CHAPTER 2

Quick Quizzes

1. (a) 200 yd (b) 0 (c) 0

2. (a) False. The car may be slowing down, so that the direction of its acceleration is opposite the direction of its velocity.

(b) True. If the velocity is in the direction chosen as negative, a positive acceleration causes a decrease in speed.

(c) True. For an accelerating particle to stop at all, the velocity and acceleration must have opposite signs, so that the speed is decreasing. If this is the case, the particle will eventually come to rest. If the acceleration remains constant, however, the particle must begin to move again, opposite to the direction of its original velocity. If the particle comes to rest and then stays at rest, the acceleration has become zero at the moment the motion stops. This is the case for a braking car—the acceleration is negative and goes to zero as the car comes to rest.

3. The velocity-time graph (a) has a constant slope, indicating a constant acceleration, which is represented by acceleration-time graph (e).

Graph (b) represents an object whose speed always increases, and does so at an ever increasing rate. Thus, the acceleration must be increasing, and the acceleration-time graph that best indicates this is (d).

Graph (c) depicts an object that first has a velocity that increases at a constant rate, which means its acceleration is constant. The motion then changes to one at constant speed, indicating that the acceleration of the object becomes zero. Thus, the best match to this situation is graph (f).

4. (b). According to *graph b*, there are some instants in time when the object is simultaneously at two different x-coordinates. This is physically impossible.

5. (a) The *blue graph* of Figure 2.14b best shows the puck's position as a function of time. As seen in Figure 2.14a, the distance the puck has traveled grows at an increasing rate for approximately three time intervals, grows at a steady rate for about four time intervals, and then grows at a diminishing rate for the last two intervals.

(b) The *red graph* of Figure 2.14c best illustrates the speed (distance traveled per time interval) of the puck as a function of time. It shows the puck gaining speed for approximately three time intervals, moving at constant speed for about four time intervals, then slowing to rest during the last two intervals.

(c) The green graph of Figure 2.14d best shows the puck's acceleration as a function of time. The puck gains velocity (positive acceleration) for approximately three time intervals, moves at constant velocity (zero acceleration) for about four time intervals, and then loses velocity (negative acceleration) for roughly the last two time intervals.

6. (c). The acceleration of the ball remains constant while it is in the air. The magnitude of its acceleration is the free-fall acceleration, $g = 9.80\ \mathrm{m/s^2}$.

7. (c). As it travels upward, its speed decreases by 9.80 m/s during each second of its motion. When it reaches the peak of its motion, its speed becomes zero. As the ball moves downward, its speed increases by 9.80 m/s each second.

8. (a) and (f). The first jumper will always be moving with a higher velocity than the second. Thus, in a given time interval, the first jumper covers more distance than the second. Thus, the separation distance between them *increases*. At any given instant of time, the velocities of the jumpers are definitely different, because one had a head start. In a time interval after this instant, however, each jumper increases his or her velocity by the same amount, because they have the same acceleration. Thus, the difference in velocities *stays the same*.

Problem Solutions

2.1 Distances traveled are

$$\Delta x_1 = v_1(\Delta t_1) = (80.0 \text{ km/h})(0.500 \text{ h}) = 40.0 \text{ km}$$
$$\Delta x_2 = v_2(\Delta t_2) = (100 \text{ km/h})(0.200 \text{ h}) = 20.0 \text{ km}$$
$$\Delta x_3 = v_3(\Delta t_3) = (40.0 \text{ km/h})(0.750 \text{ h}) = 30.0 \text{ km}$$

Thus, the total distance traveled is $\Delta x = (40.0 + 20.0 + 30.0) \text{ km} = 90.0 \text{ km}$, and the elapsed time is $\Delta t = 0.500 \text{ h} + 0.200 \text{ h} + 0.750 \text{ h} + 0.250 \text{ h} = 1.70 \text{ h}$.

(a) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{90.0 \text{ km}}{1.70 \text{ h}} = \boxed{52.9 \text{ km/h}}$

(b) $\Delta x = \boxed{90.0 \text{ km}}$ (see above)

2.2 (a) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{20 \text{ ft}}{1 \text{ yr}}\left(\dfrac{1 \text{ m}}{3.281 \text{ ft}}\right)\left(\dfrac{1 \text{ yr}}{3.156 \times 10^7 \text{ s}}\right) = \boxed{2 \times 10^{-7} \text{ m/s}}$,

or in particularly windy times

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{100 \text{ ft}}{1 \text{ yr}}\left(\frac{1 \text{ m}}{3.281 \text{ ft}}\right)\left(\frac{1 \text{ yr}}{3.156 \times 10^7 \text{ s}}\right) = \boxed{1 \times 10^{-6} \text{ m/s}}$$

(b) The time required must have been

$$\Delta t = \frac{\Delta x}{\bar{v}} = \frac{3 \times 10^3 \text{ mi}}{10 \text{ mm/yr}}\left(\frac{1609 \text{ m}}{1 \text{ mi}}\right)\left(\frac{10^3 \text{ mm}}{1 \text{ m}}\right) = \boxed{5 \times 10^8 \text{ yr}}.$$

2.3 (a) Boat A requires 1.0 h to cross the lake and 1.0 h to return, total time 2.0 h. Boat B requires 2.0 h to cross the lake at which time the race is over. $\boxed{\text{Boat A wins, being 60 km ahead of B}}$ when the race ends.

(b) Average velocity is the net displacement of the boat divided by the total elapsed time. The winning boat is back where it started, its displacement thus being zero, yielding an average velocity of $\boxed{\text{zero}}$.

2.4 (a) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{20 \text{ ft}}{4000 \text{ yr}}\left(\dfrac{1 \text{ m}}{3.281 \text{ ft}}\right)\left(\dfrac{1 \text{ yr}}{3.156 \times 10^7 \text{ s}}\right) = \boxed{5 \times 10^{-11} \text{ m/s}}$

(b) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{2\text{ ft}}{1\text{ day}}\left(\dfrac{1\text{ m}}{3.281\text{ ft}}\right)\left(\dfrac{1\text{ day}}{8.64\times 10^{4}\text{ s}}\right) = \boxed{7\times 10^{-6}\text{ m/s}}$

2.5 (a) $\text{Displacement} = (85.0\text{ km/h})\left(\dfrac{35.0}{60.0}\text{ h}\right) + 130\text{ km}$

$\Delta x = (49.6 + 130)\text{ km} = \boxed{180\text{ km}}$

(b) $\text{Average velocity} = \dfrac{\text{Displacement}}{\text{elapsed time}} = \dfrac{(49.6+130)\text{ km}}{\left[\dfrac{(35.0+15.0)}{60.0} + 2.00\right]\text{h}} = \boxed{63.4\text{ km/h}}$

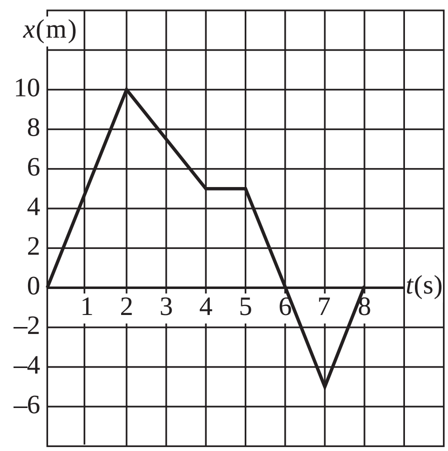
2.6 (a) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{10.0\text{ m}}{2.00\text{ s}} = \boxed{5.00\text{ m/s}}$

(b) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{5.00\text{ m}}{4.00\text{ s}} = \boxed{1.25\text{ m/s}}$

(c) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{5.00\text{ m} - 10.0\text{ m}}{4.00\text{ s} - 2.00\text{ s}} = \boxed{-2.50\text{ m/s}}$

(d) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{-5.00\text{ m} - 5.00\text{ m}}{7.00\text{ s} - 4.00\text{ s}} = \boxed{-3.33\text{ m/s}}$

(e) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{x_2 - x_1}{t_2 - t_1} = \dfrac{0-0}{8.00\text{ s} - 0} = \boxed{0}$

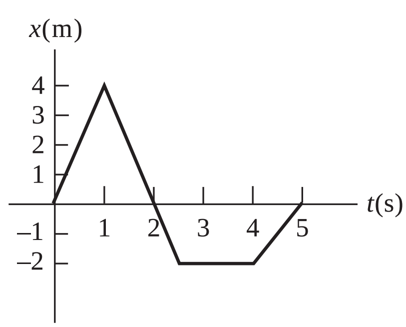


2.7 (a) $v_{0,1} = \dfrac{x_1 - x_0}{\Delta t} = \dfrac{4.0\text{ m} - 0}{1.0\text{ s}} = \boxed{+4.0\text{ m/s}}$

(b) $v_{0,4} = \dfrac{x_4 - x_0}{\Delta t} = \dfrac{-2.0\text{ m} - 0}{4.0\text{ s}} = \boxed{-0.5\text{ m/s}}$

(c) $v_{1,5} = \dfrac{x_5 - x_1}{\Delta t} = \dfrac{0 - 4.0\text{ m}}{4.0\text{ s}} = \boxed{-1.0\text{ m/s}}$

(d) $v_{0,5} = \dfrac{x_5 - x_0}{\Delta t} = \dfrac{0-0}{5.0\text{ s}} = \boxed{0}$



2.8 (a) The time for a car to make the trip is $t = \frac{\Delta x}{v}$. Thus, the difference in the times for the two cars to complete the same 10 mile trip is

$$\Delta t = t_1 - t_2 = \frac{\Delta x}{v_1} - \frac{\Delta x}{v_2} = \left(\frac{10\text{ mi}}{55\text{ mi/h}} - \frac{10\text{ mi}}{70\text{ mi/h}}\right)\left(\frac{60\text{ min}}{1\text{ h}}\right) = \boxed{2.3\text{ min}}$$

(b) When the faster car has a 15.0 min lead, it is ahead by a distance equal to that traveled by the slower car in a time of 15.0 min. This distance is given by $\Delta x_1 = v_2(\Delta t) = (55\text{ mi/h})(15\text{ min})$.

The faster car pulls ahead of the slower car at a rate of: $v_{relative} = 70\text{ mi/h} - 55\text{ mi/h} = 15\text{ mi/h}$. Thus, the time required for it to get distance Δx_1 ahead is:

$$\Delta t = \frac{\Delta x_1}{v_{relative}} = \frac{(55\text{ mi/h})(15\text{ min})}{15.0\text{ mi/h}} = 55\text{ min}.$$

Finally, the distance the faster car has traveled during this time is

$$\Delta x = vt = (70\text{ mi/h})(55\text{ min})\left(\frac{1\text{ h}}{60\text{ min}}\right) = \boxed{64\text{ mi}}$$

2.9 (a) To correspond to only forward motion, the graph must always have a positive slope. Graphs of this type are $\boxed{\text{a, e, and f}}$.

(b) For only backward motion, the slope of the graph must always be negative. Only graph $\boxed{\text{c}}$ is of this type.

(c) The slope of the graph must be constant in order to correspond to constant velocity. Graphs like this are $\boxed{\text{d and f}}$.

(d) The graph corresponding to the largest constant velocity is the one with the largest constant slope. This is graph $\boxed{\text{f}}$.

(e) To correspond to no motion (i.e., zero velocity), the slope of the graph must have a constant value of zero. This is graph $\boxed{\text{d}}$.

2.10 The distance traveled by the space shuttle in one orbit is

$$2\pi(\text{Earth's radius} + 200 \text{ miles}) = 2\pi(3963 + 200) \text{ mi} = 2.61 \times 10^4 \text{ mi}.$$

Thus, the required time is $\dfrac{2.61 \times 10^4 \text{ mi}}{19\,800 \text{ mi/h}} = \boxed{1.32 \text{ h}}$.

2.11 The total time for the trip is $t = t_1 + 22.0 \text{ min} = t_1 + 0.367 \text{ h}$, where t_1 is the time spent traveling at 89.5 km/h. Thus, the distance traveled is

$$x = \bar{v}t = (89.5 \text{ km/h})t_1 = (77.8 \text{ km/h})(t_1 + 0.367 \text{ h})$$

or, $$(89.5 \text{ km/h})t_1 = (77.8 \text{ km/h})t_1 + 28.5 \text{ km}.$$

From which, $t_1 = 2.44 \text{ h}$ for a total time of $t = t_1 + 0.367 \text{ h} = \boxed{2.80 \text{ h}}$.

Therefore, $x = \bar{v}t = (77.8 \text{ km/h})(2.80 \text{ h}) = \boxed{218 \text{ km}}$.

2.12 (a) At the end of the race, the tortoise has been moving for time *t* and the hare for a time $t - 2.0 \text{ min} = t - 120 \text{ s}$. The speed of the tortoise is $v_t = 0.100 \text{ m/s}$, and the speed of the hare is $v_h = 20v_t = 2.0 \text{ m/s}$. The tortoise travels distance x_t, which is 0.20 m larger than the distance x_h traveled by the hare. Hence, $x_t = x_h + 0.20 \text{ m}$, which becomes $v_t t = v_h(t - 120 \text{ s}) + 0.20 \text{ m}$ or

$$(0.100 \text{ m/s})t = (2.0 \text{ m/s})(t - 120 \text{ s}) + 0.20 \text{ m}.$$

This gives the time of the race as $t = \boxed{1.3 \times 10^2 \text{ s}}$.

(b) $x_t = v_t t = (0.100 \text{ m/s})(1.3 \times 10^2 \text{ s}) = \boxed{13 \text{ m}}$

2.13 The maximum time to complete the trip is

$$t_t = \frac{\text{total distance}}{\text{required average speed}} = \frac{1600\text{ m}}{250\text{ km/h}}\left(\frac{1\text{ km/h}}{0.278\text{ m/s}}\right) = 23.0\text{ s}.$$

The time spent in the first half of the trip is

$$t_1 = \frac{\text{half distance}}{\bar{v}_1} = \frac{800\text{ m}}{230\text{ km/h}}\left(\frac{1\text{ km/h}}{0.278\text{ m/s}}\right) = 12.5\text{ s}.$$

Thus, the maximum time that can be spent on the second half of the trip is $t_2 = t_t\text{-}t_1 = 23.0\text{ s} - 12.5\text{ s} = 10.5\text{ s}$, and the required average speed on the second half is

$$\bar{v}_2 = \frac{\text{half distance}}{t_2} = \frac{800\text{ m}}{10.5\text{ s}} = 76.2\text{ m/s}\left(\frac{1\text{ km/h}}{0.278\text{ m/s}}\right) = \boxed{274\text{ km/h}}.$$

2.14 Choose a coordinate axis with the origin at the flagpole and east as the positive direction. Then, using $x = x_i + v_i t + \frac{1}{2}at^2$ with $a = 0$ for each runner, the *x*-coordinate of each runner at time *t* is

$$x_A = -4.0\text{ mi} + (6.0\text{ mi/h})t \quad \text{and} \quad x_B = 3.0\text{ mi} + (-5.0\text{ mi/h})t$$

When the runners meet, $x_A = x_B$

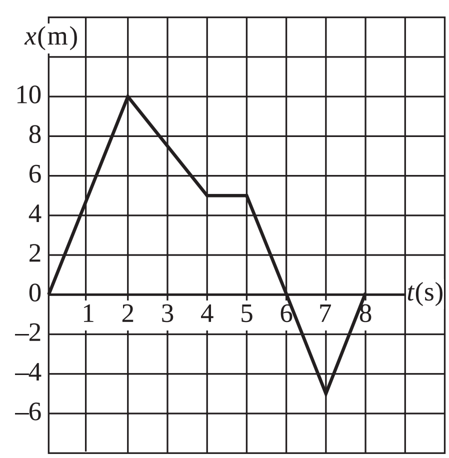
or $$-4.0\text{ mi} + (6.0\text{ mi/h})t = 3.0\text{ mi} + (-5.0\text{ mi/h})t.$$

This gives the elapsed time when they meet as $t = \dfrac{7.0\text{ mi}}{11.0\text{ mi/h}} = 0.64\text{ h}$. At this time, $x_A = x_B = -0.18\text{ mi}$. Thus, they meet $\boxed{\text{0.18 mi west of the flagpole}}$.

2.15 (a) $v = \dfrac{10.0\text{ m} - 0}{2.00\text{ s} - 0} = \boxed{5.00\text{ m/s}}$

(b) $v = \dfrac{(5.00 - 10.0)\text{ m}}{(4.00 - 2.00)\text{ s}} = \boxed{-2.50\text{ m/s}}$

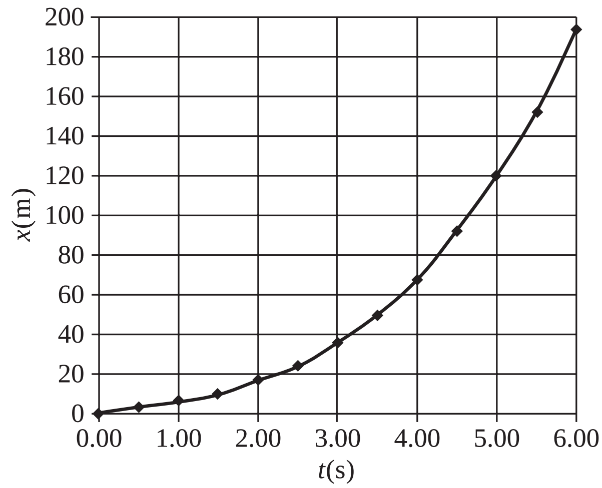
(c) $v = \dfrac{(5.00 - 5.00)\text{ m}}{(5.00 - 4.00)\text{ s}} = \boxed{0}$



(d) $v = \dfrac{0-(-5.00\text{ m})}{(8.00-7.00)\text{ s}} = \boxed{5.00\text{ m/s}}$

2.16 (a) A few typical values are

t(s)	x(m)
1.00	5.75
2.00	16.0
3.00	35.3
4.00	68.0
5.00	119
6.00	192



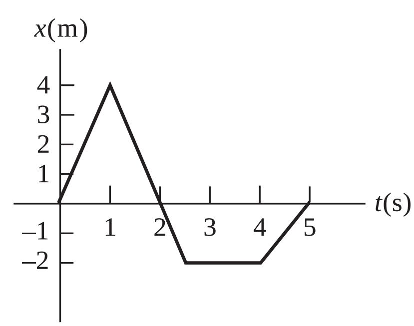
(b) We will use a 0.400 s interval centered at $t = 4.00$ s. We find at $t = 3.80$ s, $x = 60.2$ m and at $t = 4.20$ s, $x = 76.6$ m. Therefore, $v = \dfrac{\Delta x}{\Delta t} = \dfrac{16.4\text{ m}}{0.400\text{ s}} = \boxed{41.0\text{ m/s}}$.

Using a time interval of 0.200 s, we find the corresponding values to be: at $t = 3.90$ s, $x = 64.0$ m and at $t = 4.10$ s, $x = 72.2$ m. Thus, $v = \dfrac{\Delta x}{\Delta t} = \dfrac{8.20\text{ m}}{0.200\text{ s}} = \boxed{41.0\text{ m/s}}$.

For a time interval of 0.100 s, the values are: at $t = 3.95$ s, $x = 66.0$ m, and at $t = 4.05$ s, $x = 70.1$ m. Therefore, $v = \dfrac{\Delta x}{\Delta t} = \dfrac{4.10\text{ m}}{0.100\text{ s}} = \boxed{41.0\text{ m/s}}$.

(c) At $t = 4.00$ s, $x = 68.0$ m. Thus, for the first 4.00 s, $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{68.0\text{ m}}{4.00\text{ s}} = \boxed{17.0\text{ m/s}}$. This value is $\boxed{\text{much less}}$ than the instantaneous velocity at $t = 4.00$ s.

2.17 (a) $v|_{0.50\text{ s}} = \dfrac{x|_{1.0\text{ s}} - x|_{t=0}}{1.0\text{ s} - 0} = \dfrac{4.0\text{ m}}{1.0\text{ s}} = \boxed{4.0\text{ m/s}}$



(b) $v|_{2.0\text{ s}} = \dfrac{x|_{2.5\text{ s}} - x|_{1.0\text{ s}}}{2.5\text{ s} - 1.0\text{ s}} = \dfrac{-6.0\text{ m}}{1.5\text{ s}} = \boxed{-4.0\text{ m/s}}$

(c) $v|_{3.0\text{ s}} = \dfrac{x|_{4.0\text{ s}} - x|_{2.5\text{ s}}}{4.0\text{ s} - 2.5\text{ s}} = \dfrac{0}{1.5\text{ s}} = \boxed{0}$

(d) $v|_{4.5\text{ s}} = \dfrac{x|_{5.0\text{ s}} - x|_{4.0\text{ s}}}{5.0\text{ s} - 4.0\text{ s}} = \dfrac{+2.0\text{ m}}{1.0\text{ s}} = \boxed{2.0\text{ m/s}}$

2.18 (a) The average speed during a time interval Δt is $\bar{v} = \dfrac{\text{distance traveled}}{\Delta t}$.

During the first quarter mile segment, Secretariat's average speed was

$$\bar{v}_1 = \frac{0.250\ \text{mi}}{25.2\ \text{s}} = \frac{1320\ \text{ft}}{25.2\ \text{s}} = \boxed{52.4\ \text{ft/s}}\ \left(35.6\ \text{mi/h}\right).$$

During the second quarter mile segment,

$$\bar{v}_2 = \frac{1320\ \text{ft}}{24.0\ \text{s}} = \boxed{55.0\ \text{ft/s}}\ \left(37.4\ \text{mi/h}\right).$$

For the third quarter mile of the race,

$$\bar{v}_3 = \frac{1320\ \text{ft}}{23.8\ \text{s}} = \boxed{55.5\ \text{ft/s}}\ \left(37.7\ \text{mi/h}\right),$$

and during the final quarter mile,

$$\bar{v}_4 = \frac{1320\ \text{ft}}{23.0\ \text{s}} = \boxed{57.4\ \text{ft/s}}\ \left(39.0\ \text{mi/h}\right).$$

(b) Assuming that $v_f = \bar{v}_4$ and recognizing that $v_i = 0$, the average acceleration during the race was

$$\bar{a} = \frac{v_f - v_i}{\text{total elapsed time}} = \frac{57.4\ \text{ft/s} - 0}{\left(25.2+24.0+23.8+23.0\right)\ \text{s}} = \boxed{0.598\ \text{ft/s}^2}.$$

2.19 $\bar{a} = \dfrac{v_f - v_i}{t_f - t_i} = \dfrac{0 - 60.0\ \text{m/s}}{15.0\ \text{s} - 0} = \boxed{-4.00\ \text{m/s}^2}$

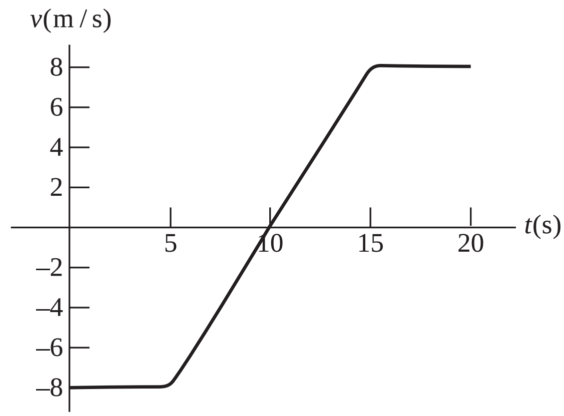
The negative sign in the above result indicates that the $\boxed{\text{acceleration is in the negative x direction}}$.

2.20 $\bar{a} = \dfrac{v_f - v_i}{t_f - t_i} = \dfrac{\left(-8.0\ \text{m/s}\right) - \left(10.0\ \text{m/s}\right)}{1.2 \times 10^{-2}\ \text{s}} = \boxed{-1.5 \times 10^3\ \text{m/s}^2}$

2.21 From $a = \dfrac{\Delta v}{\Delta t}$, we have $\Delta t = \dfrac{\Delta v}{a} = \dfrac{\left(60 - 55\right)\ \text{mi/h}}{0.60\ \text{m/s}^2}\left(\dfrac{0.447\ \text{m/s}}{1\ \text{mi/h}}\right) = \boxed{3.7\ \text{s}}$

2.22 (a) From $t=0$ to $t=5.0\text{ s}$,

$$\bar{a}=\frac{v_f-v_i}{t_f-t_i}=\frac{0-0}{5.0\text{ s}-0}=\boxed{0}.$$



From $t=5.0\text{ s}$ to $\boxed{t=15\text{ s}}$,

$$\bar{a}=\frac{8.0\text{ m/s}-(-8.0\text{ m/s})}{15\text{ s}-5.0\text{ s}}=\boxed{1.6\text{ m/s}^2},$$

and from $t=0$ to $t=20\text{ s}$,

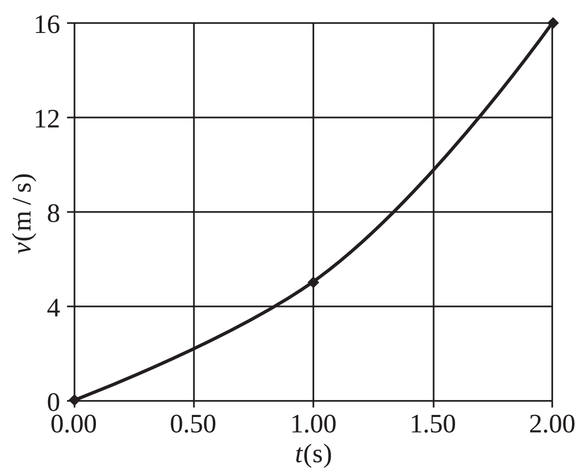
$$\bar{a}=\frac{8.0\text{ m/s}-(-8.0\text{ m/s})}{20\text{ s}-0}=\boxed{0.80\text{ m/s}^2}.$$

(b) At $t=2.0\text{ s}$, the slope of the tangent line to the curve is $\boxed{0}$. At $t=10\text{ s}$, the slope of the tangent line is $\boxed{1.6\text{ m/s}^2}$, and at $t=18\text{ s}$, the slope of the tangent line is $\boxed{0}$.

2.23 (a) The average acceleration can be found from the curve, and its value will be

$$\bar{a}=\frac{\Delta v}{\Delta t}=\frac{16\text{ m/s}}{2.0\text{ s}}=\boxed{8.0\text{ m/s}^2}.$$

(b) The instantaneous acceleration at $t=1.5\text{ s}$ equals the slope of the tangent line to the curve at that time. This slope is about $\boxed{12\text{ m/s}^2}$.



2.24 The displacement while coming to rest is $\Delta x=1.20\text{ km}=1.20\times10^3\text{ m}$. The initial speed is $v_i=300\text{ km/h}$ and the final speed is 0. Therefore, from $v_f^2=v_i^2+2a(\Delta x)$,

$$a=\frac{v_f^2-v_i^2}{2(\Delta x)}=\frac{0-(300\text{ km/h})^2}{2(1.20\times10^3\text{ m})}\left(\frac{0.278\text{ m/s}}{1\text{ km/h}}\right)=\boxed{-2.90\text{ m/s}^2}.$$

2.25 From $v_f^2=v_i^2+2a(\Delta x)$, we have $(10.97\times10^3\text{ m/s})^2=0+2a(220\text{ m})$ so that $a=\boxed{2.74\times10^5\text{ m/s}^2}$ which is $\boxed{2.79\times10^4\text{ times } g!}$

2.26 (a) $\Delta x = \bar{v}(\Delta t) = \left(\frac{v_f + v_i}{2}\right)\Delta t$ becomes $40.0 \text{ m} = \left(\frac{2.80 \text{ m/s} + v_i}{2}\right)(8.50 \text{ s})$,

which yields $v_i = \boxed{6.61 \text{ m/s}}$.

(b) $a = \frac{v_f - v_i}{\Delta t} = \frac{2.80 \text{ m/s} - 6.61 \text{ m/s}}{8.50 \text{ s}} = \boxed{-0.448 \text{ m/s}^2}$

2.27 Suppose the unknown acceleration is constant as a car initially moving at $v_i = 35.0 \text{ mi/h}$ comes to a $v_f = 0$ stop in $\Delta x = 40.0 \text{ ft}$. We find its acceleration from $v_f^2 = v_i^2 + 2a(\Delta x)$.

$$a = \frac{v_f^2 - v_i^2}{2(\Delta x)} = \frac{0 - (35.0 \text{ mi/h})^2}{2(40.0 \text{ ft})}\left(\frac{1.47 \text{ ft/s}}{1 \text{ mi/h}}\right)^2 = -33.1 \text{ ft/s}^2 .$$

Now consider a car moving at $v_i = 70.0 \text{ mi/h}$ and stopping to $v_f = 0$ with $a = -33.1 \text{ ft/s}^2$. From the same equation its stopping distance is

$$\Delta x = \frac{v_f^2 - v_i^2}{2a} = \frac{0 - (70.0 \text{ mi/h})^2}{2(-33.1 \text{ ft/s}^2)}\left(\frac{1.47 \text{ ft/s}}{1 \text{ mi/h}}\right)^2 = \boxed{160 \text{ ft}}$$

2.28 (a) From the definition of acceleration, we have

$$a = \frac{v_f - v_i}{t} = \frac{0 - 40 \text{ m/s}}{5.0 \text{ s}} = \boxed{-8.0 \text{ m/s}^2}.$$

(b) From $\Delta x = v_i t + \frac{1}{2}at^2$, the displacement is

$$\Delta x = (40 \text{ m/s})(5.0 \text{ s}) + \frac{1}{2}(-8.0 \text{ m/s}^2)(5.0 \text{ s})^2 = \boxed{100 \text{ m}}.$$

2.29 (a) With $v_f = 120 \text{ km/h}$, $v_f^2 = v_i^2 + 2a(\Delta x)$ yields

$$a = \frac{v_f^2 - v_i^2}{2(\Delta x)} = \frac{\left[(120 \text{ km/h})^2 - 0\right]}{2(240 \text{ m})}\left(\frac{0.278 \text{ m/s}}{1 \text{ km/h}}\right)^2 = \boxed{2.32 \text{ m/s}^2}.$$

(b) The required time is $t = \frac{v_f - v_i}{a} = \frac{(120\ \text{km/h} - 0)}{2.32\ \text{m/s}^2}\left(\frac{0.278\ \text{m/s}}{1\ \text{km/h}}\right) = \boxed{14.4\ \text{s}}$.

2.30 (a) The time for the truck to reach $20\ \text{m/s}$ is found from $v_f = v_i + at$ as

$$t = \frac{v_f - v_i}{a} = \frac{20\ \text{m/s} - 0}{2.0\ \text{m/s}^2} = 10\ \text{s}\ .$$

The total time is $t_{total} = 10\ \text{s} + 20\ \text{s} + 5.0\ \text{s} = \boxed{35\ \text{s}}$.

(b) The distance traveled during the first 10 s is

$$(\Delta x)_1 = \bar{v}_1 t_1 = \left(\frac{0 + 20\ \text{m/s}}{2}\right)(10\ \text{s}) = 100\ \text{m}\ .$$

The distance traveled during the next 20 s (with $a = 0$) is

$$(\Delta x)_2 = (v_i)_2\, t_2 + \frac{1}{2} a_2 t_2^{\,2} = (20\ \text{m/s})(20\ \text{s}) + 0 = 400\ \text{m}\ .$$

The distance traveled in the last 5.0 s is

$$(\Delta x)_3 = \bar{v}_3 t_3 = \left(\frac{20\ \text{m/s} + 0}{2}\right)(5.0\ \text{s}) = 50\ \text{m}\ .$$

The total displacement is then

$$\Delta x = (\Delta x)_1 + (\Delta x)_2 + (\Delta x)_3 = 100\ \text{m} + 400\ \text{m} + 50\ \text{m} = 550\ \text{m}$$

and the average velocity for the total motion is given by

$$\bar{v} = \frac{\Delta x}{t_{total}} = \frac{550\ \text{m}}{35\ \text{s}} = \boxed{16\ \text{m/s}}.$$

2.31 (a) Using $\Delta x = v_i t + \frac{1}{2} a t^2$ with $v_i = 0$ gives $400\ \text{m} = 0 + \frac{1}{2}\left(10.0\ \text{m/s}^2\right) t^2$, yielding $t = \boxed{8.94\ \text{s}}$.

(b) From $v_f = v_i + at$, with $v_i = 0$, we find $v_f = 0 + \left(10.0\ \text{m/s}^2\right)(8.94\ \text{s}) = \boxed{89.4\ \text{m/s}}$.

2.32 (a) The time required to stop is $t = \dfrac{v_f - v_i}{a} = \dfrac{0 - 100\ \text{m/s}}{-5.00\ \text{m/s}^2} = \boxed{20.0\ \text{s}}$.

(b) The minimum distance needed to stop the plane is

$$\Delta x = \bar{v}t = \left(\frac{v_f + v_i}{2}\right)t = \left(\frac{0 + 100\ \text{m/s}}{2}\right)(20.0\ \text{s}) = 1000\ \text{m} = \boxed{1.00\ \text{km}}.$$

Thus, the plane cannot stop in 0.8 km.

2.33 Using $v_f^2 = v_i^2 + 2a(\Delta x)$, with $v_f = 0$ and $v_i = 60\ \text{mi/h}$, yields

$$a = \frac{v_f^2 - v_i^2}{2(\Delta x)} = \frac{\left[0 - (60\ \text{mi/h})^2\right]}{2(100\ \text{m})}\left(\frac{0.447\ \text{m/s}}{1\ \text{mi/h}}\right)^2 = \boxed{-3.6\ \text{m/s}^2}.$$

2.34 The velocity at the end of the first interval is

$$v_f = v_i + at = 0 + (2.77\ \text{m/s})(15.0\ \text{s}) = 41.6\ \text{m/s}.$$

This is also the constant velocity during the second interval and the initial velocity for the third interval.

(a) From $\Delta x = v_i t + \frac{1}{2}at^2$, the total displacement is

$$\Delta x = (\Delta x)_1 + (\Delta x)_2 + (\Delta x)_3$$

$$= \left[0 + \frac{1}{2}(2.77\ \text{m/s}^2)(15.0\ \text{s})^2\right] + \left[(41.6\ \text{m/s})(123\ \text{s}) + 0\right]$$

$$+ \left[(41.6\ \text{m/s})(4.39\ \text{s}) + \frac{1}{2}(-9.47\ \text{m/s}^2)(4.39\ \text{s})^2\right]$$

or $\Delta x = 312\ \text{m} + 5.11 \times 10^3\ \text{m} + 91.2\ \text{m} = 5.51 \times 10^3\ \text{m} = \boxed{5.51\ \text{km}}$

(b) $\bar{v}_1 = \frac{(\Delta x)_1}{t_1} = \frac{312\text{ m}}{15.0\text{ s}} = \boxed{20.8\text{ m/s}}$,

$\bar{v}_2 = \frac{(\Delta x)_2}{t_2} = \frac{5.11\times 10^3\text{ m}}{123\text{ s}} = \boxed{41.6\text{ m/s}}$,

$\bar{v}_3 = \frac{(\Delta x)_3}{t_3} = \frac{91.2\text{ m}}{4.39\text{ s}} = \boxed{20.8\text{ m/s}}$, and the average velocity for the

total trip is $\bar{v}_{total} = \frac{\Delta x}{t_{total}} = \frac{5.51\times 10^3\text{ m}}{(15.0+123+4.39)\text{ s}} = \boxed{38.7\text{ m/s}}$

2.35 Using the uniformly accelerated motion equation $\Delta x = v_i t + \frac{1}{2}at^2$ for the full 40 s interval yields $\Delta x = (20\text{ m/s})(40\text{ s}) + \frac{1}{2}(-1.0\text{ m/s}^2)(40\text{ s})^2 = 0$, which is obviously wrong.

The source of the error is found by computing the time required for the train to come to rest. This time is $t = \frac{v_f - v_i}{a} = \frac{0-20\text{ m/s}}{-1.0\text{ m/s}^2} = 20\text{ s}$. Thus, the train is slowing down for the first 20 s and is at rest for the last 20 s of the 40 s interval.

The acceleration is not constant during the full 40 s. It is, however, constant during the first 20 s as the train slows to rest. Application of $\Delta x = v_i t + \frac{1}{2}at^2$ to this interval gives the stopping distance as

$$\Delta x = (20\text{ m/s})(20\text{ s}) + \frac{1}{2}(-1.0\text{ m/s}^2)(20\text{ s})^2 = \boxed{200\text{ m}}.$$

2.36 $v_f = 40.0\text{ mi/h} = 17.9\text{ m/s}$ and $v_i = 0$

(a) To find the distance traveled, we use

$$\Delta x = \bar{v}t = \left(\frac{v_f + v_i}{2}\right)t = \left(\frac{17.9\text{ m/s}+0}{2}\right)(12.0\text{ s}) = \boxed{107\text{ m}}.$$

(b) The acceleration is $a = \frac{v_f - v_i}{t} = \frac{17.9\text{ m/s}-0}{12.0\text{ s}} = \boxed{1.49\text{ m/s}^2}$.

2.37 At the end of the acceleration period, the velocity is

$$v_f = v_i + at = 0 + \left(1.5\ \text{m/s}^2\right)\left(5.0\ \text{s}\right) = 7.5\ \text{m/s}.$$

This is also the initial velocity for the braking period.

(a) After braking, $v_f = v_i + at = 7.5\ \text{m/s} + \left(-2.0\ \text{m/s}^2\right)\left(3.0\ \text{s}\right) = \boxed{1.5\ \text{m/s}}$.

(b) The total distance traveled is

$$\Delta x = \left(\Delta x\right)_{accel} + \left(\Delta x\right)_{brake} = \left(\bar{v}t\right)_{accel} + \left(\bar{v}t\right)_{brake}$$

$$\Delta x = \left(\frac{0 + 7.5\ \text{m/s}}{2}\right)\left(5.0\ \text{s}\right) + \left(\frac{7.5\ \text{m/s} + 1.5\ \text{m/s}}{2}\right)\left(3.0\ \text{s}\right) = \boxed{32\ \text{m}}.$$

2.38 The initial velocity of the train is $v_i = 82.4\ \text{km/h}$ and the final velocity is $v_f = 16.4\ \text{km/h}$. The time required for the $400\ \text{m}$ train to pass the crossing is found from $\Delta x = \bar{v}t = \left(\frac{v_f + v_i}{2}\right)t$ as

$$t = \frac{2\left(\Delta x\right)}{v_f + v_i} = \frac{2\left(0.400\ \text{km}\right)}{\left(82.4 + 16.4\right)\ \text{km/h}}\left(\frac{3600\ \text{s}}{1\ \text{h}}\right) = \boxed{29.1\ \text{s}}$$

2.39 (a) Take $t = 0$ at the time when the player starts to chase his opponent. At this time, the opponent is 36 m in front of the player. At time $t > 0$, the displacements of the players from their initial positions are

$$\Delta x_{player} = \left(v_i\right)_{player} t + \frac{1}{2}a_{player}t^2 = 0 + \frac{1}{2}\left(4.0\ \text{m/s}^2\right)t^2, \qquad (1)$$

and, $\Delta x_{opponent} = \left(v_i\right)_{opponent} t + \frac{1}{2}a_{opponent}t^2 = \left(12\ \text{m/s}\right)t + 0$ (2)

When the players are side-by-side, $\Delta x_{player} = \Delta x_{opponent} + 36\ \text{m}$ (3)

From Equations (1), (2), and (3), we find $t^2 - \left(6.0\ \text{s}\right)t - 18\ \text{s}^2 = 0$ which has solutions of $t = -2.2\ \text{s}$ and $t = +8.2\ \text{s}$. Since the time must be greater than zero, we must choose $t = \boxed{8.2\ \text{s}}$ as the proper answer.

(b) $\Delta x_{player} = \left(v_i\right)_{player} t + \frac{1}{2}a_{player}t^2 = 0 + \frac{1}{2}\left(4.0\ \text{m/s}^2\right)\left(8.2\ \text{s}\right)^2 = \boxed{1.3 \times 10^2\ \text{m}}$

2.40 Taking $t = 0$ when the car starts after the truck, the displacements of the vehicles from their initial positions at time $t > 0$ are:

$$\Delta x_{car} = (v_i)_{car}\, t + \frac{1}{2} a_{car} t^2 = 0 + \frac{1}{2}\left(2.5\ \text{m/s}^2\right) t^2 \,,$$

and $$\Delta x_{truck} = (v_i)_{truck}\, t + \frac{1}{2} a_{truck} t^2 = (40\ \text{km/h})\, t + 0 \,.$$

When the car overtakes the truck, $\Delta x_{car} = \Delta x_{truck}$, or

$$\frac{1}{2}\left(2.5\ \text{m/s}^2\right) t^2 = (40\ \text{km/h})\, t \,.$$

This has a solution $t = 0$ describing the initial situation and a second solution

$$t = \frac{2}{2.5\ \text{m/s}^2}\left[(40\ \text{km/h})\left(\frac{0.278\ \text{m/s}}{1\ \text{km/h}}\right)\right] = \boxed{8.9\ \text{s}}\,.$$

The distance the car has traveled before catching the truck is

$$\Delta x_{car} = +\frac{1}{2}\left(2.5\ \text{m/s}^2\right)(8.9\ \text{s})^2 = \boxed{99\ \text{m}}\,.$$

2.41 The distance the car travels at constant velocity, v_0, during the reaction time is $(\Delta x)_1 = v_0\, t_r$.

The time for the car to come to rest, from initial velocity v_0, after the brakes are applied is $t_2 = \frac{v_f - v_i}{a} = \frac{0 - v_0}{a} = -\frac{v_0}{a}$ and the distance traveled during this braking period is

$$(\Delta x)_2 = \bar{v} t_2 = \left(\frac{v_f + v_i}{2}\right) t_2 = \left(\frac{0 + v_0}{2}\right)\left(-\frac{v_0}{a}\right) = -\frac{v_0^2}{2a}\,.$$

Thus, the total distance traveled before coming to a stop is

$$s_{stop} = (\Delta x)_1 + (\Delta x)_2 = \boxed{v_0\, t_r - \frac{v_0^2}{2a}}\,.$$

2.42 (a) If a car is a distance $s_{stop} = v_0 t_r - \dfrac{v_0^2}{2a}$ (See the solution to Problem 2.41) from the intersection of length s_i when the light turns yellow, the distance the car must travel before the light turns red is

$$\Delta x = s_{stop} + s_i = v_0 t_r - \frac{v_0^2}{2a} + s_i$$

Assume the driver does not accelerate in an attempt to "beat the light" (an extremely dangerous practice!). The time the light should remain yellow is then the time required for the car to travel distance Δx at constant velocity v_0. This is

$$t_{light} = \frac{\Delta x}{v_0} = \frac{v_0 t_r - v_0^2/2a + s_i}{v_0} = \boxed{t_r - \frac{v_0}{2a} + \frac{s_i}{v_0}}.$$

(b) With $s_i = 16\ \text{m}$, $v_0 = 60\ \text{km/h}$, $a = -2.0\ \text{m/s}^2$, and $t_r = 1.1\ \text{s}$,

$$t_{light} = 1.1\ \text{s} - \frac{60\ \text{km/h}}{2\left(-2.0\ \text{m/s}^2\right)}\left(\frac{0.278\ \text{m/s}}{1\ \text{km/h}}\right) + \frac{16\ \text{m}}{60\ \text{km/h}}\left(\frac{1\ \text{km/h}}{0.278\ \text{m/s}}\right) = \boxed{6.2\ \text{s}}.$$

2.43 (a) From $v_f^2 = v_i^2 + 2a(\Delta y)$ with $v_f = 0$, we have

$$(\Delta y)_{max} = \frac{v_f^2 - v_i^2}{2a} = \frac{0 - (25.0\ \text{m/s})^2}{2\left(-9.80\ \text{m/s}^2\right)} = \boxed{31.9\ \text{m}}.$$

(b) The time to reach the highest point is

$$t_{up} = \frac{v_f - v_i}{a} = \frac{0 - 25.0\ \text{m/s}}{-9.80\ \text{m/s}^2} = \boxed{2.55\ \text{s}}.$$

(c) The time required for the ball to fall 31.9 m, starting from rest, is found from

$$\Delta y = (0)t + \frac{1}{2}at^2 \text{ as } t = \sqrt{\frac{2(\Delta y)}{a}} = \sqrt{\frac{2(-39.1\ \text{m})}{-9.80\ \text{m/s}^2}} = \boxed{2.55\ \text{s}}.$$

(d) The velocity of the ball when it returns to the original level (2.55 s after it starts to fall from rest) is

$$v_f = v_i + at = 0 + \left(-9.80\ \text{m/s}^2\right)(2.55\ \text{s}) = \boxed{-25.0\ \text{m/s}}.$$

2.44 From $v_f^2 = v_i^2 + 2a(\Delta y)$, with $v_i = 0$, $v_f = 29\ 000\ \text{km/h}$, and $\Delta y = +18\ \text{m}$,

$$a = \frac{v_f^2 - v_i^2}{2(\Delta y)} = \frac{\left[\left(2.9\times10^4\ \text{km/h}\right)^2 - 0\right]}{2(18\ \text{m})}\left(\frac{0.278\ \text{m/s}}{1\ \text{km/h}}\right)^2 = \boxed{1.8\times10^6\ \text{m/s}^2}.$$

2.45 Assume the whales are traveling straight upward as they leave the water. Then $v_f^2 = v_i^2 + 2a(\Delta y)$, with $v_f = 0$ when $\Delta y = +7.5\ \text{m}$, gives

$$v_i = \sqrt{v_f^2 - 2a(\Delta y)} = \sqrt{0 - 2\left(-9.8\ \text{m/s}^2\right)(7.5\ \text{m})} = \boxed{12\ \text{m/s}}.$$

2.46 Use $\Delta y = v_i t + \frac{1}{2}at^2$, with $v_i = 0$, $a = -9.80\ \text{m/s}^2$, and $\Delta y = -76.0\ \text{m}$ to find

$$t = \sqrt{\frac{2(\Delta y)}{a}} = \sqrt{\frac{2(-76.0\ \text{m})}{-9.80\ \text{m/s}^2}} = \boxed{3.94\ \text{s}}.$$

2.47 (a) After $2.00\ \text{s}$, the velocity of the mailbag is

$$\left(v_f\right)_{bag} = v_i + at = -1.50\ \text{m/s} + \left(-9.80\ \text{m/s}^2\right)(2.00\ \text{s}) = -21.1\ \text{m/s}.$$

The negative sign tells that the bag is moving downward and the magnitude of the velocity gives the speed as $\boxed{21.1\ \text{m/s}}$

(b) The displacement of the mailbag after $2.00\ \text{s}$ is

$$(\Delta y)_{bag} = \left(\frac{v_f + v_i}{2}\right)t = \left[\frac{-21.1\ \text{m/s} + (-1.50\ \text{m/s})}{2}\right](2.00\ \text{s}) = -22.6\ \text{m}.$$

During this time, the helicopter, moving downward with constant velocity, undergoes a displacement of

$$(\Delta y)_{copter} = v_i t + \frac{1}{2}at^2 = (-1.5\ \text{m/s})(2.00\ \text{s}) + 0 = -3.00\ \text{m}.$$

During this $2.00\ \text{s}$, both the mailbag and the helicopter are moving downward. At the end, the mailbag is $22.6\ \text{m} - 3.00\ \text{m} = \boxed{19.6\ \text{m}}$ below the helicopter.

(c) Here, $(v_i)_{bag} = (v_i)_{copter} = +1.50\ \text{m/s}$ and $a_{bag} = -9.80\ \text{m/s}^2$ while $a_{copter} = 0$. After $2.00\ \text{s}$, the *speed* of the mailbag is

$$\left|(v_f)_{bag}\right| = \left|1.50\ \frac{\text{m}}{\text{s}} + \left(-9.80\ \frac{\text{m}}{\text{s}^2}\right)(2.00\ \text{s})\right| = \left|-18.1\ \frac{\text{m}}{\text{s}}\right| = \boxed{18.1\ \frac{\text{m}}{\text{s}}}.$$

In this case, the helicopter *rises* 3.00 m during the 2.00 s interval while the mailbag has a displacement of

$$(\Delta y)_{bag} = \left[\frac{-18.1\ \text{m/s} + 1.50\ \text{m/s}}{2}\right](2.00\ \text{s}) = -16.6\ \text{m}$$

from the release point. Thus, the separation between the two at the end of $2.00\ \text{s}$ is $3.00\ \text{m} - (-16.6\ \text{m}) = \boxed{19.6\ \text{m}}$.

2.48 (a) Consider the relation $\Delta y = v_i t + \frac{1}{2}at^2$ with $a = -g$. When the ball is at the throwers hand, the displacement Δy is zero, or $0 = v_i t - \frac{1}{2}gt^2$. This equation has two solutions, $t = 0$ which corresponds to when the ball was thrown, and $t = 2v_i/g$ corresponding to when the ball is caught. Therefore, if the ball is caught at $t = 2.00\ \text{s}$, the initial velocity must have been

$$v_i = \frac{gt}{2} = \frac{(9.80\ \text{m/s}^2)(2.00\ \text{s})}{2} = \boxed{9.80\ \text{m/s}}.$$

(b) From $v_f^2 = v_i^2 + 2a(\Delta y)$, with $v_f = 0$ at the maximum height,

$$(\Delta y)_{max} = \frac{v_f^2 - v_i^2}{2a} = \frac{0 - (9.80\ \text{m/s})^2}{2(-9.80\ \text{m/s}^2)} = \boxed{4.90\ \text{m}}.$$

2.49 (a) When it reaches a height of 150 m, the speed of the rocket is

$$v_f = \sqrt{v_i^2 + 2a(\Delta y)} = \sqrt{(50.0 \text{ m/s})^2 + 2(2.00 \text{ m/s}^2)(150 \text{ m})} = 55.7 \text{ m/s} .$$

After the engines stop, the rocket continues moving upward with an initial velocity of $v_i = 55.7 \text{ m/s}$ and acceleration $a = -g = -9.80 \text{ m/s}^2$. When the rocket reaches maximum height, $v_f = 0$. The displacement of the rocket above the point where the engines stopped (i.e., above the 150 m level) is

$$\Delta y = \frac{v_f^2 - v_i^2}{2a} = \frac{0 - (55.7 \text{ m/s})^2}{2(-9.80 \text{ m/s}^2)} = 158 \text{ m} .$$

The maximum height above ground that the rocket reaches is then given by $h_{max} = 150 \text{ m} + 158 \text{ m} = \boxed{308 \text{ m}}$.

(b) The total time of the upward motion of the rocket is the sum of two intervals. The first is the time for the rocket to go from $v_i = 50.0 \text{ m/s}$ at the ground to a velocity of $v_f = 55.7 \text{ m/s}$ at an altitude of 150 m. This time is given by

$$t_1 = \frac{(\Delta y)_1}{\bar{v}_1} = \frac{2(150 \text{ m})}{(55.7 + 50.0) \text{ m/s}} = 2.84 \text{ s} .$$

The second interval is the time to rise 158 m starting with $v_i = 55.7 \text{ m/s}$ and ending with $v_f = 0$. This time is

$$t_1 = \frac{(\Delta y)_2}{\bar{v}_2} = \frac{2(158 \text{ m})}{0+55.7 \text{ m/s}} = 5.67 \text{ s} .$$

The total time of the upward flight is then

$$t_{up} = t_1 + t_2 = (2.84 + 5.67) \text{ s} = \boxed{8.51 \text{ s}}.$$

(c) The time for the rocket to fall 308 m back to the ground, with $v_i = 0$ and acceleration $a = -g = -9.80\ \text{m/s}^2$, is found from $\Delta y = v_i t + \frac{1}{2}at^2$ as

$$t_{down} = \sqrt{\frac{2(\Delta y)}{a}} = \sqrt{\frac{2(-308\ \text{m})}{-9.80\ \text{m/s}^2}} = 7.93\ \text{s},$$

so the total time of the flight is

$$t_{flight} = t_{up} + t_{down} = (8.51 + 7.93)\ \text{s} = \boxed{16.4\ \text{s}}.$$

2.50 (a) The camera falls 50 m with a free-fall acceleration, starting with $v_i = -10\ \text{m/s}$. Its velocity when it reaches the ground is

$$v_f = \sqrt{v_i^2 + 2a(\Delta y)} = \sqrt{(-10\ \text{m/s})^2 + 2(-9.80\ \text{m/s}^2)(-50\ \text{m})} = -33\ \text{m/s}.$$

The time to reach the ground is given by

$$t = \frac{v_f - v_i}{a} = \frac{-33\ \text{m/s} - (-10\ \text{m/s})}{-9.80\ \text{m/s}^2} = \boxed{2.3\ \text{s}}.$$

(b) This velocity was found to be $v_f = \boxed{-33\ \text{m/s}}$ in part (a) above.

2.51 (a) The keys have acceleration $a = -g = -9.80\ \text{m/s}^2$ from the release point until they are caught 1.50 s later. Thus, $\Delta y = v_i t + \frac{1}{2}at^2$ gives

$$v_i = \frac{\Delta y - at^2/2}{t} = \frac{(+4.00\ \text{m}) - (-9.80\ \text{m/s}^2)(1.50\ \text{s})^2/2}{1.50\ \text{s}} = +10.0\ \text{m/s},$$

or $v_i = \boxed{10.0\ \text{m/s upward}}$.

(b) The velocity of the keys just before the catch was

$$v_f = v_i + at = 10.0\ \text{m/s} + (-9.80\ \text{m/s}^2)(1.50\ \text{s}) = -4.68\ \text{m/s},$$

or $\boxed{4.68\ \text{m/s downward}}$.

2.52 In this case, $\Delta y = v_i t + \frac{1}{2}at^2$ yields $-30.0 \text{ m} = (-8.00 \text{ m/s})t + \frac{1}{2}(-9.80 \text{ m/s}^2)t^2$,

or $4.90t^2 + (8.00 \text{ s})t + (-30.0 \text{ s}^2) = 0$.

Using the quadratic formula to solve for the time gives

$$t = \frac{-8.00 \text{ s} \pm \sqrt{(8.00 \text{ s})^2 - 4(4.90)(-30.0 \text{ s}^2)}}{2(4.90)}.$$

Since the time when the ball reaches the ground must be positive, we use only the positive solution to find $t = \boxed{1.79 \text{ s}}$.

2.53 During the 0.600 s required for the rig to pass completely onto the bridge, the front bumper of the tractor moves a distance equal to the length of the rig at constant velocity of $v = 100 \text{ km/h}$. Therefor the length of the rig is

$$L_{rig} = vt = \left[100 \frac{\text{km}}{\text{h}}\left(\frac{0.278 \text{ m/s}}{1 \text{ km/h}}\right)\right](0.600 \text{ s}) = 16.7 \text{ m}.$$

While some part of the rig is on the bridge, the front bumper moves a distance $\Delta x = L_{bridge} + L_{rig} = 400 \text{ m} + 16.7 \text{ m}$. With a constant velocity of $v = 100 \text{ km/h}$, the time for this to occur is

$$t = \frac{L_{bridge} + L_{rig}}{v} = \frac{400 \text{ m} + 16.7 \text{ m}}{100 \text{ km/h}}\left(\frac{1 \text{ km/h}}{0.278 \text{ m/s}}\right) = \boxed{15.0 \text{ s}}.$$

2.54 (a) From $\Delta x = v_i t + \frac{1}{2}at^2$, we have $100 \text{ m} = (30.0 \text{ m/s})t + \frac{1}{2}(-3.50 \text{ m/s}^2)t^2$.

This reduces to $3.50t^2 + (-60.0 \text{ s})t + (200 \text{ s}^2) = 0$, and the quadratic formula gives

$$t = \frac{-(-60.0 \text{ s}) \pm \sqrt{(-60.0 \text{ s})^2 - 4(3.50)(200 \text{ s}^2)}}{2(3.50)}.$$

The desired time is the smaller solution of $t = \boxed{4.53 \text{ s}}$. The larger solution of $t = 12.6 \text{ s}$ is the time when the boat would pass the buoy moving backwards, assuming it maintained a constant acceleration.

(b) The velocity of the boat when it first reaches the buoy is

$$v_f = v_i + at = 30.0 \text{ m/s} + \left(-3.50 \text{ m/s}^2\right)\left(4.53 \text{ s}\right) = \boxed{14.1 \text{ m/s}}.$$

2.55 (a) The acceleration of the bullet is

$$a = \frac{v_f^2 - v_i^2}{2(\Delta x)} = \frac{(300 \text{ m/ s})^2 - (400 \text{ m/ s})^2}{2(0.100 \text{ m})} = \boxed{-3.50 \times 10^5 \text{ m/s}^2}.$$

(b) The time of contact with the board is

$$t = \frac{v_f - v_i}{a} = \frac{(300 - 400) \text{ m/s}}{-3.50 \times 10^5 \text{ m/s}^2} = \boxed{2.86 \times 10^{-4} \text{ s}}.$$

2.56 We assume that the bullet is a cylinder which slows down just as the front end pushes apart wood fibers.

(a) The acceleration is

$$a = \frac{v_f^2 - v_i^2}{2(\Delta x)} = \frac{(280 \text{ m/s})^2 - (420 \text{ m/s})^2}{2(0.100 \text{ m})} = \boxed{-4.90 \times 10^5 \text{ m/s}^2}.$$

(b) The average velocity as the front of the bullet passes through the board is $\bar{v}_{board} = \frac{v_f + v_i}{2} = 350 \text{ m/s}$ and the total time of contact with the board is

$$t = \frac{(\Delta x)_{board}}{\bar{v}_{board}} + \frac{L_{bullet}}{v_f} = \frac{0.100 \text{ m}}{350 \text{ m/s}} + \frac{0.0200 \text{ m}}{280 \text{ m/s}} = \boxed{3.57 \times 10^{-4} \text{ s}}$$

(c) From $v_f^2 = v_i^2 + 2a(\Delta x)$, with $v_f = 0$, gives the required thickness as

$$\Delta x = \frac{v_f^2 - v_i^2}{2a} = \frac{0 - (420 \text{ m/s})^2}{2\left(-4.90 \times 10^5 \text{ m/s}^2\right)} = \boxed{0.180 \text{ m}}.$$

2.57 The falling ball moves a distance of $(15\text{ m} - h)$ before they meet, where h is the height above the ground where they meet. Apply $\Delta y = v_i t + \frac{1}{2}at^2$, with $a = -g$ to obtain

$-(15\text{ m} - h) = 0 - \frac{1}{2}gt^2$, or $h = 15\text{ m} - \frac{1}{2}gt^2$. (1)

Applying $\Delta y = v_i t + \frac{1}{2}at^2$ to the rising ball gives $h = (25\text{ m/s})t - \frac{1}{2}gt^2$. (2)

Combining equations (1) and (2) gives $t = \frac{15\text{ m}}{25\text{ m/s}} = \boxed{0.60\text{ s}}$.

2.58 The distance required to stop the car after the brakes are applied is

$$(\Delta x)_{stop} = \frac{v_f^2 - v_i^2}{2a} = \frac{0 - \left[35.0\ \frac{\text{mi}}{\text{h}}\left(\frac{1.47\text{ ft/s}}{1\text{ mi/h}}\right)\right]^2}{2\left(-9.00\text{ ft/s}^2\right)} = 147\text{ ft}.$$

Thus, if the deer is not to be hit, the maximum distance the car can travel before the brakes are applied is given by

$$(\Delta x)_{before} = 200\text{ ft} - (\Delta x)_{stop} = 200\text{ ft} - 147\text{ ft} = 53.0\text{ ft}.$$

Before the brakes are applied, the constant speed of the car is 35.0 mi/h. Thus, the time required for it to travel 53.0 ft, and hence the maximum allowed reaction time, is

$$(t_r)_{max} = \frac{(\Delta x)_{before}}{v_i} = \frac{53.0\text{ ft}}{\left[35.0\ \frac{\text{mi}}{\text{h}}\left(\frac{1.47\text{ ft/s}}{1\text{ mi/h}}\right)\right]} = \boxed{1.03\text{ s}}.$$

2.59 (a) When either ball reaches the ground, its net displacement is $\Delta y = -19.6\text{ m}$.

Applying $\Delta y = v_i t + \frac{1}{2}at^2$ to the motion of the first ball gives

$-19.6\text{ m} = (-14.7\text{ m/s})t_1 + \frac{1}{2}(-9.80\text{ m/s}^2)t_1^2$ which has a positive solution of $t_1 = 1.00\text{ s}$.

Similarly, applying this relation to the motion of the second ball gives

$-19.6\text{ m} = (+14.7\text{ m/s})t_2 + \frac{1}{2}(-9.80\text{ m/s}^2)t_2^2$ which has a single positive solution of $t_2 = 4.00\text{ s}$.

Thus, the difference in the time of flight for the two balls is

$\Delta t = t_2 - t_1 = (4.00 - 1.00)\text{ s} = \boxed{3.00\text{ s}}$.

(b) When the balls strike the ground, their velocities are:

$$v_{1f} = v_{1i} - gt_1 = -14.7\text{ m/s} - (9.80\text{ m/s}^2)(1.00\text{ s}) = \boxed{-24.5\text{ m/s}},$$

and

$$v_{2f} = v_{2i} - gt_2 = +14.7\text{ m/s} - (9.80\text{ m/s}^2)(4.00\text{ s}) = \boxed{-24.5\text{ m/s}}.$$

(c) At t = 0.800 s, the displacement of each ball from the balcony is:

$$\Delta y_1 = y_1 - 0 = v_{1i}t - \frac{1}{2}gt^2 = (-14.7\text{ m/s})(0.800\text{ s}) - (4.90\text{ m/s}^2)(0.800\text{ s})^2,$$

$$\Delta y_2 = y_2 - 0 = v_{2i}t - \frac{1}{2}gt^2 = (+14.7\text{ m/s})(0.800\text{ s}) - (4.90\text{ m/s}^2)(0.800\text{ s})^2.$$

These yield $y_1 = -14.9\text{ m}$ and $y_2 = +8.62\text{ m}$. Therefore the distance separating the two balls at this time is

$$d = y_2 - y_1 = 8.62\text{ m} - (-14.9\text{ m}) = \boxed{23.5\text{ m}}$$

2.60 We do not know either the initial velocity nor the final velocity (i.e., velocity just before impact) for the truck. What we do know is that the truck skids 62.4 m in 4.20 s while accelerating at -5.60 m/s^2.

We have $v_f = v_i + at$ and $\Delta x = \bar{v}t = \left(\frac{v_f + v_i}{2}\right)t$. Applied to the motion of the truck, these yield

$$v_f - v_i = at \quad \text{or} \quad v_f - v_i = \left(-5.60 \text{ m/s}^2\right)\left(4.20 \text{ s}\right) = -23.5 \text{ m/s}, \tag{1}$$

and

$$v_f + v_i = \frac{2(\Delta x)}{t} = \frac{2(62.4 \text{ m})}{4.20 \text{ s}} = 29.7 \text{ m/s} \tag{2}$$

Adding equations (1) and (2) gives the velocity at moment of impact as

$$2v_f = (-23.5 + 29.7) \text{ m/s}, \text{ or } v_f = \boxed{3.10 \text{ m/s}}.$$

2.61 When Kathy has been moving for *t* seconds, Stan's elapsed time is $t + 1.00$ s. At this time, the displacements of the two cars are

$$(\Delta x)_{Kathy} = v_{iK}t + \frac{1}{2}a_K t^2 = 0 + \frac{1}{2}\left(4.90 \text{ m/s}^2\right)t^2,$$

and $$(\Delta x)_{Stan} = v_{iS}t + \frac{1}{2}a_S(t + 1.00 \text{ s})^2 = 0 + \frac{1}{2}\left(3.50 \text{ m/s}^2\right)(t + 1.00 \text{ s})^2.$$

(a) When Kathy overtakes Stan, $(\Delta x)_{Kathy} = (\Delta x)_{Stan}$, or

$$\left(4.90 \text{ m/s}^2\right)t^2 = \left(3.50 \text{ m/s}^2\right)(t + 1.00 \text{ s})^2$$

which gives the time as $t = \boxed{5.46 \text{ s}}$.

(b) Kathy's displacement at this time is

$$(\Delta x)_{Kathy} = \frac{1}{2}\left(4.90 \text{ m/s}^2\right)(5.46 \text{ s})^2 = \boxed{73.0 \text{ m}}.$$

(c) At this time, the velocities of the two cars are

$$\left(v_f\right)_{Kathy} = v_{iK} + a_K t = 0 + \left(4.90\ \text{m/s}^2\right)\left(5.46\ \text{s}\right) = \boxed{26.7\ \text{m/s}},$$

and $\left(v_f\right)_{Stan} = v_{iS} + a_S\left(t + 1.00\ \text{s}\right) = 0 + \left(3.50\ \text{m/s}^2\right)\left(6.46\ \text{s}\right) = \boxed{22.6\ \text{m/s}}$.

2.62 (a) The velocity with which the first stone hits the water is

$$v_{1f} = -\sqrt{v_{1i}^2 + 2a\left(\Delta y\right)} = -\sqrt{\left(-2.00\ \frac{\text{m}}{\text{s}}\right)^2 + 2\left(-9.80\ \frac{\text{m}}{\text{s}^2}\right)\left(-50.0\ \text{m}\right)} = -31.4\ \frac{\text{m}}{\text{s}}.$$

The time for this stone to hit the water is

$$t_1 = \frac{v_{1f} - v_{1i}}{a} = \frac{\left[-31.4\ \text{m/s} - \left(-2.00\ \text{m/s}\right)\right]}{-9.80\ \text{m/s}^2} = \boxed{3.00\ \text{s}}.$$

(b) Since they hit simultaneously, the second stone which is released $1.00\ \text{s}$ later, will hit the water after an flight time of 2.00 s. Thus,

$$v_{2i} = \frac{\Delta y - at_2^2/2}{t_2} = \frac{-50.0\ \text{m} - \left(-9.80\ \text{m/s}^2\right)\left(2.00\ \text{s}\right)^2/2}{2.00\ \text{s}} = \boxed{-15.2\ \text{m/s}}.$$

(c) From part (a), the final velocity of the first stone is $v_{1f} = \boxed{-31.4\ \text{m/s}}$.

The final velocity of the second stone is

$$v_{2f} = v_{2i} + at_2 = -15.2\ \text{m/s} + \left(-9.80\ \text{m/s}^2\right)\left(2.00\ \text{s}\right) = \boxed{-34.8\ \text{m/s}}.$$

2.63 (a) At 5.00 m above the surface, the velocity of the astronaut is given by

$$v_f = \sqrt{v_i^2 + 2a\left(\Delta y\right)} = \sqrt{0 + 2\left(2.00\ \text{m/s}^2\right)\left(5.00\ \text{m}\right)} = \boxed{+4.47\ \text{m/s}}.$$

(b) The bolt begins free-fall with an initial velocity of $v_f = +4.47\ \text{m/s}$ at 5.00 m above the surface. When it reaches the surface, $\Delta y = v_i t + \frac{1}{2}at^2$ gives

$-5.00\ \text{m} = \left(+4.47\ \text{m/s}\right)t + \frac{1}{2}\left(-1.67\ \text{m/s}^2\right)t^2$ which has a positive solution of $t = 6.31\ \text{s}$.

Thus, the bolt hits $\boxed{\text{6.31 s after it is released}}$.

(c) When it reaches the surface, the velocity of the bolt is

$$v_f = v_i + at = +4.47 \text{ m/s} + \left(-1.67 \text{ m/s}^2\right)(6.31 \text{ s}) = \boxed{-6.06 \text{ m/s}}.$$

(d) The displacement of the astronaut while the bolt is falling is

$$\Delta y = v_i t + \frac{1}{2}at^2 = (4.47 \text{ m/s})(6.31 \text{ s}) + \frac{1}{2}\left(2.00 \text{ m/s}^2\right)(6.31 \text{ s})^2 = 68.0 \text{ m}.$$

Therefore, the altitude of the astronaut when the bolt hits is

$$y_f = 5.00 \text{ m} + 68.0 \text{ m} = \boxed{73.0 \text{ m}}.$$

(e) The velocity of the astronaut when the bolt hits is

$$v_f = v_i + at = +4.47 \text{ m/s} + \left(+2.00 \text{ m/s}^2\right)(6.31 \text{ s}) = \boxed{+17.1 \text{ m/s}}.$$

2.64 (a) From $\Delta y = v_i t + \frac{1}{2}at^2$ with $v_i = 0$, we have

$$t = \sqrt{\frac{2(\Delta y)}{a}} = \sqrt{\frac{2(-23 \text{ m})}{-9.80 \text{ m/s}^2}} = \boxed{2.2 \text{ s}}.$$

(b) The final velocity is $v_f = 0 + \left(-9.80 \text{ m/s}^2 \text{ m/s}^2\right)(2.2 \text{ s}) = \boxed{-22 \text{ m/s}}$.

(c) The time take for the sound of the impact to reach the spectator is

$$t_{sound} = \frac{\Delta y}{v_{sound}} = \frac{23 \text{ m}}{340 \text{ m/s}} = 6.8 \times 10^{-2} \text{ s},$$

so the total elapsed time is $t_{total} = 2.2 \text{ s} + 6.8 \times 10^{-2} \text{ s} \approx \boxed{2.3 \text{ s}}$

2.65 (a) Since the sound has constant velocity, the distance it traveled is

$$\Delta x = v_{sound}\, t = (1100 \text{ ft/s})(5.0 \text{ s}) = \boxed{5.5 \times 10^3 \text{ ft}}.$$

(b) The plane travels this distance in a time of $5.0 \text{ s} + 10 \text{ s} = 15 \text{ s}$, so its velocity must be

$$v_{plane} = \frac{\Delta x}{t} = \frac{5.5 \times 10^3 \text{ ft}}{15 \text{ s}} = \boxed{3.7 \times 10^2 \text{ ft/s}}.$$

(c) The time the light took to reach the observer was

$$t_{light} = \frac{\Delta x}{v_{light}} = \frac{5.5 \times 10^3 \text{ ft}}{3.00 \times 10^8 \text{ m/s}} \left(\frac{1 \text{ m/s}}{3.281 \text{ ft/s}} \right) = 5.6 \times 10^{-6} \text{ s}.$$

$\boxed{\text{During this time the plane would only travel a distance of 0.002 ft}}$.

2.66 The total time for the safe to reach the ground is found from

$$\Delta y = v_i t + \frac{1}{2} a t^2 \text{ with } v_i = 0 \text{ as } t_{total} = \sqrt{\frac{2(\Delta y)}{a}} = \sqrt{\frac{2(-25.0 \text{ m})}{-9.80 \text{ m/s}^2}} = 2.26 \text{ s}.$$

The time to fall the first fifteen meters is found similarly:

$$t_{15} = \sqrt{\frac{2(\Delta y)}{a}} = \sqrt{\frac{2(-15.0 \text{ m})}{-9.80 \text{ m/s}^2}} = 1.75 \text{ s}.$$

The time Wile E. Coyote has to reach safety is

$$\Delta t = t_{total} - t_{15} = 2.26 \text{ s} - 1.75 \text{ s} = \boxed{0.509 \text{ s}}.$$

2.67 The time required for the woman to fall 3.00 m, starting from rest, is found from $\Delta y = v_i t + \frac{1}{2} a t^2$ as $-3.00 \text{ m} = 0 + \frac{1}{2}(-9.80 \text{ m/s}^2) t^2$, giving $t = 0.782 \text{ s}$.

(a) With the horse moving with constant velocity of 10.0 m/s, the horizontal distance is $\Delta x = v_{horse} t = (10.0 \text{ m/s})(0.782 \text{ s}) = \boxed{7.82 \text{ m}}$.

(b) The required time is $t = \boxed{0.782 \text{ s}}$ as calculated above.

2.68 Assume that the ball falls 1.5 m, from rest, before touching the ground. Further, assume that after contact with the ground the ball moves with constant acceleration for an additional 0.50 cm (hence compressing the ball) before coming to rest.

With the first assumption, $v_f^2 = v_i^2 + 2a(\Delta y)$ gives the velocity of the ball when it first touches the ground as

$$v_f = -\sqrt{v_i^2 + 2a(\Delta y)} = -\sqrt{0 + 2(-9.80\ \text{m/s}^2)(-1.5\ \text{m})} = -5.4\ \text{m/s}.$$

Then, using the second assumption, the acceleration while coming to rest is found to be

$$a = \frac{v_f^2 - v_i^2}{2(\Delta y)} = \frac{0 - (-5.4\ \text{m/s})^2}{2(5.0 \times 10^{-3}\ \text{m})} = 2.9 \times 10^3\ \text{m/s}^2, \text{ or } \boxed{\sim 10^3\ \text{m/s}^2}.$$

Answers to Even Numbered Conceptual Questions

2. Yes. Zero velocity means that the object is at rest. If the object also has zero acceleration, the velocity is not changing and the object will continue to be at rest.

4. You can ignore the time for the lightning to reach you because light travels at the speed of 3×10^8 m/s, a speed so fast that in our day-to-day activities it is essentially infinite.

6. The average velocity of an object is defined as the displacement of the object divided by the time interval during which the displacement occurred. If the average velocity is zero, the displacement must also be zero.

8. In Figure (b), the images are equally spaced showing that the object moved the same distance in each time interval. Hence, the velocity is constant in (b).

In Figure (c,) the images are farther apart for each successive time interval. The object is moving toward the right and speeding up. This means that the acceleration is positive in (c).

In Figure (a), The first four images show an increasing distance traveled each time interval and therefore a positive acceleration. However, after the fourth image, the spacing is decreasing showing that the object is now slowing down (or has negative acceleration).

10. Velocities are equal only if both magnitude and direction are the same. These objects are moving in different directions, so the velocities are not the same.

12. The rule of thumb assumes constant velocity. If the car(s) move with constant acceleration, the velocity would continually be changing. This would mean the distance between the cars would continually have to change for the rule of thumb to be valid, which could require a slowing down, which would imply a change in the value of the acceleration.

14. (a) The car is moving to the east and increasing in speed.

(b) The car is moving to the east but slowing in speed.

(c) The car is moving to the east at constant speed.

(d) The car is moving to the west but slowing in speed.

(e) The car is moving to the west and speeding up.

(f) The car is moving to the west at constant speed.

(g) The car starts from rest and begins to speed up toward the east.

(h) The car starts from rest and begins to speed up toward the west.

16. The balls speed up and slow down at the same rate, but the distances of travel are different in different time intervals. For example, the rising ball starts at a high speed and slows down. This means that it travels a longer distance in, say, the first second than does the slower moving dropped ball. Thus, the balls will meet above the midway point.

18. (a) Successive images on the film will be separated by a constant distance if the ball has constant velocity.

(b) Starting at the right-most image, the images will be getting closer together as one moves toward the left.

(c) Starting at the right-most image, the images will be getting farther apart as one moves toward the left.

(d) As one moves from left to right, the balls will first get farther apart in each successive image, then closer together when the ball begins to slow down.

Answers to Even Numbered Problems

2. (a) 2×10^{-7} m/s, 1×10^{-6} m/s (b) 5×10^{8} yr

4. (a) 5×10^{-11} m/s (b) 7×10^{-6} m/s

6. (a) 5.00 m/s (b) 1.25 m/s (c) –2.50 m/s (d) –3.33 m/s (e) 0

8. (a) 2.3 min (b) 64 mi

10. 1.32 h

12. (a) 1.3×10^{2} s (b) 13 m

14. 0.18 mi west of the flagpole

16. (b) 41.0 m/s, 41.0 m/s, 41.0 m/s
(c) $\overline{v} = 17.0$ m/s, much less than the results of (b)

18. (a) 52.4 ft/s, 55.0 ft/s, 55.5 ft/s, 57.4 ft/s (b) 0.598 ft/s^2

20. -1.5×10^{3} m/s^2

22. (a) 0, 1.6 m/s^2, 0.80 m/s^2 (b) 0, 1.6 m/s^2, 0

24. –2 .90 m/s^2

26. (a) 6.61 m/s (b) –0.448 m/s^2

28. (a) –8.0 m/s^2 (b) 100 m

30. (a) 35 s (b) 16 m/s

32. (a) 20.0 s (b) No, the minimum distance to stop = 1.00 km

34. (a) 5.51 km (b) 20.8 m/s, 41.6 m/s, 20.8 m/s; 38.7 m/s

36. (a) 107 m, (b) 1.49 m/s^2

38. 29.1 s

40. 8.9 s, 99 m

42. (b) 6.2 s

44. 1.8×10^6 m/s^2

46. 3.94 s

48. (a) 9.80 m/s (b) 4.90 m

50. (a) 2.3 s (b) -33 m/s

52. 1.79 s

54. (a) 4.53 s (b) 14.1 m/s

56. (a) -4.90×10^5 m/s^2 (b) 3.57×10^{-4} s (c) 0.180 m

58. 1.03 s

60. 3.10 m/s

62. (a) 3.00 s (b) -15.2 m/s (c) -31.4 m/s, -34.8 m/s

64. (a) 2.2 s (b) -22 m/s (c) 2.3 s

66. 0.51 s

68. $\sim 10^3$ m/s^2, assumes the ball drops 1.5 m and compresses ≈ 0.5 cm upon hitting the floor