frac{40.0\ \text{cm/s}}{1.0\ \text{s}} = 40.0\ \text{cm/s}^2.$$

The acceleration is negative so is directed to the left.

(e) The mouse changes direction when v_x changes sign. This happens at $t = 6.0$ s and 9.0 s.
(f) The mouse is speeding up when $|v_x|$ is increasing. This happens for $0 < t < 3.0$ s, $6.0\text{ s} < t < 7.0$ s and for $9.0\text{ s} < t < 10.0$ s. The mouse is slowing down when $|v_x|$ is decreasing. This happens at $t = 3.0$ s, for $5.0\text{ s} < t < 6.0$ s and for $7.0\text{ s} < t < 9.0$ s. The mouse is instantaneously at rest at $t = 6.0$ s and $t = 9.0$ s.
(g) No. These formulas apply only when the acceleration is constant. For constant acceleration the graph of v_x versus t is a straight line and that is not the case here.
Reflect: When v_x and a_x have the same sign, the speed is increasing. When v_x and a_x have opposite signs, the speed is decreasing. When $a_x = 0$ the speed is constant.

2.84. Set Up: In time t_S the S-waves travel a distance $d = v_S t_S$ and in time t_P the P-waves travel a distance $d = v_P t_P$.
Solve: (a) $t_S = t_P + 33$ s. $\dfrac{d}{v_S} = \dfrac{d}{v_P} + 33$ s. $d\left(\dfrac{1}{3.5\text{ km/s}} - \dfrac{1}{6.5\text{ km/s}}\right) = 33$ s and $d = 250$ km.
(b) $t = \dfrac{d}{v} = \dfrac{375\text{ km}}{3.5\text{ km/s}} = 107$ s. $t_P = \dfrac{d}{v_P} = \dfrac{375\text{ km}}{6.5\text{ km/s}} = 58$ s. $t_S - t_P = 49$ s

2.85. Set Up: $g_E = 9.80\text{ m/s}^2$ and $g_M = 3.71\text{ m/s}^2$. Take $+y$ to be downward, toward the surface of Mars, and take the origin to be at the surface.
Solve: (a) $v_{0y} = 19{,}300\text{ km/h} = 5.36 \times 10^3\text{ m/s}$, $v_y = 1600\text{ km/h} = 4.44 \times 10^2\text{ m/s}$ and $t = 4.0\text{ min} = 240$ s. $v_y = v_{0y} + a_y t$ gives

$$a_y = \frac{v_y - v_{0y}}{t} = -20.5\text{ m/s}^2 = -2.09g_E = -5.53g_M$$

The minus sign signifies that the acceleration is upward.
(b) $y = -11{,}000$ m, $y_0 = -91$ m, $v_{0y} = 1600\text{ km/h} = 4.44 \times 10^2\text{ m/s}$, $v_y = 321\text{ km/h} = 89.2\text{ m/s}$. Then $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

$$a_y = \frac{v_y - v_{0y}}{2(y - y_0)} = \frac{(89.2\text{ m/s})^2 - (4.44 \times 10^2\text{ m/s})^2}{2(-11{,}000\text{ m} + 91\text{ m})} = -8.67\text{ m/s}^2.$$

$v_y = v_{0y} + a_y t$ gives $t = \dfrac{v_y - v_{0y}}{a_y} = 40.9$ s
(c) For Stage IV, $v_{0y} = 0$, $v_y = 48\text{ km/h} = 13.3\text{ m/s}$, $a_y = 3.71\text{ m/s}^2$, and $y = 0$. Then $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

$$y_0 = -\frac{v_y^2 - v_{0y}^2}{2a_y} = \frac{(13.3\text{ m/s})^2 - 0}{2(3.71\text{ m/s}^2)} = -24\text{ m}.$$

The lander is 24 m above the surface when Stage IV begins. $v_y = v_{0y} + a_y t$ gives

$$t = \frac{v_y - v_{0y}}{a_y} = \frac{13.3\text{ m/s}}{3.71\text{ m/s}^2} = 3.6\text{ s}$$

2.86. Set Up: The acceleration is the slope of the v_x versus t graph.
Solve: (a) $a_x = 0$ for $t > 1.3$ ms, because the v_x versus t graph is horizontal.
(b) The acceleration is approximately constant between 0 and 1.3 ms and is equal to $\dfrac{133\text{ cm/s}}{1.3\text{ ms}} = 1.0 \times 10^5\text{ cm/s}^2$.
At time $t = 1.5$ ms, $a_x = 0$.

2.87. 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. $t_{\text{fall}} + t_s = 10.0$ 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 $v_{0y} = 0$ and $a_y = 9.80\ \text{m/s}^2$.

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

For the sound, $t_s = \dfrac{d}{330\ \text{m/s}} = 10.0$ 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.