(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

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

(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 m/s^2, downward, at all points in the motion.

(f) The graphs are sketched in Figure 2.48.

EVALUATE: $v_y = 0$ 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.

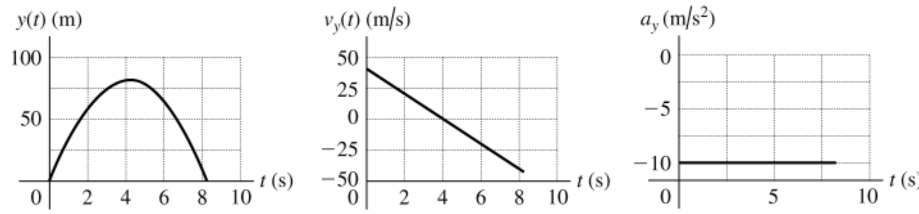

Figure 2.48

2.49. **IDENTIFY:** We can avoid solving for the common height by considering the relation between height, time of fall and acceleration due to gravity and setting up a ratio involving time of fall and acceleration due to gravity.

SET UP: Let g_{En} be the acceleration due to gravity on Enceladus and let g be this quantity on earth. Let h be the common height from which the object is dropped. Let $+y$ be downward, so $y - y_0 = h$. $v_{0y} = 0$

EXECUTE: $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ gives $h = \frac{1}{2}g t_{\text{E}}^2$ and $h = \frac{1}{2}g_{\text{En}} t_{\text{En}}^2$. Combining these two equations gives

$g t_{\text{E}}^2 = g_{\text{En}} t_{\text{En}}^2$ and $g_{\text{En}} = g\left(\dfrac{t_{\text{E}}}{t_{\text{En}}}\right)^2 = (9.80\text{ m/s}^2)\left(\dfrac{1.75\text{ s}}{18.6\text{ s}}\right)^2 = 0.0868\text{ m/s}^2$.

EVALUATE: The acceleration due to gravity is inversely proportional to the square of the time of fall.

2.50. **IDENTIFY:** The acceleration is not constant so the constant acceleration equations cannot be used. Instead, use Eqs.(2.17) and (2.18). Use the values of v_x and of x at $t = 1.0\text{ s}$ to evaluate v_{0x} and x_0.

SET UP: $\int t^n dt = \dfrac{1}{n+1}t^{n+1}$, for $n \geq 0$.

EXECUTE: **(a)** $v_x = v_{0x} + \int_0^t \alpha t dt = v_{0x} + \frac{1}{2}\alpha t^2 = v_{0x} + (0.60\text{ m/s}^3)t^2$. $v_x = 5.0\text{ m/s}$ when $t = 1.0\text{ s}$ gives $v_{0x} = 4.4\text{ m/s}$. Then, at $t = 2.0\text{ s}$, $v_x = 4.4\text{ m/s} + (0.60\text{ m/s}^3)(2.0\text{ s})^2 = 6.8\text{ m/s}$.

(b) $x = x_0 + \int_0^t (v_{0x} + \frac{1}{2}\alpha t^2)dt = x_0 + v_{0x}t + \dfrac{1}{6}\alpha t^3$. $x = 6.0\text{ m}$ at $t = 1.0\text{ s}$ gives $x_0 = 1.4\text{ m}$. Then, at $t = 2.0\text{ s}$,

$x = 1.4\text{ m} + (4.4\text{ m/s})(2.0\text{ s}) + \dfrac{1}{6}(1.24\text{ m/s}^3)(2.0\text{ s})^3 = 11.8\text{ m}$.

(c) $x(t) = 1.4\text{ m} + (4.4\text{ m/s})t + (0.20\text{ m/s}^3)t^3$. $v_x(t) = 4.4\text{ m/s} + (0.60\text{ m/s}^3)t^2$. $a_x(t) = (1.20\text{m/s}^3)t$. The graphs are sketched in Figure 2.50.

EVALUATE: We can verify that $a_x = \frac{dv_x}{dt}$ and $v_x = \frac{dx}{dt}$.

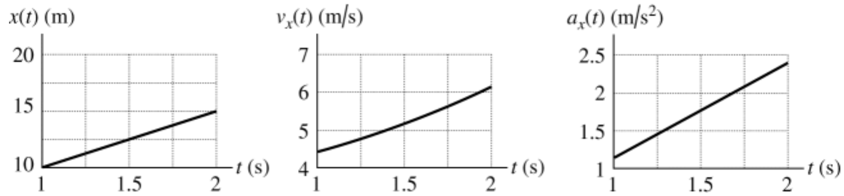

Figure 2.50

2.51. $a_x = At - Bt^2$ with $A = 1.50 \text{ m/s}^3$ and $B = 0.120 \text{ m/s}^4$

(a) IDENTIFY: Integrate $a_x(t)$ to find $v_x(t)$ and then integrate $v_x(t)$ to find $x(t)$.

SET UP: $v_x = v_{0x} + \int_0^t a_x \, dt$

EXECUTE: $v_x = v_{0x} + \int_0^t (At - Bt^2)\, dt = v_{0x} + \frac{1}{2}At^2 - \frac{1}{3}Bt^3$

At rest at $t = 0$ says that $v_{0x} = 0$, so

$v_x = \frac{1}{2}At^2 - \frac{1}{3}Bt^3 = \frac{1}{2}(1.50 \text{ m/s}^3)t^2 - \frac{1}{3}(0.120 \text{ m/s}^4)t^3$

$v_x = (0.75 \text{ m/s}^3)t^2 - (0.040 \text{ m/s}^4)t^3$

SET UP: $x - x_0 + \int_0^t v_x \, dt$

EXECUTE: $x = x_0 + \int_0^t \left(\frac{1}{2}At^2 - \frac{1}{3}Bt^3\right) dt = x_0 + \frac{1}{6}At^3 - \frac{1}{12}Bt^4$

At the origin at $t = 0$ says that $x_0 = 0$, so

$x = \frac{1}{6}At^3 - \frac{1}{12}Bt^4 = \frac{1}{6}(1.50 \text{ m/s}^3)t^3 - \frac{1}{12}(0.120 \text{ m/s}^4)t^4$

$x = (0.25 \text{ m/s}^3)t^3 - (0.010 \text{ m/s}^4)t^4$

EVALUATE: We can check our results by using them to verify that $v_x(t) = \frac{dx}{dt}$ and $a_x(t) = \frac{dv_x}{dt}$.

(b) IDENTIFY and SET UP: At time t, when v_x is a maximum, $\frac{dv_x}{dt} = 0$. (Since $a_x = \frac{dv_x}{dt}$, the maximum velocity is when $a_x = 0$. For earlier times a_x is positive so v_x is still increasing. For later times a_x is negative and v_x is decreasing.)

EXECUTE: $a_x = \frac{dv_x}{dt} = 0$ so $At - Bt^2 = 0$

One root is $t = 0$, but at this time $v_x = 0$ and not a maximum.

The other root is $t = \frac{A}{B} = \frac{1.50 \text{ m/s}^3}{0.120 \text{ m/s}^4} = 12.5 \text{ s}$

At this time $v_x = (0.75 \text{ m/s}^3)t^2 - (0.040 \text{ m/s}^4)t^3$ gives

$v_x = (0.75 \text{ m/s}^3)(12.5 \text{ s})^2 - (0.040 \text{ m/s}^4)(12.5 \text{ s})^3 = 117.2 \text{ m/s} - 78.1 \text{ m/s} = 39.1 \text{ m/s}.$

EVALUATE: For $t < 12.5$ s, $a_x > 0$ and v_x is increasing. For $t > 12.5$ s, $a_x < 0$ and v_x is decreasing.

2.52. **IDENTIFY:** $a(t)$ is the slope of the v versus t graph and the distance traveled is the area under the v versus t graph.

SET UP: The v versus t graph can be approximated by the graph sketched in Figure 2.52.

EXECUTE: **(a)** Slope $= a = 0$ for $t \geq 1.3$ ms.

(b)

$h_{max} = \text{Area under } v\text{-}t \text{ graph} \approx A_{\text{Triangle}} + A_{\text{Rectangle}} \approx \frac{1}{2}(1.3 \text{ ms})(133 \text{ cm/s}) + (2.5 \text{ ms} - 1.3 \text{ ms})(133 \text{ cm/s}) \approx 0.25 \text{ cm}$

(c) $a = $ slope of v-t graph. $a(0.5 \text{ ms}) \approx a(1.0 \text{ ms}) \approx \frac{133 \text{cm/s}}{1.3 \text{ms}} = 1.0 \times 10^5 \text{ cm/s}^2$.

$a(1.5 \text{ ms}) = 0$ because the slope is zero.

(d) $h = \text{area under } v\text{-}t \text{ graph}$. $h(0.5\text{ ms}) \approx A_{\text{Triangle}} = \frac{1}{2}(0.5\text{ ms})(33\text{ cm/s}) = 8.3\times10^{-3}\text{ cm}$.

$h(1.0\text{ ms}) \approx A_{\text{Triangle}} = \frac{1}{2}(1.0\text{ ms})(100\text{ cm/s}) = 5.0\times10^{-2}\text{ cm}$.

$h(1.5\text{ ms}) \approx A_{\text{Triangle}} + A_{\text{Rectangle}} = \frac{1}{2}(1.3\text{ ms})(133\text{ cm/s})(0.2\text{ ms})(1.33) = 0.11\text{ cm}$

EVALUATE: The acceleration is constant until $t = 1.3$ ms, and then it is zero. $g = 980\text{ cm/s}^2$. The acceleration during the first 1.3 ms is much larger than this and gravity can be neglected for the portion of the jump that we are considering.

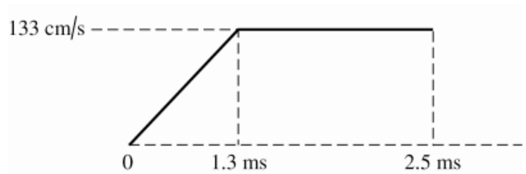

Figure 2.52

2.53. **(a) IDENTIFY and SET UP:** The change in speed is the area under the a_x versus *t* curve between vertical lines at $t = 2.5$ s and $t = 7.5$ s.

EXECUTE: This area is $\frac{1}{2}(4.00\text{ cm/s}^2 + 8.00\text{ cm/s}^2)(7.5\text{ s} - 2.5\text{ s}) = 30.0\text{ cm/s}$

This acceleration is positive so the change in velocity is positive.

(b) Slope of v_x versus *t* is positive and increasing with *t*. The graph is sketched in Figure 2.53.

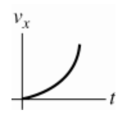

Figure 2.53

EVALUATE: The calculation in part (a) is equivalent to $\Delta v_x = (a_{\text{av-}x})\Delta t$. Since a_x is linear in *t*, $a_{\text{av-}x} = (a_{0x} + a_x)/2$. Thus $a_{\text{av-}x} = \frac{1}{2}(4.00\text{ cm/s}^2 + 8.00\text{ cm/s}^2)$ for the time interval $t = 2.5$ s to $t = 7.5$ s.

2.54. **IDENTIFY:** 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.

SET UP: 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 $\frac{10\text{ mi}}{8\text{ mi/h}} = 1.25\text{ h}$.

EXECUTE: **(a)** An average speed of 4 mi/h for 20 mi gives a total time of $\frac{20\text{ mi}}{4\text{ mi/h}} = 5.0\text{ h}$. 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 $\frac{10\text{ mi}}{3.75\text{ h}} = 2.7\text{ mi/h}$.

(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.

EVALUATE: 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.

2.55. **IDENTIFY:** $v_x(t) = \frac{dx}{dt}$ and $a_x = \frac{dv_x}{dt}$.

SET UP: $\frac{d}{dt}(t^n) = nt^{n-1}$, for $n \geq 1$.

EXECUTE: **(a)** $v_x(t) = (9.00\text{ m/s}^3)t^2 - (20.0\text{ m/s}^2)t + 9.00\text{ m/s}$. $a_x(t) = (18.0\text{ m/s}^3)t - 20.0\text{ m/s}^2$. The graphs are sketched in Figure 2.55.

(b) The particle is instantaneously at rest when $v_x(t) = 0$. $v_{0x} = 0$ and the quadratic formula gives

$t = \dfrac{1}{18.0}(20.0 \pm \sqrt{(20.0)^2 - 4(9.00)(9.00)})\ \text{s} = 1.11\ \text{s} \pm 0.48\ \text{s}$. $t = 0.63$ s and $t = 1.59$ s. These results agree with the v_x-t graphs in part (a).

(c) For $t = 0.63$ s, $a_x = (18.0\ \text{m/s}^3)(0.63\ \text{s}) - 20.0\ \text{m/s}^2 = -8.7\ \text{m/s}^2$. For $t = 1.59$ s, $a_x = +8.6\ \text{m/s}^2$. At $t = 0.63$ s the slope of the v_x-t graph is negative and at $t = 1.59$ s it is positive, so the same answer is deduced from the $v_x(t)$ graph as from the expression for $a_x(t)$.

(d) $v_x(t)$ is instantaneously not changing when $a_x = 0$. This occurs at $t = \dfrac{20.0\ \text{m/s}^2}{18.0\text{m/s}^3} = 1.11$ s.

(e) When the particle is at its greatest distance from the origin, $v_x = 0$ and $a_x < 0$ (so the particle is starting to move back toward the origin). This is the case for $t = 0.63$ s, which agrees with the *x*-*t* graph in part (a). At $t = 0.63$ s, $x = 2.45$ m.

(f) The particle's speed is changing at its greatest rate when a_x has its maximum magnitude. The a_x-t graph in part (a) shows this occurs at $t = 0$ and at $t = 2.00$ s. Since v_x is always positive in this time interval, the particle is speeding up at its greatest rate when a_x is positive, and this is for $t = 2.00$ s.

The particle is slowing down at its greatest rate when a_x is negative and this is for $t = 0$.

EVALUATE: Since $a_x(t)$ is linear in *t*, $v_x(t)$ is a parabola and is symmetric around the point where $|v_x(t)|$ has its minimum value ($t = 1.11$ s). For this reason, the answer to part (d) is midway between the two times in part (c).

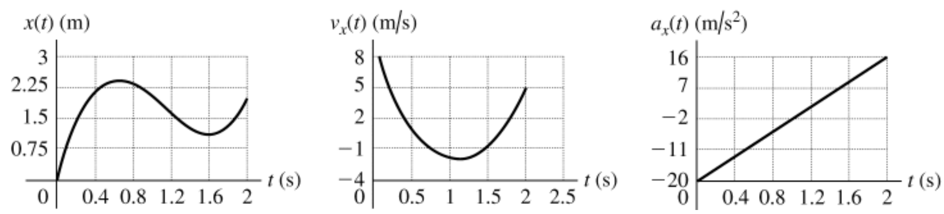

Figure 2.55

2.56. **IDENTIFY:** The average velocity is $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t}$. The average speed is the distance traveled divided by the elapsed time.

SET UP: Let $+x$ be in the direction of the first leg of the race. For the round trip, $\Delta x \ge 0$ and the total distance traveled is 50.0 m. For each leg of the race both the magnitude of the displacement and the distance traveled are 25.0 m.

EXECUTE: **(a)** $|v_{\text{av-}x}| = \left|\dfrac{\Delta x}{\Delta t}\right| = \dfrac{25.0\ \text{m}}{20.0\ \text{s}} = 1.25\ \text{m/s}$. This is the same as the average speed for this leg of the race.

(b) $|v_{\text{av-}x}| = \left|\dfrac{\Delta x}{\Delta t}\right| = \dfrac{25.0\ \text{m}}{15.0\ \text{s}} = 1.67\ \text{m/s}$. This is the same as the average speed for this leg of the race.

(c) $\Delta x = 0$ so $v_{\text{av-}x} = 0$.

(d) The average speed is $\dfrac{50.0\ \text{m}}{35.0\ \text{s}} = 1.43\ \text{m/s}$.

EVALUATE: Note that the average speed for the round trip is not equal to the arithmetic average of the average speeds for each leg.

2.57. **IDENTIFY:** Use information about displacement and time to calculate average speed and average velocity. Take the origin to be at Seward and the positive direction to be west.

(a) SET UP: average speed $= \dfrac{\text{distance traveled}}{\text{time}}$

EXECUTE: The distance traveled (different from the net displacement $(x - x_0)$) is $76\ \text{km} + 34\ \text{km} = 110\ \text{km}$.

Find the total elapsed time by using $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t} = \dfrac{x - x_0}{t}$ to find *t* for each leg of the journey.

Seward to Auora: $t = \dfrac{x - x_0}{v_{\text{av-}x}} = \dfrac{76\ \text{km}}{88\ \text{km/h}} = 0.8636\ \text{h}$

Auora to York: $t = \dfrac{x - x_0}{v_{\text{av-}x}} = \dfrac{-34 \text{ km}}{-72 \text{ km/h}} = 0.4722 \text{ h}$

Total $t = 0.8636 \text{ h} + 0.4722 \text{ h} = 1.336 \text{ h}$.

Then average speed $= \dfrac{110 \text{ km}}{1.336 \text{ h}} = 82 \text{ km/h}$.

(b) SET UP: $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t}$, where Δx is the displacement, not the total distance traveled.

For the whole trip he ends up $76 \text{ km} - 34 \text{ km} = 42 \text{ km}$ west of his starting point. $v_{\text{av-}x} = \dfrac{42 \text{ km}}{1.336 \text{ h}} = 31 \text{ km/h}$.

EVALUATE: The motion is not uniformly in the same direction so the displacement is less than the distance traveled and the magnitude of the average velocity is less than the average speed.

2.58. **IDENTIFY:** The vehicles are assumed to move at constant speed. The speed (mi/h) divided by the frequency with which vehicles pass a given point (vehicles/h) is the total space per vehicle (the length of the vehicle plus space to the next vehicle).

SET UP: $96 \text{ km/h} = 96 \times 10^3 \text{ m/h}$

EXECUTE: **(a)** The total space per vehicle is $\dfrac{96 \times 10^3 \text{ m/h}}{2400 \text{ vehicles/h}} = 40 \text{ m/vehicle}$. Since the average length of a vehicle is 4.6 m, the average space between vehicles is $40 \text{ m} - 4.6 \text{ m} = 35 \text{ m}$.

(b) The frequency of vehicles (vehicles/h) is $\dfrac{96 \times 10^3 \text{ m/h}}{(4.6 + 9.2) \text{ m/vehicle}} = 7000 \text{ vehicles/h}$.

EVALUATE: The traffic flow rate per lane would nearly triple. Note that the traffic flow rate is directly proportional to the traffic speed.

2.59. **(a) IDENTIFY:** Calculate the average acceleration using $a_{\text{av-}x} = \dfrac{\Delta v_x}{\Delta t} = \dfrac{v_x - v_{0x}}{t}$ Use the information about the time and total distance to find his maximum speed.

SET UP: $v_{0x} = 0$ since the runner starts from rest.

$t = 4.0 \text{ s}$, but we need to calculate v_x, the speed of the runner at the end of the acceleration period.

EXECUTE: For the last $9.1 \text{ s} - 4.0 \text{ s} = 5.1 \text{ s}$ the acceleration is zero and the runner travels a distance of $d_1 = (5.1 \text{ s})v_x$ (obtained using $x - x_0 = v_{0x}t + \tfrac{1}{2}a_x t^2$)

During the acceleration phase of 4.0 s, where the velocity goes from 0 to v_x, the runner travels a distance

$$d_2 = \left(\frac{v_{0x} + v_x}{2}\right)t = \frac{v_x}{2}(4.0 \text{ s}) = (2.0 \text{ s})v_x$$

The total distance traveled is 100 m, so $d_1 + d_2 = 100 \text{ m}$. This gives $(5.1 \text{ s})v_x + (2.0 \text{ s})v_x = 100 \text{ m}$.

$v_x = \dfrac{100 \text{ m}}{7.1 \text{ s}} = 14.08 \text{ m/s}$.

Now we can calculate $a_{\text{av-}x}$: $a_{\text{av-}x} = \dfrac{v_x - v_{0x}}{t} = \dfrac{14.08 \text{ s} - 0}{4.0 \text{ s}} = 3.5 \text{ m/s}^2$.

(b) For this time interval the velocity is constant, so $a_{\text{av}-x} = 0$.

EVALUATE: Now that we have v_x we can calculate $d_1 = (5.1 \text{ s})(14.08 \text{ m/s}) = 71.9 \text{ m}$ and $d_2 = (2.0 \text{ s})(14.08 \text{ m/s}) = 28.2 \text{ m}$. So, $d_1 + d_2 = 100 \text{ m}$, which checks.

(c) IDENTIFY and **SET UP:** $a_{\text{av-}x} = \dfrac{v_x - v_{0x}}{t}$, where now the time interval is the full 9.1 s of the race.

We have calculated the final speed to be 14.08 m/s, so

$$a_{\text{av-}x} = \frac{14.08 \text{ m/s}}{9.1 \text{ s}} = 1.5 \text{ m/s}^2.$$

EVALUATE: The acceleration is zero for the last 5.1 s, so it makes sense for the answer in part (c) to be less than half the answer in part (a).

(d) The runner spends different times moving with the average accelerations of parts (a) and (b).

2.60. **IDENTIFY:** Apply the constant acceleration equations to the motion of the sled. The average velocity for a time interval Δt is $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t}$.

SET UP: Let $+x$ be parallel to the incline and directed down the incline. The problem doesn't state how much time it takes the sled to go from the top to 14.4 m from the top.

EXECUTE: **(a)** 14.4 m to 25.6 m: $v_{\text{av-}x} = \dfrac{25.6\text{ m} - 14.4\text{ m}}{2.00\text{ s}} = 5.60\text{ m/s}$. 25.6 to 40.0 m:

$v_{\text{av-}x} = \dfrac{40.0\text{ m} - 25.6\text{ m}}{2.00\text{ s}} = 7.20\text{ m/s}$. 40.0 m to 57.6 m: $v_{\text{av-}x} = \dfrac{57.6\text{ m} - 40.0\text{ m}}{2.00\text{ s}} = 8.80\text{ m/s}$.

(b) For each segment we know $x - x_0$ and t but we don't know v_{0x} or v_x. Let $x_1 = 14.4\text{ m}$ and $x_2 = 25.6\text{ m}$. For this interval $\left(\dfrac{v_1 + v_2}{2}\right) = \dfrac{x_2 - x_1}{t}$ and $at = v_2 - v_1$. Solving for v_2 gives $v_2 = \frac{1}{2}at + \dfrac{x_2 - x_1}{t}$. Let $x_2 = 25.6\text{ m}$ and $x_3 = 40.0\text{ m}$. For this second interval, $\left(\dfrac{v_2 + v_3}{2}\right) = \dfrac{x_3 - x_2}{t}$ and $at = v_3 - v_2$. Solving for v_2 gives

$v_2 = -\frac{1}{2}at + \dfrac{x_3 - x_2}{t}$. Setting these two expressions for v_2 equal to each other and solving for a gives

$$a = \frac{1}{t^2}[(x_3 - x_2) - (x_2 - x_1)] = \frac{1}{(2.00\text{ s})^2}[(40.0\text{ m} - 25.6\text{ m}) - (25.6\text{ m} - 14.4\text{ m})] = 0.80\text{ m/s}^2.$$

Note that this expression for a says $a = \dfrac{v_{\text{av-23}} - v_{\text{av-12}}}{t}$, where $v_{\text{av-12}}$ and $v_{\text{av-23}}$ are the average speeds for successive 2.00 s intervals.

(c) For the motion from $x = 14.4\text{ m}$ to $x = 25.6\text{ m}$, $x - x_0 = 11.2\text{ m}$, $a_x = 0.80\text{ m/s}^2$ and $t = 2.00\text{ s}$.

$x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$ gives $v_{0x} = \dfrac{x - x_0}{t} - \frac{1}{2}a_x t = \dfrac{11.2\text{ m}}{2.00\text{ s}} - \dfrac{1}{2}(0.80\text{ m/s}^2)(2.00\text{ s}) = 4.80\text{ m/s}$.

(d) For the motion from $x = 0$ to $x = 14.4\text{ m}$, $x - x_0 = 14.4\text{ m}$, $v_{0x} = 0$, and $v_x = 4.8\text{ m/s}$.

$x - x_0 = \left(\dfrac{v_{0x} + v_x}{2}\right)t$ gives $t = \dfrac{2(x - x_0)}{v_{0x} + v_x} = \dfrac{2(14.4\text{ m})}{4.8\text{ m/s}} = 6.0\text{ s}$.

(e) For this 1.00 s time interval, $t = 1.00\text{ s}$, $v_{0x} = 4.8\text{ m/s}$, $a_x = 0.80\text{ m/s}^2$.

$x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2 = (4.8\text{ m/s})(1.00\text{ s}) + \frac{1}{2}(0.80\text{ m/s}^2)(1.00\text{ s})^2 = 5.2\text{ m}$.

EVALUATE: With $x = 0$ at the top of the hill, $x(t) = v_{0x}t + \frac{1}{2}a_x t^2 = (0.40\text{ m/s}^2)t^2$. We can verify that $t = 6.0\text{ s}$ gives $x = 14.4\text{ m}$, $t = 8.0\text{ s}$ gives 25.6 m, $t = 10.0\text{ s}$ gives 40.0 m, and $t = 12.0\text{ s}$ gives 57.6 m.

2.61. **IDENTIFY:** When the graph of v_x versus t is a straight line the acceleration is constant, so this motion consists of two constant acceleration segments and the constant acceleration equations can be used for each segment. Since v_x is always positive the motion is always in the $+x$ direction and the total distance moved equals the magnitude of the displacement. The acceleration a_x is the slope of the v_x versus t graph.

SET UP: For the $t = 0$ to $t = 10.0\text{ s}$ segment, $v_{0x} = 4.00\text{ m/s}$ and $v_x = 12.0\text{ m/s}$. For the $t = 10.0\text{ s}$ to 12.0 s segment, $v_{0x} = 12.0\text{ m/s}$ and $v_x = 0$.

EXECUTE: **(a)** For $t = 0$ to $t = 10.0\text{ s}$, $x - x_0 = \left(\dfrac{v_{0x} + v_x}{2}\right)t = \left(\dfrac{4.00\text{ m/s} + 12.0\text{ m/s}}{2}\right)(10.0\text{ s}) = 80.0\text{ m}$. For $t = 10.0\text{ s}$ to $t = 12.0\text{ s}$, $x - x_0 = \left(\dfrac{12.0\text{ m/s} + 0}{2}\right)(2.00\text{ s}) = 12.0\text{ m}$. The total distance traveled is 92.0 m.

(b) $x - x_0 = 80.0\text{ m} + 12.0\text{ m} = 92.0\text{ m}$

(c) For $t = 0$ to 10.0 s, $a_x = \dfrac{12.0\text{ m/s} - 4.00\text{ m/s}}{10.0\text{ s}} = 0.800\text{ m/s}^2$. For $t = 10.0$ s to 10.2 s,

$a_x = \dfrac{0 - 12.0\text{ m/s}}{2.00\text{ s}} = -6.00\text{ m/s}^2$. The graph of a_x versus t is given in Figure 2.61.

EVALUATE: When v_x and a_x are both positive, the speed increases. When v_x is positive and a_x is negative, the speed decreases.

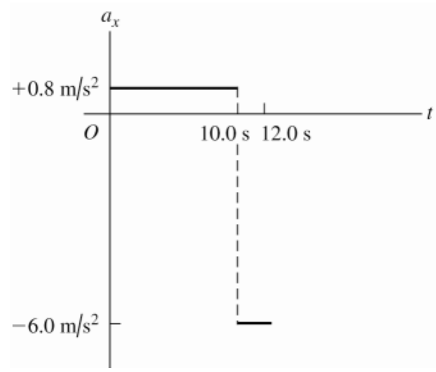

Figure 2.61

2.62. **IDENTIFY:** Since light travels at constant speed, $d = ct$

SET UP: The distance from the earth to the sun is 1.50×10^{11} m. The distance from the earth to the moon is 3.84×10^{8} m. $c = 186{,}000$ mi/s.

EXECUTE: **(a)** $d = ct = (3.0\times10^{8}\text{ m/s})(1\text{ y})\left(\dfrac{365\frac{1}{4}\text{ d}}{1\text{ y}}\right)\left(\dfrac{24\text{ h}}{1\text{ d}}\right)\left(\dfrac{3600\text{ s}}{1\text{ h}}\right) = 9.5\times10^{15}\text{ m}$

(b) $d = ct = (3.0\times10^{8}\text{ m/s})(10^{-9}\text{ s}) = 0.30\text{ m}$

(c) $t = \dfrac{d}{c} = \dfrac{1.5\times10^{11}\text{ m}}{3.0\times10^{8}\text{ m/s}} = 500\text{ s} = 8.33\text{ min}$

(d) $t = \dfrac{d}{c} = \dfrac{2(3.84\times10^{8}\text{ m})}{3.0\times10^{8}\text{ m/s}} = 2.6\text{ s}$

(e) $t = \dfrac{d}{c} = \dfrac{3\times10^{9}\text{ mi}}{186{,}000\text{ mi/s}} = 16{,}100\text{ s} = 4.5\text{ h}$

EVALUATE: The speed of light is very large but it still takes light a measurable length of time to travel a large distance.

2.63. **IDENTIFY:** Speed is distance *d* divided by time *t*. The distance around a circular path is $d = 2\pi R$, where *R* is the radius of the circular path.

SET UP: The radius of the earth is $R_{\rm E} = 6.38\times10^{6}$ m. The earth rotates once in $1\text{ day} = 86{,}400\text{ s}$. The radius of the earth's orbit around the sun is 1.50×10^{11} m and the earth completes this orbit in $1\text{ year} = 3.156\times10^{7}\text{ s}$. The speed of light in vacuum is $c = 3.00\times10^{8}$ m/s.

EXECUTE: **(a)** $v = \dfrac{d}{t} = \dfrac{2\pi R_{\rm E}}{t} = \dfrac{2\pi(6.38\times10^{6}\text{ m})}{86{,}400\text{ s}} = 464\text{ m/s}$.

(b) $v = \dfrac{2\pi R}{t} = \dfrac{2\pi(1.50\times10^{11}\text{ m})}{3.156\times10^{7}\text{ s}} = 2.99\times10^{4}\text{ m/s}$.

(c) The time for light to go around once is $t = \dfrac{d}{c} = \dfrac{2\pi R_{\rm E}}{c} = \dfrac{2\pi(6.38\times10^{6}\text{ m})}{3.00\times10^{8}\text{ m/s}} = 0.1336\text{ s}$. In 1.00 s light would go around the earth $\dfrac{1.00\text{ s}}{0.1336\text{ s}} = 7.49\text{ times}$.

EVALUATE: All these speeds are large compared to speeds of objects in our everyday experience.

2.64. **IDENTIFY:** When the graph of v_x versus *t* is a straight line the acceleration is constant, so this motion consists of two constant acceleration segments and the constant acceleration equations can be used for each segment. For $t = 0$ to 5.0 s, v_x is positive and the ball moves in the $+x$ direction. For $t = 5.0$ s to 20.0 s, v_x is negative and the ball moves in the $-x$ direction. The acceleration a_x is the slope of the v_x versus *t* graph.

SET UP: For the $t = 0$ to $t = 5.0$ s segment, $v_{0x} = 0$ and $v_x = 30.0$ m/s. For the $t = 5.0$ s to $t = 20.0$ s segment, $v_{0x} = -20.0$ m/s and $v_x = 0$.

EXECUTE: **(a)** For $t = 0$ to 5.0 s, $x - x_0 = \left(\frac{v_{0x} + v_x}{2}\right)t = \left(\frac{0 + 30.0\text{ m/s}}{2}\right)(5.0\text{ m/s}) = 75.0\text{ m}$. The ball travels a distance of 75.0 m. For $t = 5.0$ s to 20.0 s, $x - x_0 = \left(\frac{-20.0\text{ m/s} + 0}{2}\right)(15.0\text{ m/s}) = -150.0\text{ m}$. The total distance traveled is $75.0\text{ m} + 150.0\text{ m} = 225.0\text{ m}$.

(b) The total displacement is $x - x_0 = 75.0\text{ m} + (-150.0\text{ m}) = -75.0\text{ m}$. The ball ends up 75.0 m in the negative *x*-direction from where it started.

(c) For $t = 0$ to 5.0 s, $a_x = \frac{30.0\text{ m/s} - 0}{5.0\text{ s}} = 6.00\text{ m/s}^2$. For $t = 5.0$ s to 20.0 s, $a_x = \frac{0 - (-20.0\text{ m/s})}{15.0\text{ s}} = +1.33\text{ m/s}^2$. The graph of a_x versus *t* is given in Figure 2.64.

(d) The ball is in contact with the floor for a small but nonzero period of time and the direction of the velocity doesn't change instantaneously. So, no, the actual graph of $v_x(t)$ is not really vertical at 5.00 s.

EVALUATE: For $t = 0$ to 5.0 s, both v_x and a_x are positive and the speed increases. For $t = 5.0$ s to 20.0 s, v_x is negative and a_x is positive and the speed decreases. Since the direction of motion is not the same throughout, the displacement is not equal to the distance traveled.

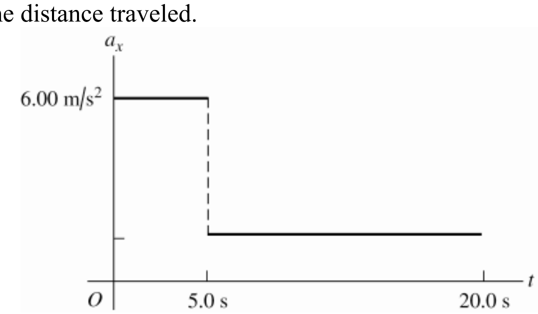

Figure 2.64

2.65. **IDENTIFY** and **SET UP:** Apply constant acceleration equations.
Find the velocity at the start of the second 5.0 s; this is the velocity at the end of the first 5.0 s. Then find $x - x_0$ for the first 5.0 s.

EXECUTE: For the first 5.0 s of the motion, $v_{0x} = 0$, $t = 5.0$ s.

$v_x = v_{0x} + a_x t$ gives $v_x = a_x(5.0\text{ s})$.

This is the initial speed for the second 5.0 s of the motion. For the second 5.0 s:

$v_{0x} = a_x(5.0\text{ s})$, $t = 5.0$ s, $x - x_0 = 150$ m.

$x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$ gives $150\text{ m} = (25\text{ s}^2)a_x + (12.5\text{ s}^2)a_x$ and $a_x = 4.0\text{ m/s}^2$

Use this a_x and consider the first 5.0 s of the motion:

$x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2 = 0 + \frac{1}{2}(4.0\text{ m/s}^2)(5.0\text{ s})^2 = 50.0\text{ m}$.

EVALUATE: The ball is speeding up so it travels farther in the second 5.0 s interval than in the first. In fact, $x - x_0$ is proportional to t^2 since it starts from rest. If it goes 50.0 m in 5.0 s, in twice the time (10.0 s) it should go four times as far. In 10.0 s we calculated it went $50\text{ m} + 150\text{ m} = 200\text{ m}$, which is four times 50 m.

2.66. **IDENTIFY:** Apply $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$ to the motion of each train. A collision means the front of the passenger train is at the same location as the caboose of the freight train at some common time.

SET UP: Let P be the passenger train and F be the freight train. For the front of the passenger train $x_0 = 0$ and for the caboose of the freight train $x_0 = 200$ m. For the freight train $v_F = 15.0$ m/s and $a_F = 0$. For the passenger train $v_P = 25.0$ m/s and $a_P = -0.100\text{ m/s}^2$.

EXECUTE: **(a)** $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$ for each object gives $x_P = v_P t + \frac{1}{2}a_P t^2$ and $x_F = 200\text{ m} + v_F t$. Setting $x_P = x_F$ gives $v_P t + \frac{1}{2}a_P t^2 = 200\text{ m} + v_F t$. $(0.0500\text{ m/s}^2)t^2 - (10.0\text{ m/s})t + 200\text{ m} = 0$. The quadratic formula gives $t = \frac{1}{0.100}\left(+10.0 \pm \sqrt{(10.0)^2 - 4(0.0500)(200)}\right)\text{ s} = (100 \pm 77.5)\text{ s}$. The collision occurs at $t = 100\text{ s} - 77.5\text{ s} = 22.5\text{ s}$. The equations that specify a collision have a physical solution (real, positive *t*), so a collision does occur.

(b) $x_P = (25.0\text{ m/s})(22.5\text{ s}) + \frac{1}{2}(-0.100\text{ m/s}^2)(22.5\text{ s})^2 = 537\text{ m}$. The passenger train moves 537 m before the collision. The freight train moves $(15.0\text{ m/s})(22.5\text{ s}) = 337\text{ m}$.

(c) The graphs of x_F and x_P versus t are sketched in Figure 2.66.

EVALUATE: The second root for the equation for t, $t = 177.5$ s is the time the trains would meet again if they were on parallel tracks and continued their motion after the first meeting.

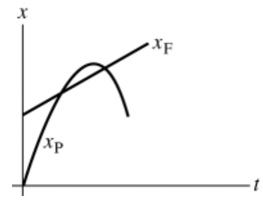

Figure 2.66

2.67. **IDENTIFY:** Apply constant acceleration equations to the motion of the two objects, you and the cockroach. You catch up with the roach when both objects are at the same place at the same time. Let T be the time when you catch up with the cockroach.

SET UP: Take $x = 0$ to be at the $t = 0$ location of the roach and positive x to be in the direction of motion of the two objects.

roach:

$v_{0x} = 1.50\text{ m/s},\ a_x = 0,\ x_0 = 0,\ x = 1.20\text{ m},\ t = T$

you:

$v_{0x} = 0.80\text{ m/s},\ x_0 = -0.90\text{ m},\ x = 1.20\text{ m},\ t = T,\ a_x = ?$

Apply $x - x_0 = v_{0x}t + \frac{1}{2}a_xt^2$ to both objects:

EXECUTE: roach: $1.20\text{ m} = (1.50\text{ m/s})T$, so $T = 0.800$ s.

you: $1.20\text{ m} - (-0.90\text{ m}) = (0.80\text{ m/s})T + \frac{1}{2}a_xT^2$

$2.10\text{ m} = (0.80\text{ m/s})(0.800\text{ s}) + \frac{1}{2}a_x(0.800\text{ s})^2$

$2.10\text{ m} = 0.64\text{ m} + (0.320\text{ s}^2)a_x$

$a_x = 4.6\text{ m/s}^2$.

EVALUATE: Your final velocity is $v_x = v_{0x} + a_xt = 4.48$ m/s. Then $x - x_0 = \left(\frac{v_{0x} + v_x}{2}\right)t = 2.10$ m, which checks.

You have to accelerate to a speed greater than that of the roach so you will travel the extra 0.90 m you are initially behind.

2.68. **IDENTIFY:** The insect has constant speed 15 m/s during the time it takes the cars to come together.

SET UP: Each car has moved 100 m when they hit.

EXECUTE: The time until the cars hit is $\frac{100\text{ m}}{10\text{ m/s}} = 10\text{ s}$. During this time the grasshopper travels a distance of $(15\text{ m/s})(10\text{ s}) = 150\text{ m}$.

EVALUATE: The grasshopper ends up 100 m from where it started, so the magnitude of his final displacement is 100 m. This is less than the total distance he travels since he spends part of the time moving in the opposite direction.

2.69. **IDENTIFY:** Apply constant acceleration equations to each object.

Take the origin of coordinates to be at the initial position of the truck, as shown in Figure 2.69a

Let d be the distance that the auto initially is behind the truck, so $x_0(\text{auto}) = -d$ and $x_0(\text{truck}) = 0$. Let T be the time it takes the auto to catch the truck. Thus at time T the truck has undergone a displacement $x - x_0 = 40.0$ m, so is at $x = x_0 + 40.0\text{ m} = 40.0$ m. The auto has caught the truck so at time T is also at $x = 40.0$ m.

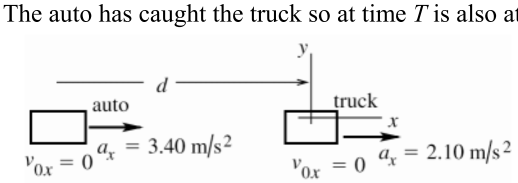

Figure 2.69a

(a) SET UP: Use the motion of the truck to calculate T:

$x - x_0 = 40.0\text{ m}, \;\; v_{0x} = 0$ (starts from rest), $a_x = 2.10\text{ m/s}^2, \;\; t = T$

$x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$

Since $v_{0x} = 0$, this gives $t = \sqrt{\dfrac{2(x - x_0)}{a_x}}$

EXECUTE: $T = \sqrt{\dfrac{2(40.0\text{ m})}{2.10\text{ m/s}^2}} = 6.17\text{ s}$

(b) SET UP: Use the motion of the auto to calculate d:

$x - x_0 = 40.0\text{ m} + d, \;\; v_{0x} = 0, \;\; a_x = 3.40\text{ m/s}^2, \;\; t = 6.17\text{ s}$

$x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$

EXECUTE: $d + 40.0\text{ m} = \frac{1}{2}(3.40\text{ m/s}^2)(6.17\text{ s})^2$

$d = 64.8\text{ m} - 40.0\text{ m} = 24.8\text{ m}$

(c) auto: $v_x = v_{0x} + a_x t = 0 + (3.40\text{ m/s}^2)(6.17\text{ s}) = 21.0\text{ m/s}$

truck: $v_x = v_{0x} + a_x t = 0 + (2.10\text{ m/s}^2)(6.17\text{ s}) = 13.0\text{ m/s}$

(d) The graph is sketched in Figure 2.69b.

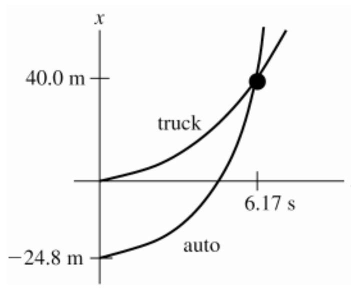

Figure 2.69b

EVALUATE: In part (c) we found that the auto was traveling faster than the truck when they come abreast. The graph in part (d) agrees with this: at the intersection of the two curves the slope of the x-t curve for the auto is greater than that of the truck. The auto must have an average velocity greater than that of the truck since it must travel farther in the same time interval.

2.70. **IDENTIFY:** Apply the constant acceleration equations to the motion of each car. The collision occurs when the cars are at the same place at the same time.

SET UP: Let $+x$ be to the right. Let $x = 0$ at the initial location of car 1, so $x_{01} = 0$ and $x_{02} = D$. The cars collide when $x_1 = x_2$. $v_{0x1} = 0$, $a_{x1} = a_x$, $v_{0x2} = -v_0$ and $a_{x2} = 0$.

EXECUTE: **(a)** $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$ gives $x_1 = \frac{1}{2}a_x t^2$ and $x_2 = D - v_0 t$. $x_1 = x_2$ gives $\frac{1}{2}a_x t^2 = D - v_0 t$.

$\frac{1}{2}a_x t^2 + v_0 t - D = 0$. The quadratic formula gives $t = \dfrac{1}{a_x}\left(-v_0 \pm \sqrt{v_0^2 + 2a_x D}\right)$. Only the positive root is physical, so $t = \dfrac{1}{a_x}\left(-v_0 + \sqrt{v_0^2 + 2a_x D}\right)$.

(b) $v_1 = a_x t = \sqrt{v_0^2 + 2a_x D} - v_0$

(c) The x-t and v_x-t graphs for the two cars are sketched in Figure 2.70.

EVALUATE: In the limit that $a_x = 0$, $D - v_0 t = 0$ and $t = D/v_0$, the time it takes car 2 to travel distance D. In the limit that $v_0 = 0$, $t = \sqrt{\dfrac{2D}{a_x}}$, the time it takes car 1 to travel distance D.

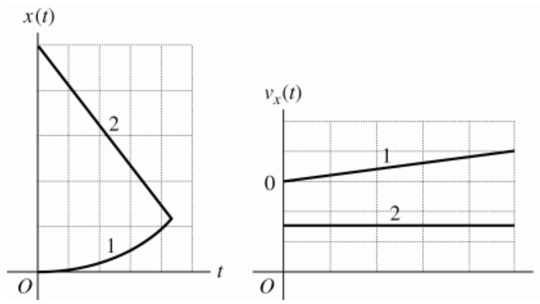

Figure 2.70

2.71. IDENTIFY: The average speed is the distance traveled divided by the time. The average velocity is $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t}$.

SET UP: The distance the ball travels is half the circumference of a circle of diameter 50.0 cm so is $\frac{1}{2}\pi d = \frac{1}{2}\pi(50.0\text{ cm}) = 78.5\text{ cm}$. Let $+x$ be horizontally from the starting point toward the ending point, so Δx equals the diameter of the bowl.

EXECUTE: **(a)** The average speed is $\dfrac{\frac{1}{2}\pi d}{t} = \dfrac{78.5\text{ cm}}{10.0\text{ s}} = 7.85\text{ cm/s}$.

(b) The average velocity is $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t} = \dfrac{50.0\text{ cm}}{10.0\text{ s}} = 5.00\text{ cm/s}$.

EVALUATE: The average speed is greater than the magnitude of the average velocity, since the distance traveled is greater than the magnitude of the displacement.

2.72. IDENTIFY: a_x is the slope of the v_x versus t graph. x is the area under the v_x versus t graph.

SET UP: The slope of v_x is positive and decreasing in magnitude. As v_x increases, the displacement in a given amount of time increases.

EXECUTE: The a_x-t and x-t graphs are sketched in Figure 2.72.

EVALUATE: v_x is the slope of the x versus t graph. The $x(t)$ graph we sketch has zero slope at $t = 0$, the slope is always positive, and the slope initially increases and then approaches a constant. This behavior agrees with the $v_x(t)$ that is given in the graph in the problem.

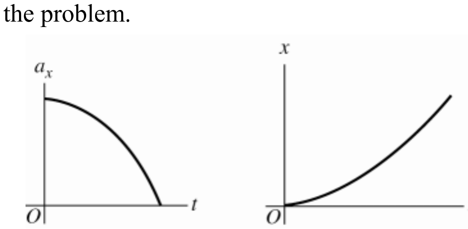

Figure 2.72

2.73. IDENTIFY: Apply constant acceleration equations to each vehicle.

SET UP: **(a)** It is very convenient to work in coordinates attached to the truck.
Note that these coordinates move at constant velocity relative to the earth. In these coordinates the truck is at rest, and the initial velocity of the car is $v_{0x} = 0$. Also, the car's acceleration in these coordinates is the same as in coordinates fixed to the earth.

EXECUTE: First, let's calculate how far the car must travel relative to the truck: The situation is sketched in Figure 2.73.

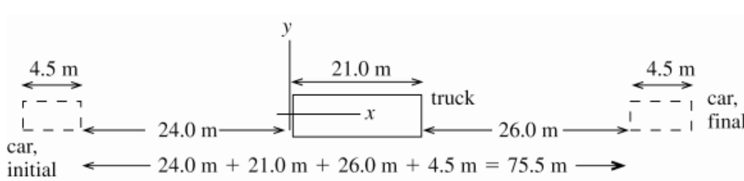

Figure 2.73

The car goes from $x_0 = -24.0$ m to $x = 51.5$ m. So $x - x_0 = 75.5$ m for the car.

Calculate the time it takes the car to travel this distance:

$a_x = 0.600\ \text{m/s}^2,\ \ v_{0x} = 0,\ \ x - x_0 = 75.5\ \text{m},\ \ t = ?$

$x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$

$$t = \sqrt{\frac{2(x-x_0)}{a_x}} = \sqrt{\frac{2(75.5\ \text{m})}{0.600\ \text{m/s}^2}} = 15.86\ \text{s}$$

It takes the car 15.9 s to pass the truck.

(b) Need how far the car travels relative to the earth, so go now to coordinates fixed to the earth. In these coordinates $v_{0x} = 20.0$ m/s for the car. Take the origin to be at the initial position of the car.

$v_{0x} = 20.0\ \text{m/s},\ \ a_x = 0.600\ \text{m/s}^2,\ \ t = 15.86\ \text{s},\ \ x - x_0 = ?$

$x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2 = (20.0\ \text{m/s})(15.86\ \text{s}) + \frac{1}{2}(0.600\ \text{m/s}^2)(15.86\ \text{s})^2$

$x - x_0 = 317.2\ \text{m} + 75.5\ \text{m} = 393\ \text{m}.$

(c) In coordinates fixed to the earth:

$v_x = v_{0x} + a_x t = 20.0\ \text{m/s} + (0.600\ \text{m/s}^2)(15.86\ \text{s}) = 29.5\ \text{m/s}$

EVALUATE: In 15.9 s the truck travels $x - x_0 = (20.0\ \text{m/s})(15.86\ \text{s}) = 317.2\ \text{m}.$ The car travels $392.7\ \text{m} - 317.2\ \text{m} = 75\ \text{m}$ farther than the truck, which checks with part (a). In coordinates attached to the truck, for the car $v_{0x} = 0,\ \ v_x = 9.5$ m/s and in 15.86 s the car travels $x - x_0 = \left(\frac{v_{0x} + v_x}{2}\right)t = 75\ \text{m},$ which checks with part (a).

2.74. **IDENTIFY:** The acceleration is not constant so the constant acceleration equations cannot be used. Instead, use $a_x(t) = \frac{dv_x}{dt}$ and $x = x_0 + \int_0^t v_x(t)dt$.

SET UP: $\int t^n dt = \frac{1}{n+1}t^{n+1}$ for $n \ge 0$.

EXECUTE: **(a)** $x(t) = x_0 + \int_0^t [\alpha - \beta t^2]dt = x_0 + \alpha t - \frac{1}{3}\beta t^3$. $x = 0$ at $t = 0$ gives $x_0 = 0$ and

$x(t) = \alpha t - \frac{1}{3}\beta t^3 = (4.00\ \text{m/s})t - (0.667\ \text{m/s}^3)t^3$. $a_x(t) = \frac{dv_x}{dt} = -2\beta t = -(4.00\ \text{m/s}^3)t$.

(b) The maximum positive *x* is when $v_x = 0$ and $a_x < 0$. $v_x = 0$ gives $\alpha - \beta t^2 = 0$ and

$t = \sqrt{\frac{\alpha}{\beta}} = \sqrt{\frac{4.00\ \text{m/s}}{2.00\ \text{m/s}^3}} = 1.41\ \text{s}$. At this *t*, a_x is negative. For $t = 1.41$ s ,

$x = (4.00\ \text{m/s})(1.41\ \text{s}) - (0.667\ \text{m/s}^3)(1.41\ \text{s})^3 = 3.77\ \text{m}$.

EVALUATE: After $t = 1.41$ s the object starts to move in the $-x$ direction and goes to $x = -\infty$ as $t \to \infty$.

2.75. $a(t) = \alpha + \beta t,$ with $\alpha = -2.00\ \text{m/s}^2$ and $\beta = 3.00\ \text{m/s}^3$

(a) IDENTIFY and **SET UP:** Integrage $a_x(t)$ to find $v_x(t)$ and then integrate $v_x(t)$ to find $x(t)$.

EXECUTE: $v_x = v_{0x} + \int_0^t a_x\ dt = v_{0x} + \int_0^t (\alpha + \beta)\ dt = v_{0x} + \alpha t + \frac{1}{2}\beta t^2$

$x = x_0 + \int_0^t v_x\ dt = x_0 + \int_0^t (v_{0x} + \alpha t + \frac{1}{2}\beta t^2)\ dt = x_0 + v_{0x}t + \frac{1}{2}\alpha t^2 + \frac{1}{6}\beta t^3$

At $t = 0,\ \ x = x_0.$

To have $x = x_0$ at $t_1 = 4.00$ s requires that $v_{0x}t_1 + \frac{1}{2}\alpha t_1^2 + \frac{1}{6}\beta t_1^3 = 0.$

Thus $v_{0x} = -\frac{1}{6}\beta t_1^2 - \frac{1}{2}\alpha t_1 = -\frac{1}{6}(3.00\ \text{m/s}^3)(4.00\ \text{s})^2 - \frac{1}{2}(-2.00\ \text{m/s}^2)(4.00\ \text{s}) = -4.00\ \text{m/s}.$

(b) With v_{0x} as calculated in part (a) and $t = 4.00$ s,

$v_0 = v_{0x} + \alpha t + \frac{1}{2}\beta t^2 = -4.00\ \text{s} + (-2.00\ \text{m/s}^2)(4.00\ \text{s}) + \frac{1}{2}(3.00\ \text{m/s}^3)(4.00\ \text{s})^2 = +12.0\ \text{m/s}.$

EVALUATE: $a_x = 0$ at $t = 0.67$ s. For $t > 0.67$ s, $a_x > 0.$ At $t = 0,$ the particle is moving in the $-x$-direction and is speeding up. After $t = 0.67$ s, when the acceleration is positive, the object slows down and then starts to move in the $+x$-direction with increasing speed.

2.76. **IDENTIFY:** Find the distance the professor walks during the time t it takes the egg to fall to the height of his head.

SET UP: Let $+y$ be downward. The egg has $v_{0y} = 0$ and $a_y = 9.80\ \text{m/s}^2$. At the height of the professor's head, the egg has $y - y_0 = 44.2\ \text{m}$.

EXECUTE: $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ 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.

EVALUATE: 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.

2.77. **IDENTIFY:** Use the constant acceleration equations to establish a relationship between maximum height and acceleration due to gravity and between time in the air and acceleration due to gravity.

SET UP: Let $+y$ be upward. At the maximum height, $v_y = 0$. When the rock returns to the surface, $y - y_0 = 0$.

EXECUTE: **(a)** $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $a_y H = -\frac{1}{2}v_{0y}^2$, which is constant, so $a_\text{E} H_\text{E} = a_\text{M} H_\text{M}$.

$$H_\text{M} = H_\text{E}\left(\frac{a_\text{E}}{a_\text{M}}\right) = H\left(\frac{9.80\ \text{m/s}^2}{3.71\ \text{m/s}^2}\right) = 2.64H.$$

(b) $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ with $y - y_0 = 0$ gives $a_y t = -2v_{0y}$, which is constant, so $a_\text{E} T_\text{E} = a_\text{M} T_\text{M}$.

$$T_\text{M} = T_\text{E}\left[\frac{a_\text{E}}{a_\text{M}}\right] = 2.64T.$$

EVALUATE: On Mars, where the acceleration due to gravity is smaller, the rocks reach a greater height and are in the air for a longer time.

2.78. **IDENTIFY:** Calculate the time it takes her to run to the table and return. This is the time in the air for the thrown ball. The thrown ball is in free-fall after it is thrown. Assume air resistance can be neglected.

SET UP: For the thrown ball, let $+y$ be upward. $a_y = -9.80\ \text{m/s}^2$. $y - y_0 = 0$ when the ball returns to its original position.

EXECUTE: **(a)** It takes her $\frac{5.50\ \text{m}}{2.50\ \text{m/s}} = 2.20\ \text{s}$ to reach the table and an equal time to return. For the ball, $y - y_0 = 0$, $t = 4.40\ \text{s}$ and $a_y = -9.80\ \text{m/s}^2$. $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ gives $v_{0y} = -\frac{1}{2}a_y t = -\frac{1}{2}(-9.80\ \text{m/s}^2)(4.40\ \text{s}) = 21.6\ \text{m/s}$.

(b) Find $y - y_0$ when $t = 2.20\ \text{s}$. $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2 = (21.6\ \text{m/s})(2.20\ \text{s}) + \frac{1}{2}(-9.80\ \text{m/s}^2)(2.20\ \text{s})^2 = 23.8\ \text{m}$

EVALUATE: It takes the ball the same amount of time to reach its maximum height as to return from its maximum height, so when she is at the table the ball is at its maximum height. Note that this large maximum height requires that the act either be done outdoors, or in a building with a very high ceiling.

2.79. **(a) IDENTIFY:** Use constant acceleration equations, with $a_y = g$, downward, to calculate the speed of the diver when she reaches the water.

SET UP: Take the origin of coordinates to be at the platform, and take the $+y$-direction to be downward.

$y - y_0 = +21.3\ \text{m}$, $a_y = +9.80\ \text{m/s}^2$, $v_{0y} = 0$ (since diver just steps off), $v_y = ?$

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

EXECUTE: $v_y = +\sqrt{2a_y(y-y_0)} = +\sqrt{2(9.80\ \text{m/s}^2)(31.3\ \text{m})} = +20.4\ \text{m/s}.$

We know that v_y is positive because the diver is traveling downward when she reaches the water.

The announcer has exaggerated the speed of the diver.

EVALUATE: We could also use $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ to find $t = 2.085\ \text{s}$. The diver gains 9.80 m/s of speed each second, so has $v_y = (9.80\ \text{m/s}^2)(2.085\ \text{s}) = 20.4\ \text{m/s}$ when she reaches the water, which checks.

(b) IDENTIFY: Calculate the initial upward velocity needed to give the diver a speed of 25.0 m/s when she reaches the water. Use the same coordinates as in part (a).

SET UP: $v_{0y} = ?$, $v_y = +25.0\ \text{m/s}$, $a_y = +9.80\ \text{m/s}^2$, $y - y_0 = +21.3\ \text{m}$

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

EXECUTE: $v_{0y} = -\sqrt{v_y^2 - 2a_y(y - y_0)} = -\sqrt{(25.0\text{ m/s})^2 - 2(9.80\text{ m/s}^2)(21.3\text{ m})} = -14.4\text{ m/s}$

(v_{0y} is negative since the direction of the initial velocity is upward.)

EVALUATE: One way to decide if this speed is reasonable is to calculate the maximum height above the platform it would produce:

$v_{0y} = -14.4\text{ m/s}$, $v_y = 0$ (at maximum height), $a_y = +9.80\text{ m/s}^2$, $y - y_0 = ?$

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

$$y - y_0 = \frac{v_y^2 - v_{0y}^2}{2a_y} = \frac{0 - (-14.4\text{ s})^2}{2(+9.80\text{ m/s})} = -10.6\text{ m}$$

This is not physically attainable; a vertical leap of 10.6 m upward is not possible.

2.80. IDENTIFY: The flowerpot is in free-fall. Apply the constant acceleration equations. Use the motion past the window to find the speed of the flowerpot as it reaches the top of the window. Then consider the motion from the windowsill to the top of the window.

SET UP: Let $+y$ be downward. Throughout the motion $a_y = +9.80\text{ m/s}^2$.

EXECUTE: Motion past the window: $y - y_0 = 1.90\text{ m}$, $t = 0.420\text{ s}$, $a_y = +9.80\text{ m/s}^2$. $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ gives $v_{0y} = \frac{y - y_0}{t} - \frac{1}{2}a_y t = \frac{1.90\text{ m}}{0.420\text{ s}} - \frac{1}{2}(9.80\text{ m/s}^2)(0.420\text{ s}) = 2.466\text{ m/s}$. This is the velocity of the flowerpot when it is at the top of the window.

Motion from the windowsill to the top of the window: $v_{0y} = 0$, $v_y = 2.466\text{ m/s}$, $a_y = +9.80\text{ m/s}^2$.

$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $y - y_0 = \frac{v_y^2 - v_{0y}^2}{2a_y} = \frac{(2.466\text{ m/s})^2 - 0}{2(9.80\text{ m/s}^2)} = 0.310\text{ m}$. The top of the window is 0.310 m below the windowsill.

EVALUATE: It takes the flowerpot $t = \frac{v_y - v_{0y}}{a_y} = \frac{2.466\text{ m/s}}{9.80\text{ m/s}^2} = 0.252\text{ s}$ to fall from the sill to the top of the window. Our result says that from the windowsill the pot falls $0.310\text{ m} + 1.90\text{ m} = 2.21\text{ m}$ in $0.252\text{ s} + 0.420\text{ s} = 0.672\text{ s}$. $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2 = \frac{1}{2}(9.80\text{ m/s}^2)(0.672\text{ s})^2 = 2.21\text{ m}$, which checks.

2.81. IDENTIFY: For parts (a) and (b) apply the constant acceleration equations to the motion of the bullet. In part (c) neglect air resistance, so the bullet is free-fall. Use the constant acceleration equations to establish a relation between initial speed v_0 and maximum height *H*.

SET UP: For parts (a) and (b) let $+x$ be in the direction of motion of the bullet. For part (c) let $+y$ be upward, so $a_y = -g$. At the maximum height, $v_y = 0$.

EXECUTE: **(a)** $x - x_0 = 0.700\text{ m}$, $v_{0x} = 0$, $v_x = 965\text{ m/s}$. $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ gives

$a_x = \frac{v_x^2 - v_{0x}^2}{2(x - x_0)} = \frac{(965\text{ m/s})^2 - 0}{2(0.700\text{ m})} = 6.65\times10^5\text{ m/s}^2$. $\frac{a_x}{g} = 6.79\times10^4$, so $a_x = (6.79\times10^4)g$.

(b) $x - x_0 = \left(\frac{v_{0x} + v_x}{2}\right)t$ gives $t = \frac{2(x - x_0)}{v_{0x} + v_x} = \frac{2(0.700\text{ m})}{0 + 965\text{ m/s}} = 1.45\text{ ms}$.

(c) $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ and $v_y = 0$ gives $\frac{v_{0y}^2}{y - y_0} = -2a_y$, which is constant. $\frac{v_{01}^2}{H_1} = \frac{v_{02}^2}{H_2}$.

$$H_2 = H_1\left(\frac{v_{02}^2}{v_{01}^2}\right) = H\left(\frac{\frac{1}{2}v_{01}}{v_{01}}\right)^2 = H/4.$$

EVALUATE: $H = \frac{v_y^2 - v_{0y}^2}{2a_y} = \frac{-(965\text{ m/s})^2}{2(-9.80\text{ m/s}^2)} = 47.5\text{ km}$. Rifle bullets fired vertically don't actually reach such a large height; it is not an accurate approximation to ignore air resistance.

2.82. IDENTIFY: Assume the firing of the second stage lasts a very short time, so the rocket is in free-fall after 25.0 s. The motion consists of two constant acceleration segments.

SET UP: Let $+y$ be upward. After $t = 25.0\text{ s}$, $a_y = -9.80\text{ m/s}^2$.

EXECUTE: **(a)** Find the height of the rocket at $t = 25.0\text{ s}$: $v_{0y} = 0$, $a_y = +3.50\text{ m/s}^2$, $t = 25.0\text{ s}$.

$y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2 = \frac{1}{2}(3.50\text{ m/s})(25.0\text{ s})^2 = 1.0938\times10^3\text{ m}$. Find the displacement of the rocket from firing of the second stage until the maximum height is reached: $v_{0y} = 132.5 \text{ m/s}$, $v_y = 0$ (at maximum height), $a_y = -9.80 \text{ m/s}^2$.

$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $y - y_0 = \dfrac{v_y^2 - v_{0y}^2}{2a_y} = \dfrac{0 - (132.5 \text{ m/s})^2}{2(-9.80 \text{ m/s}^2)} = 896 \text{ m}$. The total height is

$1094 \text{ m} + 896 \text{ m} = 1990 \text{ m}$.

(b) $v_{0y} = +132.5 \text{ m/s}$, $a_y = -9.80 \text{ m/s}^2$, $y - y_0 = -1094 \text{ m}$. $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ gives

$-1093.8 \text{ m} = (132.5 \text{ m/s})t - (4.90 \text{ m/s}^2)t^2$. The quadratic formula gives $t = 33.7 \text{ s}$ as the positive root. The rocket returns to the launch pad 33.7 s after the second stage fires.

(c) $v_y = v_{0y} + a_y t = +132.5 \text{ m/s} + (-9.80 \text{ m/s}^2)(33.7 \text{ s}) = -198 \text{ m/s}$. The rocket has speed 198 m/s as it reaches the launch pad.

EVALUATE: The speed when the rocket returns to the launch pad is greater than 132.5 m/s. When the rocket returns to the height where the second stage fired, its velocity is 132.5 m/s downward and it continues to speed up during the rest of the descent.

2.83. Take positive y to be upward.

(a) IDENTIFY: Consider the motion from when he applies the acceleration to when the shot leaves his hand.

SET UP: $v_{0y} = 0$, $v_y = ?$, $a_y = 45.0 \text{ m/s}^2$, $y - y_0 = 0.640 \text{ m}$

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

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

(b) IDENTIFY: 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.

SET UP: $y_0 = 2.20 \text{ m}$, $y = ?$, $a_y = -9.80 \text{ m/s}^2$ (free fall), $v_{0y} = 7.59 \text{ m/s}$

(from part (a), $v_y = 0$ at maximum height)

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

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

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

(c) IDENTIFY: 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.

SET UP: $y_0 = 2.20 \text{ m}$, $y = 1.83 \text{ m}$, $a_y = -9.80 \text{ m/s}^2$, $v_{0y} = +7.59 \text{ m/s}$, $t = ?$ $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$

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

$= (7.59 \text{ m/s})t - (4.90 \text{ m/s}^2)t^2$

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

Use the quadratic formula to solve for t:

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

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

EVALUATE: Calculate the time to the maximum height: $v_y = v_{0y} + a_y t$, so

$t = (v_y - v_{0y})/a_y = -(7.59 \text{ m/s})/(-9.80 \text{ m/s}^2) = 0.77 \text{ s}$. 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.

2.84. **IDENTIFY:** The teacher is in free-fall and falls with constant acceleration 9.80 m/s^2, downward. The sound from her shout travels at constant speed. The sound travels from the top of the cliff, reflects from the ground and then travels upward to her present location. If the height of the cliff is h and she falls a distance y in 3.0 s, the sound must travel a distance $h + (h - y)$ in 3.0 s.

SET UP: Let $+y$ be downward, so for the teacher $a_y = 9.80 \text{ m/s}^2$ and $v_{0y} = 0$. Let $y = 0$ at the top of the cliff.

EXECUTE: **(a)** For the teacher, $y = \frac{1}{2}(9.80 \text{ m/s}^2)(3.0 \text{ s})^2 = 44.1 \text{ m}$. For the sound, $h + (h - y) = v_s t$.

$h = \frac{1}{2}(v_s t + y) = \frac{1}{2}([340 \text{ m/s}][3.0 \text{ s}] + 44.1 \text{ m}) = 532 \text{ m}$, which rounds to 530 m.

(b) $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $v_y = \sqrt{2a_y(y - y_0)} = \sqrt{2(9.80 \text{ m/s}^2)(532 \text{ m})} = 102 \text{ m/s}$.

EVALUATE: She is in the air for $t = \frac{v_y - v_{0y}}{a_y} = \frac{102 \text{ m/s}}{9.80 \text{ m/s}^2} = 10.4 \text{ s}$ and strikes the ground at high speed.

2.85. **IDENTIFY** and **SET UP:** Let $+y$ be upward. Each ball moves with constant acceleration $a_y = -9.80 \text{ m/s}^2$. In parts (c) and (d) require that the two balls be at the same height at the same time.

EXECUTE: **(a)** At ceiling, $v_y = 0$, $y - y_0 = 3.0$ m, $a_y = -9.80 \text{ m/s}^2$. Solve for v_{0y}.

$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $v_{0y} = 7.7$ m/s.

(b) $v_y = v_{0y} + a_y t$ with the information from part (a) gives $t = 0.78$ s.

(c) Let the first ball travel downward a distance *d* in time *t*. It starts from its maximum height, so $v_{0y} = 0$.

$$y - y_0 = v_{0_y} t = \tfrac{1}{2} a_y t^2 \text{ gives } d = (4.9 \text{ m/s}^2)t^2$$

The second ball has $v_{0y} = \frac{2}{3}(7.7 \text{ m/s}) = 5.1$ m/s. In time *t* it must travel upward $3.0 \text{ m} - d$ to be at the same place as the first ball.

$y - y_0 = v_{0y} t + \frac{1}{2} a_y t^2$ gives $3.0 \text{ m} - d = (5.1 \text{ m/s})t - (4.9 \text{ m/s}^2)t^2$.

We have two equations in two unknowns, *d* and *t*. Solving gives $t = 0.59$ s and $d = 1.7$ m.

(d) $3.0 \text{ m} - d = 1.3$ m

EVALUATE: In 0.59 s the first ball falls $d = (4.9 \text{ m/s}^2)(0.59 \text{ s})^2 = 1.7$ m, so is at the same height as the second ball.

2.86. **IDENTIFY:** The helicopter has two segments of motion with constant acceleration: upward acceleration for 10.0 s and then free-fall until it returns to the ground. Powers has three segments of motion with constant acceleration: upward acceleration for 10.0 s, free-fall for 7.0 s and then downward acceleration of 2.0 m/s^2.

SET UP: Let $+y$ be upward. Let $y = 0$ at the ground.

EXECUTE: **(a)** When the engine shuts off both objects have upward velocity $v_y = v_{0y} + a_y t = (5.0 \text{ m/s}^2)(10.0 \text{ s}) = 50.0$ m/s and are at $y = v_{0y} t + \frac{1}{2} a_y t^2 = \frac{1}{2}(5.0 \text{ m/s}^2)(10.0 \text{ s})^2 = 250$ m. For the helicopter, $v_y = 0$ (at the maximum height), $v_{0y} = +50.0$ m/s, $y_0 = 250$ m, and $a_y = -9.80 \text{ m/s}^2$.

$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $y = \frac{v_y^2 - v_{0y}^2}{2a_y} + y_0 = \frac{0 - (50.0 \text{ m/s})^2}{2(-9.80 \text{ m/s}^2)} + 250 \text{ m} = 378$ m, which rounds to 380 m.

(b) The time for the helicopter to crash from the height of 250 m where the engines shut off can be found using $v_{0y} = +50.0$ m/s, $a_y = -9.80 \text{ m/s}^2$, and $y - y_0 = -250$ m. $y - y_0 = v_{0y} t + \frac{1}{2} a_y t^2$ gives $-250 \text{ m} = (50.0 \text{ m/s})t - (4.90 \text{ m/s}^2)t^2$. $(4.90 \text{ m/s}^2)t^2 - (50.0 \text{ m/s})t - 250 \text{ m} = 0$. The quadratic formula gives $t = \frac{1}{9.80}\left(50.0 \pm \sqrt{(50.0)^2 + 4(4.90)(250)}\right)$ s. Only the positive solution is physical, so $t = 13.9$ s. Powers therefore has free-fall for 7.0 s and then downward acceleration of 2.0 m/s^2 for $13.9 \text{ s} - 7.0 \text{ s} = 6.9$ s. After 7.0 s of free-fall he is at $y - y_0 = v_{0y} t + \frac{1}{2} a_y t^2 = 250 \text{ m} + (50.0 \text{ m/s})(7.0 \text{ s}) + \frac{1}{2}(-9.80 \text{ m/s}^2)(7.0 \text{ s})^2 = 360$ m and has velocity $v_x = v_{0x} + a_x t = 50.0 \text{ m/s} + (-9.80 \text{ m/s}^2)(7.0 \text{ s}) = -18.6$ m/s. After the next 6.9 s he is at $y - y_0 = v_{0y} t + \frac{1}{2} a_y t^2 = 360 \text{ m} + (-18.6 \text{ m/s})(6.9 \text{ s}) + \frac{1}{2}(-2.00 \text{ m/s}^2)(6.9 \text{ s})^2 = 184$ m. Powers is 184 m above the ground when the helicopter crashes.

EVALUATE: When Powers steps out of the helicopter he retains the initial velocity he had in the helicopter but his acceleration changes abruptly from 5.0 m/s^2 upward to 9.80 m/s^2 downward. Without the jet pack he would have crashed into the ground at the same time as the helicopter. The jet pack slows his descent so he is above the ground when the helicopter crashes.

2.87. **IDENTIFY:** Apply the constant acceleration equations to his motion. Consider two segments of the motion: the last 1.0 s and the motion prior to that. The final velocity for the first segment is the initial velocity for the second segment.

SET UP: Let $+y$ be downward, so $a_y = +9.80 \text{ m/s}^2$.

EXECUTE: Motion from the roof to a height of $h/4$ above ground: $y - y_0 = 3h/4$, $a_y = +9.80 \text{ m/s}^2$, $v_{0y} = 0$.

$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $v_y = \sqrt{2a_y(y - y_0)} = 3.834\sqrt{h}\ \sqrt{\text{m}}/\text{s}$. Motion from height of $h/4$ to the ground: $y - y_0 = h/4$, $a_y = +9.80 \text{ m/s}^2$, $v_{0y} = 3.834\sqrt{h}\ \sqrt{\text{m}}/\text{s}$, $t = 1.00$ s. $y - y_0 = v_{0y} t + \frac{1}{2} a_y t^2$ gives

$\frac{h}{4} = 3.834\sqrt{h}\ \sqrt{\text{m}} + 4.90\text{ m}$. Let $h = u^2$ and solve for *u*. $\frac{1}{4}u^2 - 3.834u\ \sqrt{\text{m}} - 4.90\text{ m} = 0$.

$u = 2\left(3.834 \pm \sqrt{(-3.834)^2 + 4.90}\right)\sqrt{\text{m}}$. Only the positive root is physical, so $u = 16.52\ \sqrt{\text{m}}$ and $h = u^2 = 273\text{ m}$, which rounds to 270 m. The building is 270 m tall.

EVALUATE: With $h = 273\text{ m}$ the total time of fall is $t = \sqrt{\frac{2h}{a_y}} = 7.46\text{ s}$. In $7.47\text{ s} - 1.00\text{ s} = 6.46\text{ s}$ Spider-Man falls a distance $y - y_0 = \frac{1}{2}(9.80\text{ m/s}^2)(6.46\text{ s})^2 = 204\text{ m}$. This leaves 69 m for the last 1.0 s of fall, which is $h/4$.

2.88. **IDENTIFY:** Apply constant acceleration equations to the motion of the rock. Sound travels at constant speed.

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

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

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

(b) You would have calculated $d = \frac{1}{2}(9.80\text{ m/s}^2)(10.0\text{ s})^2 = 490\text{ m}$. 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.

EVALUATE: Once we know *d* we can calculate that $t_{\text{fall}} = 8.8\text{ s}$ and $t_{\text{s}} = 1.2\text{ s}$. 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.

2.89. **(a) IDENTIFY:** Let $+y$ be upward. The can has constant acceleration $a_y = -g$. The initial upward velocity of the can equals the upward velocity of the scaffolding; first find this speed.

SET UP: $y - y_0 = -15.0\text{ m},\ t = 3.25\text{ s},\ a_y = -9.80\text{ m/s}^2,\ v_{0y} = ?$

EXECUTE: $y - y_0 = v_{0y}t + \frac{1}{2}a_yt^2$ gives $v_{0y} = 11.31\text{ m/s}$

Use this v_{0y} in $v_y = v_{0y} + a_yt$ to solve for v_y: $v_y = -20.5\text{ m/s}$

(b) IDENTIFY: Find the maximum height of the can, above the point where it falls from the scaffolding:

SET UP: $v_y = 0,\ v_{0y} = +11.31\text{ m/s},\ a_y = -9.80\text{ m/s}^2,\ y - y_0 = ?$

EXECUTE: $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $y - y_0 = 6.53\text{ m}$

The can will pass the location of the other painter. Yes, he gets a chance.

EVALUATE: Relative to the ground the can is initially traveling upward, so it moves upward before stopping momentarily and starting to fall back down.

2.90. **IDENTIFY:** Both objects are in free-fall. Apply the constant acceleration equations to the motion of each person.

SET UP: Let $+y$ be downward, so $a_y = +9.80\text{ m/s}^2$ for each object.

EXECUTE: **(a)** Find the time it takes the student to reach the ground: $y - y_0 = 180\text{ m}$, $v_{0y} = 0$, $a_y = 9.80\text{ m/s}^2$.

$y - y_0 = v_{0y}t + \frac{1}{2}a_yt^2$ gives $t = \sqrt{\frac{2(y - y_0)}{a_y}} = \sqrt{\frac{2(180\text{ m})}{9.80\text{ m/s}^2}} = 6.06\text{ s}$. Superman must reach the ground in $6.06\text{ s} - 5.00\text{ s} = 1.06\text{ s}$: $t = 1.06\text{ s}$, $y - y_0 = 180\text{ m}$, $a_y = +9.80\text{ m/s}^2$. $y - y_0 = v_{0y}t + \frac{1}{2}a_yt^2$ gives

$v_{0y} = \frac{y - y_0}{t} - \frac{1}{2}a_yt = \frac{180\text{ m}}{1.06\text{ s}} - \frac{1}{2}(9.80\text{ m/s}^2)(1.06\text{ s}) = 165\text{ m/s}$. Superman must have initial speed $v_0 = 165\text{ m/s}$.

(b) The graphs of *y-t* for Superman and for the student are sketched in Figure 2.90.

(c) The minimum height of the building is the height for which the student reaches the ground in 5.00 s, before Superman jumps. $y - y_0 = v_{0y}t + \frac{1}{2}a_yt^2 = \frac{1}{2}(9.80\text{ m/s}^2)(5.00\text{ s})^2 = 122\text{ m}$. The skyscraper must be at least 122 m high.

EVALUATE: 165 m/s = 369 mi/h, so only Superman could jump downward with this initial speed.

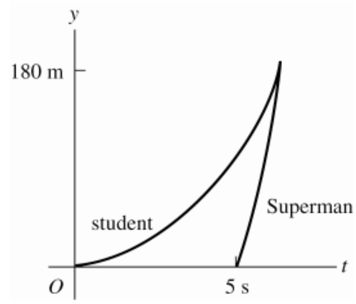

Figure 2.90

2.91. **IDENTIFY:** Apply constant acceleration equations to the motion of the rocket and to the motion of the canister after it is released. Find the time it takes the canister to reach the ground after it is released and find the height of the rocket after this time has elapsed. The canister travels up to its maximum height and then returns to the ground.

SET UP: Let $+y$ be upward. At the instant that the canister is released, it has the same velocity as the rocket. After it is released, the canister has $a_y = -9.80\text{ m/s}^2$. At its maximum height the canister has $v_y = 0$.

EXECUTE: **(a)** Find the speed of the rocket when the canister is released: $v_{0y} = 0$, $a_y = 3.30\text{ m/s}^2$, $y - y_0 = 235\text{ m}$. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $v_y = \sqrt{2a_y(y - y_0)} = \sqrt{2(3.30\text{ m/s}^2)(235\text{ m})} = 39.4\text{ m/s}$. For the motion of the canister after it is released, $v_{0y} = +39.4\text{ m/s}$, $a_y = -9.80\text{ m/s}^2$, $y - y_0 = -235\text{ m}$.
$y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ gives $-235\text{ m} = (39.4\text{ m/s})t - (4.90\text{ m/s}^2)t^2$. The quadratic formula gives $t = 12.0\text{ s}$ as the positive solution. Then for the motion of the rocket during this 12.0 s,
$y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2 = 235\text{ m} + (39.4\text{ m/s})(12.0\text{ s}) + \frac{1}{2}(3.30\text{ m/s}^2)(12.0\text{ s})^2 = 945\text{ m}$.

(b) Find the maximum height of the canister above its release point: $v_{0y} = +39.4\text{ m/s}$, $v_y = 0$, $a_y = -9.80\text{ m/s}^2$.
$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $y - y_0 = \dfrac{v_y^2 - v_{0y}^2}{2a_y} = \dfrac{0 - (39.4\text{ m/s})^2}{2(-9.80\text{ m/s}^2)} = 79.2\text{ m}$. After its release the canister travels upward 79.2 m to its maximum height and then back down $79.2\text{ m} + 235\text{ m}$ to the ground. The total distance it travels is 393 m.

EVALUATE: The speed of the rocket at the instant that the canister returns to the launch pad is $v_y = v_{0y} + a_y t = 39.4\text{ m/s} + (3.30\text{ m/s}^2)(12.0\text{ s}) = 79.0\text{ m/s}$. We can calculate its height at this instant by $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ with $v_{0y} = 0$ and $v_y = 79.0\text{ m/s}$. $y - y_0 = \dfrac{v_y^2 - v_{0y}^2}{2a_y} = \dfrac{(79.0\text{ m/s})^2}{2(3.30\text{ m/s}^2)} = 946\text{ m}$, which agrees with our previous calculation.

2.92. **IDENTIFY:** Both objects are in free-fall and move with constant acceleration 9.80 m/s^2, downward. The two balls collide when they are at the same height at the same time.

SET UP: Let $+y$ be upward, so $a_y = -9.80\text{ m/s}^2$ for each ball. Let $y = 0$ at the ground. Let ball *A* be the one thrown straight up and ball *B* be the one dropped from rest at height *H*. $y_{0A} = 0$, $y_{0B} = H$.

EXECUTE: **(a)** $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ applied to each ball gives $y_A = v_0 t - \frac{1}{2}gt^2$ and $y_B = H - \frac{1}{2}gt^2$. $y_A = y_B$ gives $v_0 t - \frac{1}{2}gt^2 = H - \frac{1}{2}gt^2$ and $t = \dfrac{H}{v_0}$.

(b) For ball *A* at its highest point, $v_{yA} = 0$ and $v_y = v_{0y} + a_y t$ gives $t = \dfrac{v_0}{g}$. Setting this equal to the time in part (a) gives $\dfrac{H}{v_0} = \dfrac{v_0}{g}$ and $H = \dfrac{v_0^2}{g}$.

EVALUATE: In part (a), using $t = \dfrac{H}{v_0}$ in the expressions for y_A and y_B gives $y_A = y_B = H\left(1 - \dfrac{gH}{2v_0^2}\right)$. *H* must be less than $\dfrac{2v_0^2}{g}$ in order for the balls to collide before ball *A* returns to the ground. This is because it takes ball *A* time $t = \frac{2v_0}{g}$ to return to the ground and ball B falls a distance $\frac{1}{2}gt^2 = \frac{2v_0^2}{g}$ during this time. When $H = \frac{2v_0^2}{g}$ the two balls collide just as ball A reaches the ground and for H greater than this ball A reaches the ground before they collide.

2.93. **IDENTIFY** and **SET UP:** Use $v_x = dx/dt$ and $a_x = dv_x/dt$ to calculate $v_x(t)$ and $a_x(t)$ for each car. Use these equations to answer the questions about the motion.

EXECUTE: $x_A = \alpha t + \beta t^2$, $v_{Ax} = \frac{dx_A}{dt} = \alpha + 2\beta t$, $a_{Ax} = \frac{dv_{Ax}}{dt} = 2\beta$

$x_B = \gamma t^2 - \delta t^3$, $v_{Bx} = \frac{dx_B}{dt} = 2\gamma t - 3\delta t^2$, $a_{Bx} = \frac{dv_{Bx}}{dt} - 2\gamma - 6\delta t$

(a) IDENTIFY and **SET UP:** The car that initially moves ahead is the one that has the larger v_{0x}.

EXECUTE: At $t = 0$, $v_{Ax} = \alpha$ and $v_{Bx} = 0$. So initially car A moves ahead.

(b) IDENTIFY and **SET UP:** Cars at the same point implies $x_A = x_B$.

$\alpha t + \beta t^2 = \gamma t^2 - \delta t^3$

EXECUTE: One solution is $t = 0$, which says that they start from the same point. To find the other solutions, divide by t: $\alpha + \beta t = \gamma t - \delta t^2$

$\delta t^2 + (\beta - \gamma)t + \alpha = 0$

$$t = \frac{1}{2\delta}\left(-(\beta-\gamma) \pm \sqrt{(\beta-\gamma)^2 - 4\delta\alpha}\right) = \frac{1}{0.40}\left(+1.60 \pm \sqrt{(1.60)^2 - 4(0.20)(2.60)}\right) = 4.00 \text{ s} \pm 1.73 \text{ s}$$

So $x_A = x_B$ for $t = 0$, $t = 2.27$ s and $t = 5.73$ s.

EVALUATE: Car A has constant, positive a_x. Its v_x is positive and increasing. Car B has $v_{0x} = 0$ and a_x that is initially positive but then becomes negative. Car B initially moves in the $+x$-direction but then slows down and finally reverses direction. At $t = 2.27$ s car B has overtaken car A and then passes it. At $t = 5.73$ s, car B is moving in the $-x$-direction as it passes car A again.

(c) IDENTIFY: The distance from A to B is $x_B - x_A$. The rate of change of this distance is $\frac{d(x_B - x_A)}{dt}$. If this distance is not changing, $\frac{d(x_B - x_A)}{dt} = 0$. But this says $v_{Bx} - v_{Ax} = 0$. (The distance between A and B is neither decreasing nor increasing at the instant when they have the same velocity.)

SET UP: $v_{Ax} = v_{Bx}$ requires $\alpha + 2\beta t = 2\gamma t - 3\delta t^2$

EXECUTE: $3\delta t^2 + 2(\beta - \gamma)t + \alpha = 0$

$$t = \frac{1}{6\delta}\left(-2(\beta-\gamma) \pm \sqrt{4(\beta-\gamma)^2 - 12\delta\alpha}\right) = \frac{1}{1.20}\left(3.20 \pm \sqrt{4(-1.60)^2 - 12(0.20)(2.60)}\right)$$

$t = 2.667 \text{ s} \pm 1.667$ s, so $v_{Ax} = v_{Bx}$ for $t = 1.00$ s and $t = 4.33$ s.

EVALUATE: At $t = 1.00$ s, $v_{Ax} = v_{Bx} = 5.00$ m/s. At $t = 4.33$ s, $v_{Ax} = v_{Bx} = 13.0$ m/s. Now car B is slowing down while A continues to speed up, so their velocities aren't ever equal again.

(d) IDENTIFY and **SET UP:** $a_{Ax} = a_{Bx}$ requires $2\beta = 2\gamma - 6\delta t$

EXECUTE: $t = \frac{\gamma - \beta}{3\delta} = \frac{2.80 \text{ m/s}^2 - 1.20 \text{ m/s}^2}{3(0.20 \text{ m/s}^3)} = 2.67$ s.

EVALUATE: At $t = 0$, $a_{Bx} > a_{Ax}$, but a_{Bx} is decreasing while a_{Ax} is constant. They are equal at $t = 2.67$ s but for all times after that $a_{Bx} < a_{Ax}$.

2.94. **IDENTIFY:** The apple has two segments of motion with constant acceleration. For the motion from the tree to the top of the grass the acceleration is g, downward and the apple falls a distance $H - h$. For the motion from the top of the grass to the ground the acceleration is a, upward, the apple travels downward a distance h, and the final speed is zero.

SET UP: Let $+y$ be upward and let $y = 0$ at the ground. The apple is initially a height $H + h$ above the ground.

EXECUTE: **(a)** Motion from $y_0 = H + h$ to $y = H$: $y - y_0 = -H$, $v_{0y} = 0$, $a_y = -g$. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $v_y = -\sqrt{2gH}$. The speed of the apple is $\sqrt{2gH}$ as it enters the grass.

(b) Motion from $y_0 = h$ to $y = 0$: $y - y_0 = -h$, $v_{0y} = -\sqrt{2gH}$. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

$a_y = \dfrac{v_y^2 - v_{0y}^2}{2(y - y_0)} = \dfrac{-2gH}{2(-h)} = \dfrac{gH}{h}$. The acceleration of the apple while it is in the grass is gH/h, upward.

(c) Graphs of y-t, v_y-t and a_y-t are sketched in Figure 2.94.

EVALUATE: The acceleration a produced by the grass increases when H increases and decreases when h increases.

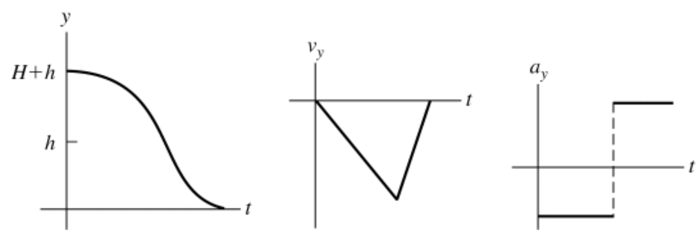

Figure 2.94

2.95. IDENTIFY: Apply constant acceleration equations to the motion of the two objects, the student and the bus.

SET UP: For convenience, let the student's (constant) speed be v_0 and the bus's initial position be x_0. Note that these quantities are for separate objects, the student and the bus. The initial position of the student is taken to be zero, and the initial velocity of the bus is taken to be zero. The positions of the student x_1 and the bus x_2 as functions of time are then $x_1 = v_0 t$ and $x_2 = x_0 + (1/2)at^2$.

EXECUTE: **(a)** Setting $x_1 = x_2$ and solving for the times t gives $t = \dfrac{1}{a}\left(v_0 \pm \sqrt{v_0^2 - 2ax_0}\right)$.

$$t = \frac{1}{(0.170\ \text{m/s}^2)}\left((5.0\ \text{m/s}) \pm \sqrt{(5.0\ \text{m/s})^2 - 2(0.170\ \text{m/s}^2)(40.0\ \text{m})}\right) = 9.55\ \text{s and } 49.3\ \text{s}.$$

The student will be likely to hop on the bus the first time she passes it (see part (d) for a discussion of the later time). During this time, the student has run a distance $v_0 t = (5\ \text{m/s})(9.55\ \text{s}) = 47.8\ \text{m}$.

(b) The speed of the bus is $(0.170\ \text{m/s}^2)(9.55\ \text{s}) = 1.62\ \text{m/s}$.

(c) The results can be verified by noting that the x lines for the student and the bus intersect at two points, as shown in Figure 2.95a.

(d) At the later time, the student has passed the bus, maintaining her constant speed, but the accelerating bus then catches up to her. At this later time the bus's velocity is $(0.170\ \text{m/s}^2)(49.3\ \text{s}) = 8.38\ \text{m/s}$.

(e) No; $v_0^2 < 2ax_0$, and the roots of the quadratic are imaginary. When the student runs at $3.5\ \text{m/s}$, Figure 2.95b shows that the two lines do *not* intersect:

(f) For the student to catch the bus, $v_0^2 > 2ax_0$. and so the minimum speed is

$\sqrt{2(0.170\ \text{m/s}^2)(40\ \text{m/s})} = 3.688\ \text{m/s}$. She would be running for a time $\dfrac{3.69\ \text{m/s}}{0.170\ \text{m/s}^2} = 21.7\ \text{s}$, and covers a distance $(3.688\ \text{m/s})\ (21.7\ \text{s}) = 80.0\ \text{m}$.

However, when the student runs at $3.688\ \text{m/s}$, the lines intersect at *one* point, at $x = 80\ \text{m}$, as shown in Figure 2.95c.

EVALUATE: The graph in part (c) shows that the student is traveling faster than the bus the first time they meet but at the second time they meet the bus is traveling faster.

$t_2 = t_{\text{tot}} - t_1$

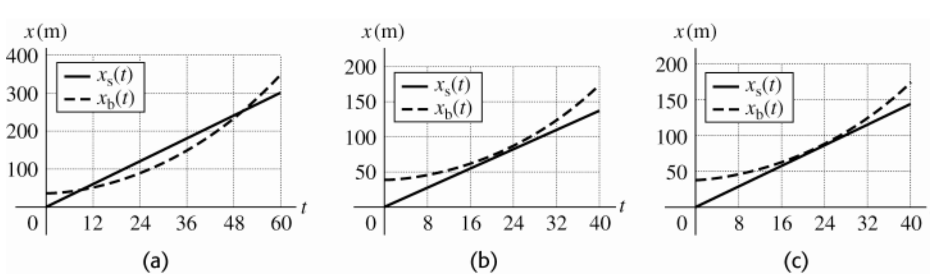

Figure 2.95

2.96. **IDENTIFY:** Apply $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ to the motion from the maximum height, where $v_{0y} = 0$. The time spent above $y_{max}/2$ on the way down equals the time spent above $y_{max}/2$ on the way up.

SET UP: Let $+y$ be downward. $a_y = g$. $y - y_0 = y_{max}/2$ when he is a distance $y_{max}/2$ above the floor.

EXECUTE: The time from the maximum height to $y_{max}/2$ above the floor is given by $y_{max}/2 = \frac{1}{2}gt_1^2$. The time from the maximum height to the floor is given by $y_{max} = \frac{1}{2}gt_{tot}^2$ and the time from a height of $y_{max}/2$ to the floor is .

$$\frac{t_1}{t_2} = \frac{\sqrt{y_{max}/2}}{\sqrt{y_{max}} - \sqrt{y_{max}/2}} = \frac{1}{\sqrt{2} - 1} = 2.4 .$$

EVALUATE: The person spends over twice as long above $y_{max}/2$ as below $y_{max}/2$. His average speed is less above $y_{max}/2$ than it is when he is below this height.

2.97. **IDENTIFY:** Apply constant acceleration equations to both objects.

SET UP: Let $+y$ be upward, so each ball has $a_y = -g$. For the purpose of doing all four parts with the least repetition of algebra, quantities will be denoted symbolically. That is, let $y_1 = h + v_0 t - \frac{1}{2}gt^2$, $y_2 = h - \frac{1}{2}g(t - t_0)^2$. In this case, $t_0 = 1.00\text{ s}$.

EXECUTE: **(a)** Setting $y_1 = y_2 = 0$, expanding the binomial $(t - t_0)^2$ and eliminating the common term $\frac{1}{2}gt^2$ yields $v_0 t = gt_0 t - \frac{1}{2}gt_0^2$. Solving for *t*: $t = \dfrac{\frac{1}{2}gt_0^2}{gt_0 - v_0} = \dfrac{t_0}{2}\left(\dfrac{1}{1 - v_0/(gt_0)}\right)$.

Substitution of this into the expression for y_1 and setting $y_1 = 0$ and solving for *h* as a function of v_0 yields, after some algebra, $h = \frac{1}{2}gt_0^2 \dfrac{\left(\frac{1}{2}gt_0 - v_0\right)^2}{\left(gt_0 - v_0\right)^2}$. Using the given value $t_0 = 1.00\text{ s}$ and $g = 9.80\text{ m/s}^2$,

$$h = 20.0\text{ m} = (4.9\text{ m})\left(\frac{4.9\text{ m/s} - v_0}{9.8\text{ m/s} - v_0}\right)^2 .$$

This has two solutions, one of which is unphysical (the first ball is still going up when the second is released; see part (c)). The physical solution involves taking the negative square root before solving for v_0, and yields 8.2 m/s. The graph of *y* versus *t* for each ball is given in Figure 2.97.

(b) The above expression gives for (i), 0.411 m and for (ii) 1.15 km.

(c) As v_0 approaches 9.8 m/s, the height *h* becomes infinite, corresponding to a relative velocity at the time the second ball is thrown that approaches zero. If $v_0 > 9.8\text{ m/s}$, the first ball can never catch the second ball.

(d) As v_0 approaches 4.9 m/s, the height approaches zero. This corresponds to the first ball being closer and closer (on its way down) to the top of the roof when the second ball is released. If $v_0 < 4.9\text{ m/s}$, the first ball will already have passed the roof on the way down before the second ball is released, and the second ball can never catch up.

EVALUATE: Note that the values of v_0 in parts (a) and (b) are all greater than v_{min} and less than v_{max}.

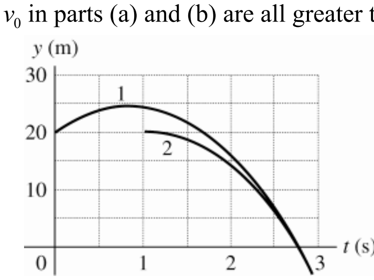

Figure 2.97

2.98. **IDENTIFY:** Apply constant acceleration equations to the motion of the boulder.

SET UP: Let $+y$ be downward, so $a_y = +g$.

EXECUTE: **(a)** Let the height be h and denote the 1.30-s interval as Δt; the simultaneous equations $h = \frac{1}{2}gt^2, \frac{2}{3}h = \frac{1}{2}g(t-\Delta t)^2$ can be solved for t. Eliminating h and taking the square root, $\frac{t}{t-\Delta t} = \sqrt{\frac{3}{2}}$, and $t = \frac{\Delta t}{1-\sqrt{2/3}}$, and substitution into $h = \frac{1}{2}gt^2$ gives $h = 246$ m.

(b) The above method assumed that $t > 0$ when the square root was taken. The negative root (with $\Delta t = 0$) gives an answer of 2.51 m, clearly not a "cliff". This would correspond to an object that was initially near the bottom of this "cliff" being thrown upward and taking 1.30 s to rise to the top and fall to the bottom. Although physically possible, the conditions of the problem preclude this answer.

EVALUATE: For the first two-thirds of the distance, $y - y_0 = 164\text{ m}$, $v_{0y} = 0$, and $a_y = 9.80\text{ m/s}^2$. $v_y = \sqrt{2a_y(y-y_0)} = 56.7\text{ m/s}$. Then for the last third of the distance, $y - y_0 = 82.0\text{ m}$, $v_{0y} = 56.7\text{ m/s}$ and $a_y = 9.80\text{ m/s}^2$. $y - y_0 = v_{0y}t + \frac{1}{2}a_yt^2$ gives $(4.90\text{ m/s}^2)t^2 + (56.7\text{ m/s})t - 82.0\text{ m} = 0$.

$t = \frac{1}{9.8}\left(-56.7 + \sqrt{(56.7)^2 + 4(4.9)(82.0)}\right)\text{ s} = 1.30\text{ s}$, as required.