Chapter 2

Motion in One Dimension

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-vs.-time graph (a) has a constant slope, indicating a constant acceleration, which is represented by the acceleration-vs.-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-vs.-time graph that best indicates this behavior is (d).

   Graph (c) depicts an object which first has a velocity that increases at a constant rate, which means that the object's 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. (e). The acceleration of the ball remains constant while it is in the air. The magnitude of its acceleration is the free-fall acceleration, $g = 9.80 \text{ m/s}^2$.

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*.

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. **(a)** positive, negative, zero

(b) The ball has the free-fall acceleration (-9.80 m/s^2) at each point.

(c) $2t_1$

(d) $-v_0$

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. 12.2 mi/h

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) $v_{\text{av}} = 17.0$ 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. 0.75 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. –1.33 m/s^2

26. **(a)** 6.61 m/s **(b)** –0.448 m/s^2

28. **(a)** 12.5 s **(b)** –2.29 m/s^2 **(c)** 13.1 s

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. Idea (a) is not true unless the acceleration is zero. Idea (b) is true for all constant values of acceleration.

42. 96 m

44. **(a)** 510 m **(b)** 20.4 s

46. Hardwood Floor: $a = 2.0 \times 10^3 \text{ m/s}^2$, $\Delta t = 1.4 \text{ ms}$
Carpeted Floor: $a = 3.9 \times 10^2 \text{ m/s}^2$, $\Delta t = 7.1 \text{ ms}$

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

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

52. **(a)** 4.0 m/s, 1.0 ms **(b)** 0.82 m

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

56. **(a)** $-4.90 \times 10^5 \text{ m/s}^2$ **(b)** $3.57 \times 10^{-4} \text{ s}$ **(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)** -21 m/s **(c)** 2.3 s

66. 0.51 s

68. $\sim 10^3 \text{ m/s}^2$, assumes the ball drops 1.5 m and compresses $\approx 1.0 \text{ cm}$ upon hitting the floor

70. Yes, her maximum acceleration is more than sufficient.

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) $v_{av} = \dfrac{\Delta x}{\Delta t} = \dfrac{90.0 \text{ km}}{1.70 \text{ h}} = \boxed{52.9 \text{ km/h}}$

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

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

or in particularly windy times

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

(b) The time required must have been

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

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 The average speed is $v_{av} = \frac{\Delta x}{\Delta t}$ where

$$\Delta x = 26.0 \text{ mi} + (385 \text{ yard})\left(\frac{3 \text{ ft}}{1 \text{ yard}}\right)\left(\frac{1 \text{ mi}}{5280 \text{ ft}}\right) = 26.2 \text{ mi}$$

and $$\Delta t = 2.00 \text{ h} + (9.00 \text{ min})\left(\frac{1 \text{ h}}{60 \text{ min}}\right) + (21.0 \text{ s})\left(\frac{1 \text{ h}}{3600 \text{ s}}\right) = 2.16 \text{ h}$$

Thus, $$v_{av} = \frac{26.2 \text{ mi}}{2.16 \text{ h}} = \boxed{12.2 \ \frac{\text{mi}}{\text{h}}}$$

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

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

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

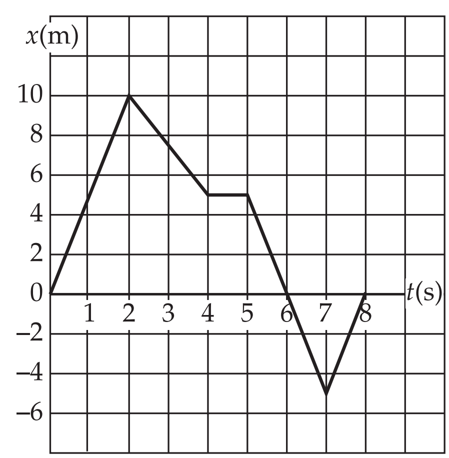
2.6 (a) $$v_{av} = \frac{\Delta x}{\Delta t} = \frac{10.0 \text{ m} - 0}{2.00 \text{ s} - 0} = \boxed{5.00 \text{ m/s}}$$

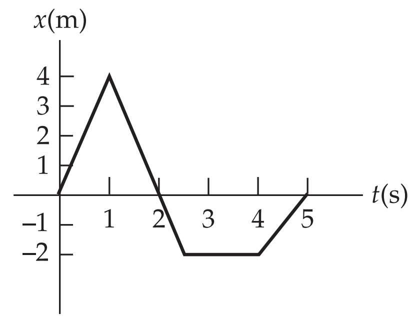
(b) $$v_{av} = \frac{\Delta x}{\Delta t} = \frac{5.00 \text{ m} - 0}{4.00 \text{ s} - 0} = \boxed{1.25 \text{ m/s}}$$

(c) $$v_{av} = \frac{\Delta x}{\Delta t} = \frac{5.00 \text{ m} - 10.0 \text{ m}}{4.00 \text{ s} - 2.00 \text{ s}} = \boxed{-2.50 \text{ m/s}}$$

(d) $$v_{av} = \frac{\Delta x}{\Delta t} = \frac{-5.00 \text{ m} - 5.00 \text{ m}}{7.00 \text{ s} - 4.00 \text{ s}} = \boxed{-3.33 \text{ m/s}}$$

(e) $$v_{av} = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{0 - 0}{8.00 \text{ s} - 0} = \boxed{0}$$





2.7 (a) $v_{av} = \dfrac{\Delta x}{\Delta t} = \dfrac{4.0\ \text{m} - 0}{1.0\ \text{s} - 0} = \boxed{+4.0\ \text{m/s}}$

(b) $v_{av} = \dfrac{\Delta x}{\Delta t} = \dfrac{-2.0\ \text{m} - 0}{4.0\ \text{s} - 0} = \boxed{-0.50\ \text{m/s}}$

(c) $v_{av} = \dfrac{\Delta x}{\Delta t} = \dfrac{0 - 4.0\ \text{m}}{5.0\ \text{s} - 1.0\ \text{s}} = \boxed{-1.0\ \text{m/s}}$

(d) $v_{av} = \dfrac{\Delta x}{\Delta t} = \dfrac{0 - 0}{5.0\ \text{s} - 0} = \boxed{0}$

2.8 (a) The time for a car to make the trip is $t = \dfrac{\Delta x}{v}$. 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 The average velocity is $v_{av} = \Delta x/\Delta t$ where we take Δx to be positive when the displacement is in the direction the athlete swims during the first half of the trip.

(a) For the first half of the trip, $v_{av} = \dfrac{+50.0\ \text{m}}{20.0\ \text{s}} = \boxed{2.50\ \text{m/s}}$

(b) On the second half, $v_{av} = \dfrac{-50.0\ \text{m}}{22.0\ \text{s}} = \boxed{-2.27\ \text{m/s}}$

(c) For the entire trip, $\Delta x = +50.0\text{ m} - 50.0\text{ m} = 0$ giving $v_{\text{av}} = \boxed{0}$

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

$$2\pi(\text{Earth's radius} + 200\text{ miles}) = 2\pi(3963 + 200)\text{ mi} = 2.61\times10^{4}\text{ mi}$$

Thus, the required time is $\dfrac{2.61\times10^{4}\text{ mi}}{19\,800\text{ mi/h}} = \boxed{1.32\text{ h}}$

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

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

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, $$x = v_{\text{av}}t = (77.8\text{ km/h})(2.80\text{ h}) = \boxed{218\text{ km}}$$

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 $t = \boxed{1.3\times10^{2}\text{ s}}$

(b) $x_t = v_t t = (0.100\text{ m/s})(1.3\times10^{2}\text{ s}) = \boxed{13\text{ m}}$

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

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

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

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

2.14 Choose a coordinate axis with the origin at the flagpole and east as the positive direction. Then, using $x = x_0 + v_0 t + \frac{1}{2}at^2$ with $a = 0$ for each runner, the x-coordinate of each runner at time t is

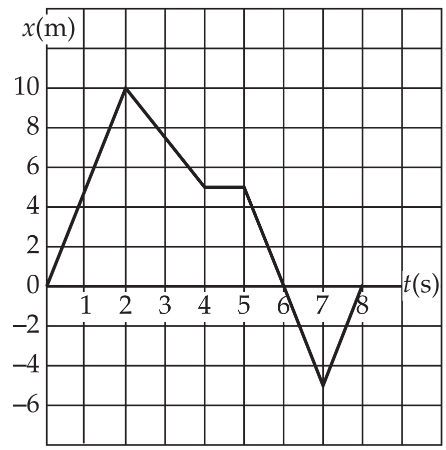
$$x_A = -4.0\text{ mi} + (6.0\text{ mi/h})t \quad \text{and} \quad x_B = 3.0\text{ mi} + (-5.0\text{ mi/h})t$$

When the runners meet, $x_A = x_B$

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

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



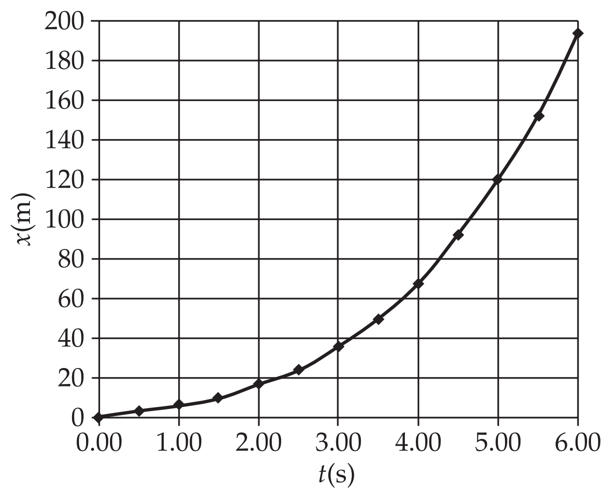
(b) $v=\dfrac{(5.00-10.0)\text{ m}}{(4.00-2.00)\text{ s}}=\boxed{-2.50\text{ m/s}}$

(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,

$$v=\frac{\Delta x}{\Delta t}=\frac{16.4\text{ m}}{0.400\text{ s}}=\boxed{41.0\text{ m/s}}$$

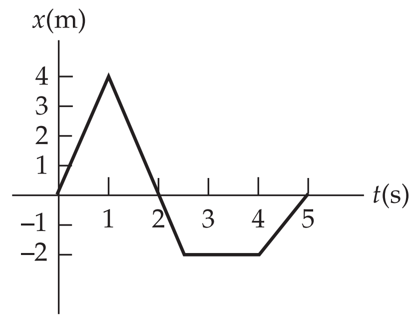
Using a time interval of 0.200 s, we find the corresponding values to be: at $t=3.90$ s, $x=64.0$ m and at $t=4.10$ s, $x=72.2$ m. Thus,

$$v=\frac{\Delta x}{\Delta t}=\frac{8.20\text{ m}}{0.200\text{ s}}=\boxed{41.0\text{ m/s}}$$

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, $v_{av}=\dfrac{\Delta x}{\Delta t}=\dfrac{68.0\text{ m}}{4.00\text{ s}}=\boxed{17.0\text{ m/s}}$

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 $v_{\text{av}} = \dfrac{\text{distance traveled}}{\Delta t}$

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

$$(v_{\text{av}})_1 = \frac{0.250\text{ mi}}{25.2\text{ s}} = \frac{1320\text{ ft}}{25.2\text{ s}} = \boxed{52.4\text{ ft/s}}\ \ (35.6\text{ mi/h})$$

During the second quarter mile segment,

$$(v_{\text{av}})_2 = \frac{1320\text{ ft}}{24.0\text{ s}} = \boxed{55.0\text{ ft/s}}\ \ (37.4\text{ mi/h})$$

For the third quarter mile of the race,

$$(v_{\text{av}})_3 = \frac{1320\text{ ft}}{23.8\text{ s}} = \boxed{55.5\text{ ft/s}}\ \ (37.7\text{ mi/h})$$

and during the final quarter mile,

$$(v_{\text{av}})_4 = \frac{1320\text{ ft}}{23.0\text{ s}} = \boxed{57.4\text{ ft/s}}\ \ (39.0\text{ mi/h})$$

(b) Assuming that $v = (v_{\text{av}})_4$ and recognizing that $v_0 = 0$, the average acceleration during the race was

$$a_{\text{av}} = \frac{v - v_0}{\text{total elapsed time}} = \frac{57.4\text{ ft/s} - 0}{(25.2+24.0+23.8+23.0)\text{ s}} = \boxed{0.598\text{ ft/s}^2}$$

2.19 (a) $a_{av} = \dfrac{\Delta v}{\Delta t} = \dfrac{175\text{ mi/h} - 0}{2.5\text{ s}} = \boxed{70.0\ \text{mi/h}\cdot\text{s}}$

or $$a_{av} = \left(70.0\ \frac{\text{mi}}{\text{h}\cdot\text{s}}\right)\left(\frac{1609\text{ m}}{1\text{ mi}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right) = \boxed{31.3\ \text{m/s}^2}$$

Alternatively, $$a_{av} = \left(31.3\ \frac{\text{m}}{s^2}\right)\left(\frac{1\,g}{9.80\ \text{m/s}^2}\right) = \boxed{3.19\,g}$$

(b) If the acceleration is constant, $\Delta x = v_0 t + \frac{1}{2}at^2$

$$\Delta x = 0 + \tfrac{1}{2}\left(31.3\ \frac{\text{m}}{\text{s}^2}\right)(2.50\text{ s})^2 = \boxed{97.8\text{ m}}$$

or $$\Delta x = (97.8\text{ m})\left(\frac{3.281\text{ ft}}{1\text{ m}}\right) = \boxed{321\text{ ft}}$$

2.20 $$a_{av} = \frac{v - v_0}{t - t_0} = \frac{(+8.0\ \text{m/s}) - (+5.0\ \text{m/s})}{4.0\text{ s}} = \boxed{0.75\ \text{m/s}^2}$$

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

2.22 (a) From $t = 0$ to $t = 5.0$ s,

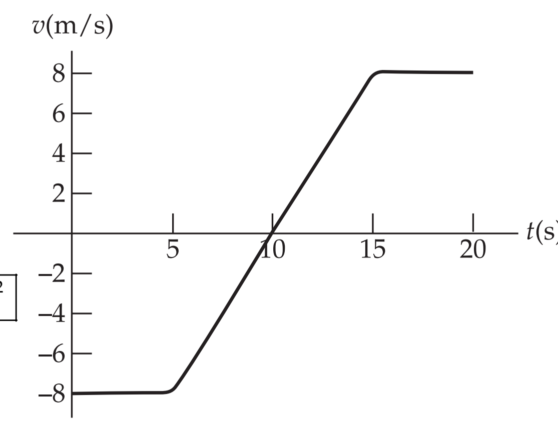
$$a_{av} = \frac{v - v_0}{t - t_0} = \frac{0 - 0}{5.0\text{ s} - 0} = \boxed{0}$$

From $t = 5.0$ s to $t = 15$ s,

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

and from $t = 0$ to $t = 20$ s,

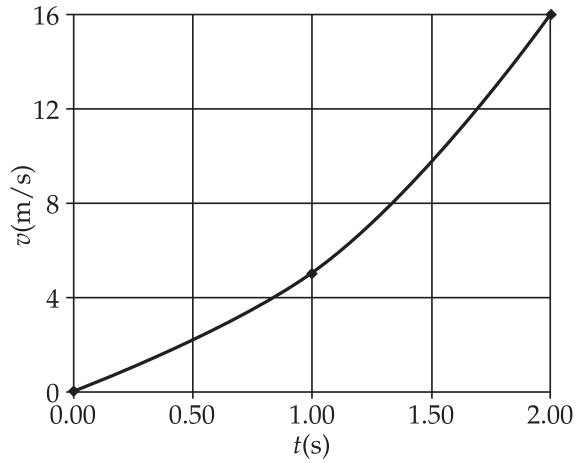
$$a_{av} = \frac{8.0\ \text{m/s} - (-8.0\ \text{m/s})}{20\text{ s} - 0} = \boxed{0.80\ \text{m/s}^2}$$



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

$$a_{av} = \frac{\Delta v}{\Delta t} = \frac{16\ \text{m/s}}{2.0\ \text{s}} = \boxed{8.0\ \text{m/s}^2}$$



(b) The instantaneous acceleration at $t = 1.5$ 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 $a_{av} = \dfrac{v - v_0}{t - t_0} = \dfrac{(+6.00\ \text{m/s}) - (+10.0\ \text{m/s})}{3.00\ \text{s}} = \boxed{-1.33\ \text{m/s}^2}$

The negative sign in the answer indicates that the direction of the average acceleration is opposite to that of the initial and final velocities, which were taken to be positive.

2.25 From $v^2 = v_0^2 + 2a(\Delta x)$, we have $(10.97 \times 10^3\ \text{m/s})^2 = 0 + 2a(220\ \text{m})$ so that $a = \boxed{2.74 \times 10^5\ \text{m/s}^2}$ which is $\boxed{2.79 \times 10^4\ \text{times } g!}$

2.26 (a) $\Delta x = v_{av}(\Delta t) = \left(\dfrac{v + v_0}{2}\right)\Delta t$ becomes $40.0\ \text{m} = \left(\dfrac{2.80\,\text{m/s} + v_0}{2}\right)(8.50\ \text{s})$,

which yields $v_0 = \boxed{6.61\ \text{m/s}}$.

(b) $a = \dfrac{v - v_0}{\Delta t} = \dfrac{2.80\ \text{m/s} - 6.61\ \text{m/s}}{8.50\ \text{s}} = \boxed{-0.448\ \text{m/s}^2}$

2.27 Suppose the unknown acceleration is constant as a boat initially moving at $v_0 = 20\ \text{m/s}$ has a displacement of $\Delta x = 200\ \text{m}$ as it accelerates to $v = 30\ \text{m/s}$.

(a) We find the acceleration from $v^2 = v_0^2 + 2a(\Delta x)$.

$$a = \frac{v^2 - v_0^2}{2(\Delta x)} = \frac{(30\ \text{m/s})^2 - (20\ \text{m/s})^2}{2(200\ \text{m})} = \boxed{1.3\ \text{m/s}^2}$$

(b) The required time may be found from $\Delta x = v_{av} t = \left(\frac{v + v_0}{2}\right) t$

$$t = \frac{2(\Delta x)}{v + v_0} = \frac{2(200\ \text{m})}{30\ \text{m/s} + 20\ \text{m/s}} = \ 8.0\ \text{s}$$

2.28 (a) With constant acceleration, the time required for the lead car to stop may be found from $a = \Delta v / \Delta t$ as

$$\Delta t = \frac{v - v_0}{a} = \frac{0 - 25.0\ \text{m/s}}{-2.00\ \text{m/s}^2} = \boxed{12.5\ \text{s}}$$

During this time, the lead car travels an additional distance of

$$\Delta x_{additional} = v_{av}(\Delta t) = \left(\frac{0 + 25.0\ \text{m/s}}{2}\right)(12.5\ \text{s}) = 156\ \text{m}$$

(b) If a collision is to be avoided, the maximum displacement of the chase car while the lead car is stopping is

$$(\Delta x)_{max} = \Delta x_0 + \Delta x_{additional} = 40.0\ \text{m} + 156\ \text{m} = 196\ \text{m}$$

The minimum negative acceleration of the chase car is

$$a_{min} = \frac{v^2 - v_0^2}{2(\Delta x)_{max}} = \frac{0 - (30.0\ \text{m/s})^2}{2(196\ \text{m})} = \boxed{-2.29\ \text{m/s}^2}$$

(c) The time required for the chase car to stop is

$$\Delta t = \frac{v - v_0}{a_{min}} = \frac{0 - 30.0\ \text{m/s}}{-2.29\ \text{m/s}^2} = \boxed{13.1\ \text{s}}$$

2.29 (a) With $v = 120\ \text{km/h}$, $v^2 = v_0^2 + 2a(\Delta x)$ yields

$$a = \frac{v^2 - v_0^2}{2(\Delta x)} = \frac{\left[(120\ \text{km/h})^2 - 0\right]}{2(240\ \text{m})}\left(\frac{0.278\ \text{m/s}}{1\ \text{km/h}}\right)^2 = \boxed{2.32\ \text{m/s}^2}$$

(b) The required time is $t = \frac{v - v_0}{a} = \frac{(120\ \text{km/h} - 0)}{2.32\ \text{m/s}^2}\left(\frac{0.278\ \text{m/s}}{1\ \text{km/h}}\right) = \boxed{14.4\ \text{s}}$

2.30 (a) The time for the truck to reach $20\ \text{m/s}$ is found from $v = v_0 + at$ as

$$t = \frac{v - v_0}{a} = \frac{20\ \text{m/s} - 0}{2.0\ \text{m/s}^2} = 10\ \text{s}$$

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

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

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

$$(\Delta x)_2 = (v_0)_2 t_2 + \frac{1}{2}a_2 t_2{}^2 = (20\ \text{m/s})(20\ \text{s}) + 0 = 400\ \text{m}$$

The distance traveled in the last 5.0 s is

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

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

$$v_{\text{av}} = \frac{\Delta x}{t_{total}} = \frac{550\ \text{m}}{35\ \text{s}} = \boxed{16\ \text{m/s}}$$

2.31 (a) Using $\Delta x = v_0 t + \frac{1}{2}at^2$ with $v_0 = 0$ 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 $v = v_0 + at$, with $v_0 = 0$, we find $v = 0 + \left(10.0\ \text{m/s}^2\right)(8.94\ \text{s}) = \boxed{89.4\ \text{m/s}}$

2.32 (a) The time required to stop is $t = \dfrac{v - v_0}{a} = \dfrac{0 - 100 \text{ m/s}}{-5.00 \text{ m/s}^2} = \boxed{20.0 \text{ s}}$

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

$$\Delta x = v_{\text{av}} t = \left(\frac{v + v_0}{2}\right) t = \left(\frac{0 + 100 \text{ m/s}}{2}\right)(20.0 \text{ s}) = 1000 \text{ m} = \boxed{1.00 \text{ km}}$$

Thus, the plane cannot stop in 0.8 km.

2.33 Using $v^2 = v_0^2 + 2a(\Delta x)$, with $v = 0$ and $v_0 = 60 \text{ mi/h}$, yields

$$a = \frac{v^2 - v_0^2}{2(\Delta x)} = \frac{\left[0 - (60 \text{ mi/h})^2\right]}{2(100 \text{ m})}\left(\frac{0.447 \text{ m/s}}{1 \text{ mi/h}}\right)^2 = \boxed{-3.6 \text{ m/s}^2}$$

2.34 The velocity at the end of the first interval is

$$v = v_0 + at = 0 + (2.77 \text{ m/s})(15.0 \text{ s}) = 41.6 \text{ m/s}$$

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

(a) From $\Delta x = v_0 t + \frac{1}{2} a t^2$, 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) $$\left(v_{\text{av}}\right)_1 = \frac{(\Delta x)_1}{t_1} = \frac{312\text{ m}}{15.0\text{ s}} = \boxed{20.8\text{ m/s}}$$

$$\left(v_{\text{av}}\right)_2 = \frac{(\Delta x)_2}{t_2} = \frac{5.11\times 10^3\text{ m}}{123\text{ s}} = \boxed{41.6\text{ m/s}}$$

$\left(v_{\text{av}}\right)_3 = \dfrac{(\Delta x)_3}{t_3} = \dfrac{91.2\text{ m}}{4.39\text{ s}} = 20.8\text{ m/s}$, and the average velocity for the

total trip is $\left(v_{\text{av}}\right)_{total} = \dfrac{\Delta x}{t_{total}} = \dfrac{5.51\times 10^3\text{ m}}{(15.0+123+4.39)\text{ s}} = \boxed{38.7\text{ m/s}}$

2.35 Using the uniformly accelerated motion equation $\Delta x = v_0 t + \frac{1}{2}at^2$ 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 $t = \dfrac{v - v_0}{a} = \dfrac{0-20\text{ m/s}}{-1.0\text{ m/s}^2} = 20\text{ s}$. 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 $\Delta x = v_0 t + \frac{1}{2}at^2$ 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 $v = 40.0\text{ mi/h} = 17.9\text{ m/s}$ and $v_0 = 0$

(a) To find the distance traveled, we use

$$\Delta x = v_{\text{av}} t = \left(\frac{v+v_0}{2}\right)t = \left(\frac{17.9\text{ m/s}+0}{2}\right)(12.0\text{ s}) = \boxed{107\text{ m}}$$

(b) The acceleration is $a = \dfrac{v-v_0}{t} = \dfrac{17.9\text{ m/s}-0}{12.0\text{ s}} = \boxed{1.49\text{ m/s}^2}$

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

$$v = v_0 + at = 0 + \left(1.5\ \mathrm{m/s^2}\right)\left(5.0\ \mathrm{s}\right) = 7.5\ \mathrm{m/s}$$

This is also the initial velocity for the braking period.

(a) After braking, $v = v_0 + at = 7.5\ \mathrm{m/s} + \left(-2.0\ \mathrm{m/s^2}\right)\left(3.0\ \mathrm{s}\right) = \boxed{1.5\ \mathrm{m/s}}$

(b) The total distance traveled is

$$\Delta x = \left(\Delta x\right)_{accel} + \left(\Delta x\right)_{brake} = \left(v_{\mathrm{av}} t\right)_{accel} + \left(v_{\mathrm{av}} t\right)_{brake}$$

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

2.38 The initial velocity of the train is $v_0 = 82.4\ \mathrm{km/h}$ and the final velocity is $v = 16.4\ \mathrm{km/h}$. The time required for the $400\ \mathrm{m}$ train to pass the crossing is found from $\Delta x = v_{\mathrm{av}} t = \left(\frac{v + v_0}{2}\right) t$ as

$$t = \frac{2\left(\Delta x\right)}{v + v_0} = \frac{2\left(0.400\ \mathrm{km}\right)}{\left(82.4 + 16.4\right)\ \mathrm{km/h}}\left(\frac{3600\ \mathrm{s}}{1\ \mathrm{h}}\right) = \boxed{29.1\ \mathrm{s}}$$

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

$$\Delta x_{player} = \left(v_0\right)_{player} t + \frac{1}{2} a_{player} t^2 = 0 + \frac{1}{2}\left(4.0\ \mathrm{m/s^2}\right) t^2 \tag{1}$$

and, $\Delta x_{opponent} = \left(v_0\right)_{opponent} t + \frac{1}{2} a_{opponent} t^2 = \left(12\ \mathrm{m/s}\right) t + 0$ (2)

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

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

(b) $\Delta x_{player} = \left(v_0\right)_{player} t + \frac{1}{2} a_{player} t^2 = 0 + \frac{1}{2}\left(4.0\ \mathrm{m/s^2}\right)\left(8.2\ \mathrm{s}\right)^2 = \boxed{1.3 \times 10^2\ \mathrm{m}}$

2.40 If the glider has constant acceleration and enters the gate with initial velocity v_0, its displacement ℓ during time Δt_d is $\ell = v_0(\Delta t_d) + \frac{1}{2}a(\Delta t_d)^2$. Thus, the average velocity of the glider as it passes through the gate is

$$v_d = \frac{\ell}{\Delta t_d} = v_0 + \tfrac{1}{2}a(\Delta t_d) \tag{1}$$

(a) The instantaneous velocity v_{hs} when the glider is halfway through the gate in space (that is, when $\Delta x = \ell/2$) is found from $v^2 = v_0^2 + 2a(\Delta x)$ to be

$$v_{hs} = \sqrt{v_0^2 + 2a(\ell/2)} = \sqrt{v_0^2 + a\ell} = \sqrt{v_0^2 + av_d(\Delta t_d)} \tag{2}$$

Comparing Equations (1) and (2), we see that $\boxed{v_{hs} = v_d \text{ only if } a = 0}$

(b) The instantaneous velocity v_{ht} when the glider is halfway through the gate in time (that is, when $t = \Delta t_d/2$) is found from $v = v_0 + at$ to be given by

$$v_{ht} = v_0 + a\left(\frac{\Delta t_d}{2}\right) = v_0 + \tfrac{1}{2}a(\Delta t_d) \tag{3}$$

Comparing Equations (1) and (3) shows that $\boxed{v_{ht} = v_d \text{ for all constant values of } a}$

2.41 The time the Thunderbird spends slowing down is

$$\Delta t_1 = \frac{\Delta x_1}{(v_{\text{av}})_1} = \frac{2(\Delta x_1)}{v + v_0} = \frac{2(250\text{ m})}{0 + 71.5\text{ m/s}} = 6.99\text{ s}$$

The time required to regain speed after the pit stop is

$$\Delta t_2 = \frac{\Delta x_2}{(v_{\text{av}})_2} = \frac{2(\Delta x_2)}{v + v_0} = \frac{2(350\text{ m})}{71.5\text{ m/s} + 0} = 9.79\text{ s}$$

Thus, the total elapsed time before the Thunderbird is back up to speed is

$$\Delta t = \Delta t_1 + 5.00\text{ s} + \Delta t_2 = 6.99\text{ s} + 5.00\text{ s} + 9.79\text{ s} = 21.8\text{ s}$$

During this time, the Mercedes has traveled (at constant speed) a distance

$$\Delta x_M = v_0(\Delta t) = (71.5\text{ m/s})(21.8\text{ s}) = 1558\text{ m}$$

and the Thunderbird has fallen behind a distance

$$d = \Delta x_M - \Delta x_1 - \Delta x_2 = 1558\text{ m} - 250\text{ m} - 350\text{ m} = \boxed{958\text{ m}}$$

2.42 The car is distance d from the dog and has initial velocity v_0 when the brakes are applied giving it a constant acceleration a.

Apply $v_{av} = \frac{\Delta x}{\Delta t} = \frac{v + v_0}{2}$ to the entire trip (for which $\Delta x = d + 4.0\text{ m}$, $\Delta t = 10\text{ s}$, and $v = 0$) to obtain

$$\frac{d + 4.0\text{ m}}{10\text{ s}} = \frac{0 + v_0}{2} \qquad \text{or} \qquad v_0 = \frac{d + 4.0\text{ m}}{5.0\text{ s}} \tag{1}$$

Then, applying $v^2 = v_0^2 + 2a(\Delta x)$ to the entire trip yields $0 = v_0^2 + 2a(d + 4.0\text{ m})$.

Substitute for v_0 from Equation (1) to find that $a = -\frac{d + 4.0\text{ m}}{50\text{ s}^2}$ (2)

Finally, apply $\Delta x = v_0 t + \frac{1}{2}at^2$ to the first 8.0 s of the trip (for which $\Delta x = d$).

This gives $d = v_0(8.0\text{ s}) + \frac{1}{2}a(64\text{ s}^2)$ (3)

Substitute Equations (1) and (2) into Equation (3) and solve for the three unknowns v_0, a, and d to find that $v_0 = 20\text{ m/s}$, $a = -2.0\text{ m/s}^2$, and $d = \boxed{96\text{ m}}$

2.43 (a) From $v^2 = v_0^2 + 2a(\Delta y)$ with $v = 0$, we have

$$(\Delta y)_{max} = \frac{v^2 - v_0^2}{2a} = \frac{0 - (25.0\text{ m/s})^2}{2(-9.80\text{ m/s}^2)} = \boxed{31.9\text{ m}}$$

(b) The time to reach the highest point is

$$t_{up} = \frac{v - v_0}{a} = \frac{0 - 25.0\text{ m/s}}{-9.80\text{ m/s}^2} = \boxed{2.55\text{ s}}$$

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

$$\Delta y = (0)t + \frac{1}{2}at^2 \text{ as } t = \sqrt{\frac{2(\Delta y)}{a}} = \sqrt{\frac{2(-31.9\text{ m})}{-9.80\text{ m/s}^2}} = \boxed{2.55\text{ s}}$$

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

$$v = v_0 + at = 0 + (-9.80\text{ m/s}^2)(2.55\text{ s}) = \boxed{-25.0\text{ m/s}}$$

2.44 (a) For the upward flight of the arrow, $v_0 = +100\ \text{m/s}$, $a = -g = -9.80\ \text{m/s}^2$, and the final velocity is $v = 0$. Thus, $v^2 = v_0^2 + 2a(\Delta y)$ yields

$$(\Delta y)_{\text{max}} = \frac{v^2 - v_0^2}{2a} = \frac{0 - (100\ \text{m/s})^2}{2(-9.80\ \text{m/s}^2)} = \boxed{510\ \text{m}}$$

(b) The time for the upward flight is $t_{up} = \dfrac{(\Delta y)_{\text{max}}}{(v_{\text{av}})_{up}} = \dfrac{2(\Delta y)_{\text{max}}}{v_{\text{o}} + v} = \dfrac{2(510\ \text{m})}{100\ \text{m/s} + 0} = 10.2\ \text{s}$

For the downward flight, $\Delta y = -(\Delta y)_{\text{max}} = -510\ \text{m}$, $v_0 = 0$, and $a = -9.8\ \text{m/s}^2$. Thus,

$\Delta y = v_0 t + \frac{1}{2}at^2$ gives $t_{down} = \sqrt{\dfrac{2(\Delta y)}{a}} = \sqrt{\dfrac{2(-510\ \text{m})}{-9.80\ \text{m/s}^2}} = 10.2\ \text{s}$ and the total time of the flight is $t_{total} = t_{down} + t_{down} = 10.2\ \text{s} + 10.2\ \text{s} = \boxed{20.4\ \text{s}}$

2.45 The velocity of the object when it was $30.0\ \text{m}$ above the ground can be determined by applying $\Delta y = v_0 t + \frac{1}{2}at^2$ to the last $1.50\ \text{s}$ of the fall. This gives

$$-30.0\ \text{m} = v_0(1.50\ \text{s}) + \frac{1}{2}\left(-9.80\ \frac{\text{m}}{\text{s}^2}\right)(1.50\ \text{s})^2 \quad \text{or} \quad v_0 = -12.6\ \text{m/s}$$

The displacement the object must have undergone, starting from rest, to achieve this velocity at a point 30.0 m above the ground is given by $v^2 = v_0^2 + 2a(\Delta y)$ as

$$(\Delta y)_1 = \frac{v^2 - v_0^2}{2a} = \frac{(-12.6\ \text{m/s})^2 - 0}{2(-9.80\ \text{m/s}^2)} = -8.16\ \text{m}$$

The total distance the object drops during the fall is

$$\left|(\Delta y)_{total}\right| = \left|(\Delta y)_1 + (-30.0\ \text{m})\right| = \boxed{38.2\ \text{m}}$$

2.46 The velocity of the child's head just before impact (after falling a distance of 0.40 m, starting from rest) is given by $v^2 = v_0^2 + 2a(\Delta y)$ as

$$v_I = -\sqrt{v_0^2 + 2a(\Delta y)} = -\sqrt{0 + 2(-9.8\ \text{m/s}^2)(-0.40\ \text{m})} = -2.8\ \text{m/s}$$

If, upon impact, the child's head undergoes an additional displacement $\Delta y = -h$ before coming to rest, the acceleration during the impact can be found from $v^2 = v_0^2 + 2a(\Delta y)$ to be $a = (0 - v_I^2)/2(-h) = v_I^2/2h$. The duration of the impact is found from $v = v_0 + at$ as $t = \Delta v/a = -v_I/(v_I^2/2h)$, or $t = -2h/v_I$.

Applying these results to the two cases yields:

Hardwood Floor ($h = 2.0 \times 10^{-3}$ m): $a = \dfrac{v_I^2}{2h} = \dfrac{(-2.8\ \text{m/s})^2}{2(2.0 \times 10^{-3}\ \text{m})} = \boxed{2.0 \times 10^3\ \text{m/s}^2}$

and $\quad t = \dfrac{-2h}{v_I} = \dfrac{-2(2.0 \times 10^{-3}\ \text{m})}{-2.8\ \text{m/s}} = 1.4 \times 10^{-3}\ \text{s} = \boxed{1.4\ \text{ms}}$

Carpeted Floor ($h = 1.0 \times 10^{-2}$ m): $a = \dfrac{v_I^2}{2h} = \dfrac{(-2.8\ \text{m/s})^2}{2(1.0 \times 10^{-2}\ \text{m})} = \boxed{3.9 \times 10^2\ \text{m/s}^2}$

and $\quad t = \dfrac{-2h}{v_I} = \dfrac{-2(1.0 \times 10^{-2}\ \text{m})}{-2.8\ \text{m/s}} = 7.1 \times 10^{-3}\ \text{s} = \boxed{7.1\ \text{ms}}$

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

$$v_{bag} = v_0 + at = -1.50\ \text{m/s} + (-9.80\ \text{m/s}^2)(2.00\ \text{s}) = -21.1\ \text{m/s}$$

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

$$(\Delta y)_{bag} = \left(\frac{v+v_0}{2}\right)t = \left[\frac{-21.1\ \text{m/s} + (-1.50\ \text{m/s})}{2}\right](2.00\ \text{s}) = -22.6\ \text{m}$$

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

$$(\Delta y)_{copter} = v_0 t + \frac{1}{2}at^2 = (-1.5\ \text{m/s})(2.00\ \text{s}) + 0 = -3.00\ \text{m}$$

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, $(v_0)_{bag} = (v_0)_{copter} = +1.50\ \text{m/s}$ and $a_{bag} = -9.80\ \text{m/s}^2$ while $a_{copter} = 0$. After $2.00\ \text{s}$, the *speed* of the mailbag is

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

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 $\Delta y = v_0 t + \frac{1}{2}at^2$ with $a = -g$. When the ball is at the throwers hand, the displacement Δy is zero, or $0 = v_0 t - \frac{1}{2}gt^2$. This equation has two solutions, $t = 0$ which corresponds to when the ball was thrown, and $t = 2v_0/g$ 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

$$v_0 = \frac{gt}{2} = \frac{(9.80\ \text{m/s}^2)(2.00\ \text{s})}{2} = \boxed{9.80\ \text{m/s}}$$

(b) From $v^2 = v_0^2 + 2a(\Delta y)$, with $v = 0$ at the maximum height,

$$(\Delta y)_{\text{max}} = \frac{v^2 - v_0^2}{2a} = \frac{0 - (9.80\ \text{m/s})^2}{2(-9.80\ \text{m/s}^2)} = \boxed{4.90\ \text{m}}$$

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

$$v = \sqrt{v_0^2 + 2a(\Delta y)} = \sqrt{(50.0\ \text{m/s})^2 + 2(2.00\ \text{m/s}^2)(150\ \text{m})} = 55.7\ \text{m/s}$$

After the engines stop, the rocket continues moving upward with an initial velocity of $v_0 = 55.7\ \text{m/s}$ and acceleration $a = -g = -9.80\ \text{m/s}^2$. When the rocket reaches maximum height, $v = 0$. The displacement of the rocket above the point where the engines stopped (that is, above the 150 m level) is

$$\Delta y = \frac{v^2 - v_0^2}{2a} = \frac{0 - (55.7\ \text{m/s})^2}{2(-9.80\ \text{m/s}^2)} = 158\ \text{m}$$

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

(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 $v_0 = 50.0\ \text{m/s}$ at the ground to a velocity of $v = 55.7\ \text{m/s}$ at an altitude of 150 m. This time is given by

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

The second interval is the time to rise 158 m starting with $v_0 = 55.7\ \text{m/s}$ and ending with $v = 0$. This time is

$$t_2 = \frac{(\Delta y)_2}{(v_{\text{av}})_2} = \frac{2(158\ \text{m})}{0 + 55.7\ \text{m/s}} = 5.67\ \text{s}$$

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 $v_0 = 0$ and acceleration $a = -g = -9.80\ \text{m/s}^2$, is found from $\Delta y = v_0 t + \frac{1}{2}at^2$ 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 $v_0 = -10\ \text{m/s}$. Its velocity when it reaches the ground is

$$v = \sqrt{v_0^2 + 2a(\Delta y)} = \sqrt{(-10\ \text{m/s})^2 + 2(-9.80\ \text{m/s}^2)(-50\ \text{m})} = -33\ \text{m/s}$$

The time to reach the ground is given by

$$t = \frac{v - v_0}{a} = \frac{-33\ \text{m/s} - (-10\ \text{m/s})}{-9.80\ \text{m/s}^2} = \boxed{2.3\ \text{s}}$$

(b) This velocity was found to be $v = \boxed{-33\ \text{m/s}}$ 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, $\Delta y = v_0 t + \frac{1}{2}at^2$ gives

$$v_0 = \frac{\Delta y - at^2/2}{t} = \frac{(+4.00\ \text{m}) - (-9.80\ \text{m/s}^2)(1.50\ \text{s})^2/2}{1.50\ \text{s}} = +10.0\ \text{m/s}$$

or $v_0 = \boxed{10.0\ \text{m/s upward}}$

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

$$v = v_0 + at = 10.0\ \text{m/s} + (-9.80\ \text{m/s}^2)(1.50\ \text{s}) = -4.68\ \text{m/s}$$

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

2.52 (a) From $v^2 = v_0^2 + 2a(\Delta y)$, the insect's velocity after straightening its legs is

$$v = \sqrt{v_0^2 + 2a(\Delta y)} = \sqrt{0 + 2(4\,000 \text{ m/s}^2)(2.0 \times 10^{-3} \text{ m})} = \boxed{4.0 \text{ m/s}}$$

and the time to reach this velocity is

$$t = \frac{v - v_0}{a} = \frac{4.0 \text{ m/s} - 0}{4\,000 \text{ m/s}^2} = 1.0 \times 10^{-3} \text{ s} = \boxed{1.0 \text{ ms}}$$

(b) The upward displacement of the insect between when its feet leave the ground and it comes to rest momentarily at maximum altitude is

$$\Delta y = \frac{v^2 - v_0^2}{2a} = \frac{0 - v_0^2}{2(-g)} = \frac{-(4.0 \text{ m/s})^2}{2(-9.8 \text{ m/s}^2)} = \boxed{0.82 \text{ m}}$$

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 $v = 100 \text{ km/h}$. Therefore 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 $\Delta x = v_0 t + \frac{1}{2}at^2$, 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

$$v = v_0 + at = 30.0\ \text{m/s} + \left(-3.50\ \text{m/s}^2\right)(4.53\ \text{s}) = \boxed{14.1\ \text{m/s}}$$

2.55 (a) The acceleration of the bullet is

$$a = \frac{v^2 - v_0^2}{2(\Delta x)} = \frac{(300\ \text{m/s})^2 - (400\ \text{m/s})^2}{2(0.100\ \text{m})} = \boxed{-3.50 \times 10^5\ \text{m/s}^2}$$

(b) The time of contact with the board is

$$t = \frac{v - v_0}{a} = \frac{(300 - 400)\ \text{m/s}}{-3.50 \times 10^5\ \text{m/s}^2} = \boxed{2.86 \times 10^{-4}\ \text{s}}$$

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

$$a = \frac{v^2 - v_0^2}{2(\Delta x)} = \frac{(280\ \text{m/s})^2 - (420\ \text{m/s})^2}{2(0.100\ \text{m})} = \boxed{-4.90 \times 10^5\ \text{m/s}^2}$$

(b) The average velocity as the front of the bullet passes through the board is $(v_{\text{av}})_{board} = \dfrac{v + v_0}{2} = 350\ \text{m/s}$ and the total time of contact with the board is

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

(c) From $v^2 = v_0^2 + 2a(\Delta x)$, with $v = 0$, gives the required thickness as

$$\Delta x = \frac{v^2 - v_0^2}{2a} = \frac{0 - (420\ \text{m/s})^2}{2\left(-4.90 \times 10^5\ \text{m/s}^2\right)} = \boxed{0.180\ \text{m}}$$

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 $\Delta y = v_0 t + \frac{1}{2}at^2$, 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 $\Delta y = v_0 t + \frac{1}{2}at^2$ to the rising ball gives $h=(25\ \text{m/s})t-\frac{1}{2}gt^2$ (2)

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

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

$$(\Delta x)_{stop}=\frac{v^2-v_0^2}{2a}=\frac{0-\left[35.0\ \dfrac{\text{mi}}{\text{h}}\left(\dfrac{1.47\ \text{ft/s}}{1\ \text{mi/h}}\right)\right]^2}{2\left(-9.00\ \text{ft/s}^2\right)}=147\ \text{ft}$$

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

$$(t_r)_{max}=\frac{(\Delta x)_{before}}{v_0}=\frac{53.0\text{ ft}}{\left[35.0\ \dfrac{\text{mi}}{\text{h}}\left(\dfrac{1.47\ \text{ft/s}}{1\ \text{mi/h}}\right)\right]}=\boxed{1.03\text{ s}}$$

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

Applying $\Delta y = v_0 t + \frac{1}{2}at^2$ 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 $t_1 = 1.00$ 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 $t_2 = 4.00$ 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:

$$v_1 = (v_0)_1 - gt_1 = -14.7\text{ m/s} - (9.80\text{ m/s}^2)(1.00\text{ s}) = \boxed{-24.5\text{ m/s}}$$

and

$$v_2 = (v_0)_2 - gt_2 = +14.7\text{ m/s} - (9.80\text{ m/s}^2)(4.00\text{ s}) = \boxed{-24.5\text{ m/s}}$$

(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 $y_1 = -14.9$ m and $y_2 = +8.62$ 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 (that is, 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 $-5.60\ \text{m/s}^2$.

We have $v = v_0 + at$ and $\Delta x = v_{\text{av}} t = \left(\dfrac{v + v_0}{2}\right) t$. Applied to the motion of the truck, these yield

$$v - v_0 = at \quad \text{or} \quad v - v_0 = \left(-5.60\ \text{m/s}^2\right)(4.20\ \text{s}) = -23.5\ \text{m/s} \tag{1}$$

and

$$v + v_0 = \frac{2(\Delta x)}{t} = \frac{2(62.4\ \text{m})}{4.20\ \text{s}} = 29.7\ \text{m/s} \tag{2}$$

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

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

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

$$(\Delta x)_{Kathy} = (v_0)_{Kathy} t + \frac{1}{2} a_{Kathy} t^2 = 0 + \frac{1}{2}\left(4.90\ \text{m/s}^2\right) t^2$$

and $$(\Delta x)_{Stan} = (v_0)_{Stan} t + \frac{1}{2} a_{Stan} (t + 1.00\ \text{s})^2 = 0 + \frac{1}{2}\left(3.50\ \text{m/s}^2\right)(t + 1.00\ \text{s})^2$$

(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

$$v_{Kathy} = (v_0)_{Kathy} + a_{Kathy} t = 0 + \left(4.90\ \text{m/s}^2\right)(5.46\ \text{s}) = \boxed{26.7\ \text{m/s}}$$

and $$v_{Stan} = (v_0)_{Stan} + a_{Stan}(t + 1.00\ \text{s}) = 0 + \left(3.50\ \text{m/s}^2\right)(6.46\ \text{s}) = \boxed{22.6\ \text{m/s}}$$

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

$$v_1 = -\sqrt{(v_0)_1^2 + 2a(\Delta y)} = -\sqrt{\left(-2.00\ \frac{\text{m}}{\text{s}}\right)^2 + 2\left(-9.80\ \frac{\text{m}}{\text{s}^2}\right)(-50.0\ \text{m})} = -31.4\ \frac{\text{m}}{\text{s}}$$

The time for this stone to hit the water is

$$t_1 = \frac{v_1 - (v_0)_1}{a} = \frac{[-31.4\ \text{m/s} - (-2.00\ \text{m/s})]}{-9.80\ \text{m/s}^2} = \boxed{3.00\ \text{s}}$$

(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,

$$(v_0)_2 = \frac{\Delta y - at_2^2/2}{t_2} = \frac{-50.0\ \text{m} - (-9.80\ \text{m/s}^2)(2.00\ \text{s})^2/2}{2.00\ \text{s}} = \boxed{-15.2\ \text{m/s}}$$

(c) From part (a), the final velocity of the first stone is $v_1 = \boxed{-31.4\ \text{m/s}}$.

The final velocity of the second stone is

$$v_2 = (v_0)_2 + at_2 = -15.2\ \text{m/s} + (-9.80\ \text{m/s}^2)(2.00\ \text{s}) = \boxed{-34.8\ \text{m/s}}$$

2.63 (a) The displacement Δx_1 of the sled during the time t_1 that it has acceleration

$$a_1 = +40\ \text{ft/s}^2 \text{ is: } \Delta x_1 = (0)t_1 + \tfrac{1}{2}a_1 t_1^2 = (20\ \text{ft/s}^2)t_1^2 \text{ or } \Delta x_1 = (20\ \text{ft/s}^2)t_1^2 \qquad (1)$$

At the end of time t_1, the sled had achieved a velocity of

$$v = v_0 + a_1 t_1 = 0 + (40\ \text{ft/s}^2)t_1 \text{ or } v = (40\ \text{ft/s}^2)t_1 \qquad (2)$$

The displacement of the sled while moving at constant velocity v for time t_2 is

$$\Delta x_2 = vt_2 = [(40\ \text{ft/s}^2)t_1]t_2 \text{ or } \Delta x_2 = (40\ \text{ft/s}^2)t_1 t_2 \qquad (3)$$

It is known that $\Delta x_1 + \Delta x_2 = 17\,500\text{ ft}$, and substitutions from Equations (1) and (3) give: $\left(20\text{ ft/s}^2\right)t_1^2 + \left(40\text{ ft/s}^2\right)t_1 t_2 = 17500\text{ ft}$

or $\quad t_1^2 + 2t_1 t_2 = 875\text{ s}^2 \qquad (4)$

Also, it is known that: $t_1 + t_2 = 90\text{ s} \qquad (5)$

Solving Equations (4) and (5) simultaneously yields $\boxed{t_1 = 5.0\text{ s and } t_2 = 85\text{ s}}$

(b) From Equation (2) above, $v = \left(40\text{ ft/s}^2\right)t_1 = \left(40\text{ ft/s}^2\right)\left(5.0\text{ s}\right) = \boxed{200\text{ ft/s}}$

(c) The displacement Δx_3 of the sled as it comes to rest (with acceleration $a_3 = -20\text{ ft/s}^2$) is: $\Delta x_3 = \dfrac{0 - v^2}{2a_3} = \dfrac{-\left(200\text{ ft/s}\right)^2}{2\left(-20\text{ ft/s}^2\right)} = 1\,000\text{ ft}$

Thus, the total displacement for the trip (measured from the starting point) is

$$\Delta x_{total} = \left(\Delta x_1 + \Delta x_2\right) + \Delta x_3 = 17\,500\text{ ft} + 1\,000\text{ ft} = \boxed{18\,500\text{ ft}}$$

(d) The time required to come to rest from velocity v (with acceleration a_3) is

$$t_3 = \frac{0 - v}{a_3} = \frac{-200\text{ ft/s}}{-20\text{ ft/s}^2} = \boxed{10\text{ s}}$$

so the duration of the entire trip is: $t_{total} = t_1 + t_2 + t_3 = 5.0\text{ s} + 85\text{ s} + 10\text{ s} = \boxed{100\text{ s}}$

2.64 (a) From $\Delta y = v_0 t + \dfrac{1}{2}at^2$ with $v_0 = 0$, we have

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

(b) The final velocity is $v = 0 + \left(-9.80\text{ m/s}^2\ \text{ m/s}^2\right)\left(2.2\text{ s}\right) = \boxed{-21\text{ m/s}}$

(c) The time it takes 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

$$\Delta x = v_{sound}\, t = (1\,100 \text{ ft/s})(5.0 \text{ s}) = \boxed{5.5\times 10^{3} \text{ ft}}$$

(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

$$\Delta y = v_0 t + \frac{1}{2}at^2 \text{ with } v_0 = 0 \text{ as } t_{total} = \sqrt{\frac{2(\Delta y)}{a}} = \sqrt{\frac{2(-25.0 \text{ m})}{-9.80 \text{ m/s}^2}} = 2.26 \text{ s}$$

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

$$\Delta t = t_{total} - t_{15} = 2.26 \text{ s} - 1.75 \text{ s} = \boxed{0.51 \text{ s}}$$

2.67 The time required for the woman to fall 3.00 m, starting from rest, is found from $\Delta y = v_0 t + \frac{1}{2}at^2$ 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 1.0 cm (hence compressing the ball) before coming to rest.

With the first assumption, $v^2 = v_0^2 + 2a(\Delta y)$ gives the velocity of the ball when it first touches the ground as

$$v = -\sqrt{v_0^2 + 2a(\Delta y)} = -\sqrt{0 + 2(-9.80\ \text{m/s}^2)(-1.5\ \text{m})} = -5.4\ \text{m/s}$$

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

$$a = \frac{v^2 - v_0^2}{2(\Delta y)} = \frac{0 - (-5.4\ \text{m/s})^2}{2(1.0 \times 10^{-2}\ \text{m})} = 1.5 \times 10^3\ \text{m/s}^2\text{, or } \boxed{\sim 10^3\ \text{m/s}^2}$$

2.69 (a) Starting from rest and accelerating at $a_b = 13.0\ \text{mi/h} \cdot \text{s}$, the bicycle reaches its maximum speed of $v_{b,\max} = 20.0\ \text{mi/h}$ in a time

$$t_{b,1} = \frac{v_{b,\max} - 0}{a_b} = \frac{20.0\ \text{mi/h}}{13.0\ \text{mi/h} \cdot \text{s}} = 1.54\ \text{s}$$

Since the acceleration a_c of the car is less than that of the bicycle, the car cannot catch the bicycle until some time $t > t_{b,1}$ (that is, some time after the bicycle ceases to accelerate and starts moving at constant speed $v = v_{b,\max}$). The total displacement of the bicycle at time *t* is

$$\Delta x_b = \tfrac{1}{2} a_b t_{b,1}^2 + v_{b,\max}(t - t_{b,1})$$

$$= \left(\frac{1.47\ \text{ft/s}}{1\ \text{mi/h}}\right)\left[\tfrac{1}{2}\left(13.0\ \frac{\text{mi/h}}{\text{s}}\right)(1.54\ \text{s})^2 + (20.0\ \text{mi/h})(t - 1.54\ \text{s})\right]$$

$$= \left(29.4\ \frac{\text{ft}}{\text{s}}\right)t - 22.6\ \text{ft}$$

The total displacement of the car at this time is

$$\Delta x_c = \tfrac{1}{2} a_c t^2 = \left(\frac{1.47\ \text{ft/s}}{1\ \text{mi/h}}\right)\left[\tfrac{1}{2}\left(9.00\ \frac{\text{mi/h}}{s}\right)t^2\right] = \left(6.62\ \frac{\text{ft}}{\text{s}}\right)t^2$$

At the time the car catches the bicycle, $\Delta x_c = \Delta x_b$. This gives

$$\left(6.62\ \frac{\text{ft}}{\text{s}^2}\right)t^2 = \left(29.4\ \frac{\text{ft}}{\text{s}}\right)t - 22.6\ \text{ft} \quad \text{or} \quad t^2 - (4.44\ \text{s})t + 3.42\ \text{s}^2 = 0$$

which has only one acceptable solution $t > t_{b,1}$. This solution gives the total time the bicycle leads the car and is $t = \boxed{3.45\ \text{s}}$

(b) The lead the bicycle has over the car continues to increase until the car attains a speed of $v_c = v_{b,\max} = 20.0\ \text{mi/h}$. Thus, the elapsed time when the bicycle's lead ceases to increase is

$$t = \frac{v_{b,\max}}{a_c} = \frac{20.0\ \text{mi/h}}{9.00\ \text{mi/h}\cdot\text{s}} = 2.22\ \text{s}$$

At this time, the lead is

$$(\Delta x_b - \Delta x_c)_{\max} = (\Delta x_b - \Delta x_c)\big|_{t=2.22\ \text{s}} = \left[(29.4\ \text{ft/s})(2.22\ \text{s}) - 22.6\ \text{ft}\right] - \left[(6.62\ \text{ft/s}^2)(2.22\ \text{s})^2\right]$$

or $\qquad (\Delta x_b - \Delta x_c)_{\max} = \boxed{10.0\ \text{ft}}$

2.70 The constant speed the student has maintained for the first 10 minutes, and hence her initial speed for the final 500 yard dash, is

$$v_0 = \frac{\Delta x_{10}}{\Delta t} = \frac{1.0\ \text{mi} - 500\ \text{yards}}{10\ \text{min}} = \frac{(5280\ \text{ft} - 1500\ \text{ft})}{600\ \text{s}}\left(\frac{1\ \text{m}}{3.281\ \text{ft}}\right) = 1.9\ \text{m/s}$$

With an initial speed of $v_0 = 1.9\ \text{m/s}$ and constant acceleration of $a = 0.15\ \text{m/s}^2$, the maximum distance the student can travel in the remaining 2.0 min (120 s) of her allotted time is

$$(\Delta x_{2.0})_{\max} = v_0 t + \tfrac{1}{2}a_{\max}t^2 = \left(1.9\ \frac{\text{m}}{\text{s}}\right)(120\ \text{s}) + \tfrac{1}{2}\left(0.15\ \frac{\text{m}}{\text{s}^2}\right)(120\ \text{s})^2 = 1.3\times10^3\ \text{m}$$

or $\qquad (\Delta x_{2.0})_{\max} = (1.3\times10^3\ \text{m})\left(\frac{3.281\ \text{ft}}{1\ \text{m}}\right)\left(\frac{1\ \text{yard}}{3\ \text{ft}}\right) = 1.4\times10^3\ \text{yards}$

Since $(\Delta x_{2.0})_{\max}$ is considerably greater than the 500 yards she must still run, she can $\boxed{\text{easily meet the requirment}}$ of running 1.0 miles in 12 minutes.

2.71 Swimming at a constant speed of $v_1 = 4.0 \text{ m/s}$, the time required for the leader to travel the remaining 50.0 m is

$$\Delta t = \frac{\Delta x_1}{v_1} = \frac{50 \text{ m}}{4.0 \text{ m/s}} = (50/4.0) \text{ s}$$

The current lead the first swimmer has is the distance he swims in 0.50 s, or

$$\Delta x_{lead} = v_1 (0.50 \text{ s}) = (4.0 \text{ m/s})(0.50 \text{ s}) = 2.0 \text{ m}$$

Thus, if the second-place swimmer is to arrive at the end of the pool simultaneously with lead swimmer, he must travel $\Delta x_2 = \Delta x_1 + \Delta x_{lead} = 52 \text{ m}$ in $\Delta t = (50/4.0) \text{ s}$. The constant speed he must maintain is

$$v_2 = \frac{\Delta x_2}{\Delta t} = \frac{52 \text{ m}}{(50/4.0) \text{ s}} = \boxed{4.2 \text{ m/s}}$$