CHAPTER 2 | *KINEMATICS IN ONE DIMENSION*

ANSWERS TO FOCUS ON CONCEPTS QUESTIONS

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1. (b) Displacement, being a vector, conveys information about magnitude and direction. Distance conveys no information about direction and, hence, is not a vector.

2. (c) Since each runner starts at the same place and ends at the same place, the three displacement vectors are equal.

3. (c) The average speed is the distance of 16.0 km divided by the elapsed time of 2.0 h. The average velocity is the displacement of 0 km divided by the elapsed time. The displacement is 0 km, because the jogger begins and ends at the same place.

4. (a) Since the bicycle covers the same number of meters per second everywhere on the track, its speed is constant.

5. (e) The average velocity is the displacement (2.0 km due north) divided by the elapsed time (0.50 h), and the direction of the velocity is the same as the direction of the displacement.

6. (c) The average acceleration is the change in velocity (final velocity minus initial velocity) divided by the elapsed time. The change in velocity has a magnitude of 15.0 km/h. Since the change in velocity points due east, the direction of the average acceleration is also due east.

7. (d) This is always the situation when an object at rest begins to move.

8. (b) If neither the magnitude nor the direction of the velocity changes, then the velocity is constant, and the change in velocity is zero. Since the average acceleration is the change in velocity divided by the elapsed time, the average acceleration is also zero.

9. (a) The runners are always moving after the race starts and, therefore, have a non-zero average speed. The average velocity is the displacement divided by the elapsed time, and the displacement is zero, since the race starts and finishes at the same place. The average acceleration is the change in the velocity divided by the elapsed time, and the velocity changes, since the contestants start at rest and finish while running.

10. (c) The equations of kinematics can be used only when the acceleration remains constant and cannot be used when it changes from moment to moment.

11. (a) Velocity, not speed, appears as one of the variables in the equations of kinematics. Velocity is a vector. The magnitude of the instantaneous velocity is the speed.

12. (b) According to one of the equation of kinematics $\left(v^2 = v_0^2 + 2ax,\ \text{with } v_0 = 0\ \text{m/s}\right)$, the displacement is proportional to the square of the velocity.

13. (d) According to one of the equation of kinematics $\left(x = v_0 t + \frac{1}{2}at^2,\ \text{with } v_0 = 0\ \text{m/s}\right)$, the displacement is proportional to the acceleration.

14. (b) For a single object each equation of kinematics contains four variables, one of which is the unknown variable.

15. (e) An equation of kinematics $\left(v = v_0 + at\right)$ gives the answer directly, since the initial velocity, the final velocity, and the time are known.

16. (c) An equation of kinematics $\left[x = \frac{1}{2}\left(v_0 + v\right)t\right]$ gives the answer directly, since the initial velocity, the final velocity, and the time are known.

17. (e) An equation of kinematics $\left(v^2 = v_0^2 + 2ax\right)$ gives the answer directly, since the initial velocity, the final velocity, and the acceleration are known.

18. (d) This statement is false. Near the earth's surface the acceleration due to gravity has the approximate magnitude of 9.80 m/s^2 and always points downward, toward the center of the earth.

19. (b) Free-fall is the motion that occurs while the acceleration is solely the acceleration due to gravity. While the rocket is picking up speed in the upward direction, the acceleration is not just due to gravity, but is due to the combined effect of gravity and the engines. In fact, the effect of the engines is greater than the effect of gravity. Only when the engines shut down does the free-fall motion begin.

20. (c) According to an equation of kinematics $\left(v^2 = v_0^2 + 2ax,\ \text{with } v = 0\ \text{m/s}\right)$, the launch speed v_0 is proportional to the square root of the maximum height.

21. (a) An equation of kinematics $\left(v = v_0 + at\right)$ gives the answer directly.

22. (d) The acceleration due to gravity points downward, in the same direction as the initial velocity of the stone thrown from the top of the cliff. Therefore, this stone picks up speed as it approaches the nest. In contrast, the acceleration due to gravity points opposite to the initial velocity of the stone thrown from the ground, so that this stone loses speed as it approaches the nest. The result is that, on average, the stone thrown from the top of the cliff travels faster than the stone thrown from the ground and hits the nest first.

23. 1.13 s

24. (a) The slope of the line in a position versus time graph gives the velocity of the motion. The slope for part A is positive. For part B the slope is negative. For part C the slope is positive.

25. (b) The slope of the line in a position versus time graph gives the velocity of the motion. Section A has the smallest slope and section B the largest slope.

26. (c) The slope of the line in a position versus time graph gives the velocity of the motion. Here the slope is positive at all times, but it decreases as time increases from left to right in the graph. This means that the positive velocity is decreasing as time increases, which is a condition of deceleration.

CHAPTER 2 *KINEMATICS IN ONE DIMENSION*

PROBLEMS

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1. ***REASONING*** The distance traveled by the Space Shuttle is equal to its speed multiplied by the time. The number of football fields is equal to this distance divided by the length *L* of one football field.

   SOLUTION The number of football fields is

$$\text{Number} = \frac{x}{L} = \frac{vt}{L} = \frac{\left(7.6\times10^{3}\ \text{m/s}\right)\left(110\times10^{-3}\text{s}\right)}{91.4\ \text{m}} = \boxed{9.1}$$

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2. ***REASONING*** The displacement is a vector that points from an object's initial position to its final position. If the final position is greater than the initial position, the displacement is positive. On the other hand, if the final position is less than the initial position, the displacement is negative. (a) The final position is greater than the initial position, so the displacement will be positive. (b) The final position is less than the initial position, so the displacement will be negative. (c) The final position is greater than the initial position, so the displacement will be positive.

   SOLUTION The displacement is defined as Displacement = $x - x_0$, where x is the final position and x_0 is the initial position. The displacements for the three cases are:

   (a) Displacement = 6.0 m – 2.0 m = $\boxed{+4.0\ \text{m}}$

   (b) Displacement = 2.0 m – 6.0 m = $\boxed{-4.0\ \text{m}}$

   (c) Displacement = 7.0 m – (–3.0 m) = $\boxed{+10.0\ \text{m}}$

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3. SSM ***REASONING*** The average speed is the distance traveled divided by the elapsed time (Equation 2.1). Since the average speed and distance are known, we can use this relation to find the time.

   SOLUTION The time it takes for the continents to drift apart by 1500 m is

$$\text{Elapsed time} = \frac{\text{Distance}}{\text{Average speed}} = \frac{1500\,\text{m}}{\left(3\,\dfrac{\text{cm}}{\text{yr}}\right)\left(\dfrac{1\ \text{m}}{100\ \text{cm}}\right)} = \boxed{5\times10^{4}\ \text{yr}}$$

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4. ***REASONING*** Since the average speed of the impulse is equal to the distance it travels divided by the elapsed time (see Equation 2.1), the elapsed time is just the distance divided by the average speed.

SOLUTION The time it takes for the impulse to travel from the foot to the brain is

$$\text{Time} = \frac{\text{Distance}}{\text{Average speed}} = \frac{1.8\text{ m}}{1.1\times10^{2}\text{ m/s}} = \boxed{1.6\times10^{-2}\text{ s}} \qquad (2.1)$$

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5. ***REASONING*** According to Equation 2.2 $\left(\bar{v} = \dfrac{x - x_0}{t - t_0}\right)$, the average velocity $(\bar{v})$ is equal to the displacement $(x - x_0)$ divided by the elapsed time $(t - t_0)$, and the direction of the average velocity is the same as that of the displacement. The displacement is equal to the difference between the final and initial positions.

SOLUTION Equation 2.2 gives the average velocity as

$$\bar{v} = \frac{x - x_0}{t - t_0}$$

Therefore, the average velocities for the three cases are:

(a) Average velocity = (6.0 m – 2.0 m)/(0.50 s) = $\boxed{+8.0\text{ m/s}}$

(b) Average velocity = (2.0 m – 6.0 m)/(0.50 s) = $\boxed{-8.0\text{ m/s}}$

(c) Average velocity = [7.0 m – (–3.0 m)]/(0.50 s) = $\boxed{+2.0\times10^{1}\text{ m/s}}$

The algebraic sign of the answer conveys the direction in each case.

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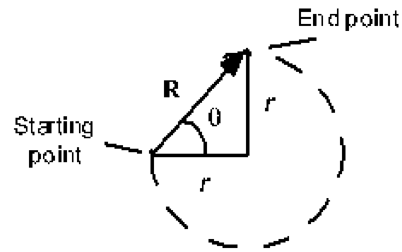
6. ***REASONING*** Distance and displacement are different physical quantities. Distance is a scalar, and displacement is a vector. Distance and the magnitude of the displacement, however, are both measured in units of length.

SOLUTION
a. The distance traveled is equal to three-fourths of the circumference of the circular lake. The circumference of a circle is $2\pi r$, where r is the radius of the circle. Thus, the distance d that the couple travels is

$$d = \tfrac{3}{4}(2\pi r) = \tfrac{3}{4}\left[2\pi(1.50\text{ km})\right] = \boxed{7.07\text{ km}}$$

b. The couple's displacement is the hypotenuse of a right triangle with sides equal to the radius of the circle (see the drawing). The magnitude R of the displacement can be obtained with the aid of the Pythagorean theorem:



$$R = \sqrt{r^2 + r^2} = \sqrt{2(1.50\text{ km})^2} = \boxed{2.12\text{ km}}$$

The angle θ that the displacement makes with due east is

$$\theta = \tan^{-1}\left(\frac{r}{r}\right) = \tan^{-1}(1) = \boxed{45.0°\text{ north of east}}$$

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7. ***REASONING AND SOLUTION*** In 12 minutes the sloth travels a distance of

$$x_s = v_s t = (0.037\text{ m/s})(12\text{ min})\left(\frac{60\text{ s}}{1\text{ min}}\right) = 27\text{ m}$$

while the tortoise travels a distance of

$$x_t = v_t t = (0.076\text{ m/s})(12\text{ min})\left(\frac{60\text{ s}}{1\text{ min}}\right) = 55\text{ m}$$

The tortoise goes farther than the sloth by an amount that equals 55 m – 27 m = $\boxed{28\text{ m}}$

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8. ***REASONING*** The younger (and faster) runner should start the race after the older runner, the delay being the difference between the time required for the older runner to complete the race and that for the younger runner. The time for each runner to complete the race is equal to the distance of the race divided by the average speed of that runner (see Equation 2.1).

SOLUTION The difference between the times for the two runners to complete the race is $t_{50} - t_{18}$, where

$$t_{50} = \frac{\text{Distance}}{(\text{Average Speed})_{\text{50-yr-old}}} \quad \text{and} \quad t_{18} = \frac{\text{Distance}}{(\text{Average Speed})_{\text{18-yr-old}}} \qquad (2.1)$$

The difference between these two times (which is how much later the younger runner should start) is

$$t_{50} - t_{18} = \frac{\text{Distance}}{\left(\text{Average Speed}\right)_{\text{50-yr-old}}} - \frac{\text{Distance}}{\left(\text{Average Speed}\right)_{\text{18-yr-old}}}$$

$$= \frac{10.0\times10^3 \text{ m}}{4.27 \text{ m/s}} - \frac{10.0\times10^3 \text{ m}}{4.39 \text{ m/s}} = \boxed{64 \text{ s}}$$

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9. ***REASONING*** In order for the bear to catch the tourist over the distance d, the bear must reach the car at the same time as the tourist. During the time t that it takes for the tourist to reach the car, the bear must travel a total distance of d + 26 m. From Equation 2.1,

$$v_{\text{tourist}} = \frac{d}{t} \quad (1) \qquad \text{and} \qquad v_{\text{bear}} = \frac{d + 26 \text{ m}}{t} \quad (2)$$

Equations (1) and (2) can be solved simultaneously to find d.

SOLUTION Solving Equation (1) for t and substituting into Equation (2), we find

$$v_{\text{bear}} = \frac{d + 26 \text{ m}}{d / v_{\text{tourist}}} = \frac{(d + 26 \text{ m})v_{\text{tourist}}}{d}$$

$$v_{\text{bear}} = \left(1 + \frac{26 \text{ m}}{d}\right)v_{\text{tourist}}$$

Solving for d yields:

$$d = \frac{26 \text{ m}}{\dfrac{v_{\text{bear}}}{v_{\text{tourist}}} - 1} = \frac{26 \text{ m}}{\dfrac{6.0 \text{ m/s}}{4.0 \text{ m/s}} - 1} = \boxed{52 \text{ m}}$$

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10. ***REASONING AND SOLUTION*** Let west be the positive direction. The average velocity of the backpacker is

$$v = \frac{x_{\text{w}} + x_{\text{e}}}{t_{\text{w}} + t_{\text{e}}} \quad \text{where} \quad t_{\text{w}} = \frac{x_{\text{w}}}{v_{\text{w}}} \quad \text{and} \quad t_{\text{e}} = \frac{x_{\text{e}}}{v_{\text{e}}}$$

Combining these equations and solving for x_{e} (suppressing the units) gives

$$x_{\text{e}} = \frac{-\left(1 - v / v_{\text{w}}\right)x_{\text{w}}}{\left(1 - v / v_{\text{e}}\right)} = \frac{-\left[1 - (1.34 \text{ m/s})/(2.68 \text{ m/s})\right](6.44 \text{ km})}{1 - (1.34 \text{ m/s})/(0.447 \text{ m/s})} = -0.81 \text{ km}$$

The distance traveled is the magnitude of x_e, or $\boxed{0.81\text{ km}}$.

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11. SSM ***REASONING AND SOLUTION***

a. The total displacement traveled by the bicyclist for the entire trip is equal to the sum of the displacements traveled during each part of the trip. The displacement traveled during each part of the trip is given by Equation 2.2: $\Delta x = \bar{v}\Delta t$. Therefore,

$$\Delta x_1 = (7.2\text{ m/s})(22\text{ min})\left(\frac{60\text{ s}}{1\text{ min}}\right) = 9500\text{ m}$$

$$\Delta x_2 = (5.1\text{ m/s})(36\text{ min})\left(\frac{60\text{ s}}{1\text{ min}}\right) = 11\ 000\text{ m}$$

$$\Delta x_3 = (13\text{ m/s})(8.0\text{ min})\left(\frac{60\text{ s}}{1\text{ min}}\right) = 6200\text{ m}$$

The total displacement traveled by the bicyclist during the entire trip is then

$$\Delta x = 9500\text{ m} + 11\ 000\text{ m} + 6200\text{ m} = \boxed{2.67\times 10^4\text{ m}}$$

b. The average velocity can be found from Equation 2.2.

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{2.67\times 10^4\text{ m}}{(22\text{ min} + 36\text{ min} + 8.0\text{ min})}\left(\frac{1\text{min}}{60\text{ s}}\right) = \boxed{6.74\text{ m/s, due north}}$$

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12. ***REASONING*** The definition of average velocity is given by Equation 2.2 as Average velocity = Displacement/(Elapsed time). The displacement in this expression is the total displacement, which is the sum of the displacements for each part of the trip. Displacement is a vector quantity, and we must be careful to account for the fact that the displacement in the first part of the trip is north, while the displacement in the second part is south.

SOLUTION According to Equation 2.2, the displacement for each part of the trip is the average velocity for that part times the corresponding elapsed time. Designating north as the positive direction, we find for the total displacement that

$$\text{Displacement} = \underbrace{(27\text{ m/s})t_{\text{North}}}_{\text{Northward}} + \underbrace{(-17\text{ m/s})t_{\text{South}}}_{\text{Southward}}$$

where t_{North} and t_{South} denote, respectively, the times for each part of the trip. Note that the minus sign indicates a direction due south. Noting that the total elapsed time is

$t_{North} + t_{South}$, we can use Equation 2.2 to find the average velocity for the entire trip as follows:

$$\text{Average velocity} = \frac{\text{Displacement}}{\text{Elapsed time}} = \frac{(27\text{ m/s})t_{North} + (-17\text{ m/s})t_{South}}{t_{North} + t_{South}}$$

$$= (27\text{ m/s})\left(\frac{t_{North}}{t_{North} + t_{South}}\right) + (-17\text{ m/s})\left(\frac{t_{South}}{t_{North} + t_{South}}\right)$$

But $\left(\frac{t_{North}}{t_{North} + t_{South}}\right) = \frac{3}{4}$ and $\left(\frac{t_{South}}{t_{North} + t_{South}}\right) = \frac{1}{4}$. Therefore, we have that

$$\text{Average velocity} = (27\text{ m/s})\left(\frac{3}{4}\right) + (-17\text{ m/s})\left(\frac{1}{4}\right) = \boxed{+16\text{ m/s}}$$

The plus sign indicates that the average velocity for the entire trip points north.

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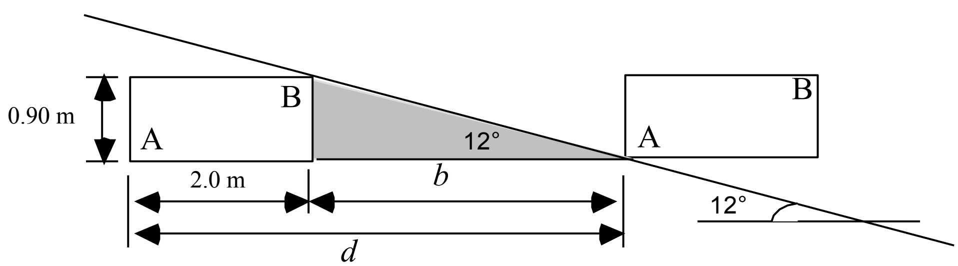
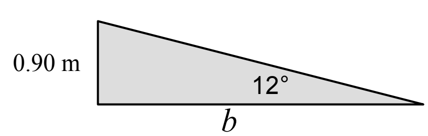
13. ***REASONING AND SOLUTION*** The upper edge of the wall will disappear after the train has traveled the distance *d* in the figure below.



The distance *d* is equal to the length of the window plus the base of the 12° right triangle of height 0.90 m.

The base of the triangle is given by

$$b = \frac{0.90\text{ m}}{\tan 12°} = 4.2\text{ m}$$



Thus, $d = 2.0\text{ m} + 4.2\text{ m} = 6.2\text{ m}$.

The time required for the train to travel 6.2 m is, from the definition of average speed,

$$t = \frac{x}{v} = \frac{6.2\text{ m}}{3.0\text{ m/s}} = \boxed{2.1\text{ s}}$$

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14. ***REASONING AND SOLUTION*** Since $v = v_0 + at$, the acceleration is given by $a = \left(v - v_0\right)/t$. Since the direction of travel is in the negative direction throughout the problem, all velocities will be negative.

a.
$$a = \frac{(-29.0\text{ m/s}) - (-27.0\text{ m/s})}{5.0\text{ s}} = \boxed{-0.40\text{ m/s}^2}$$

Since the acceleration is negative, it is in the same direction as the velocity and the car is speeding up.

b.
$$a = \frac{(-23.0\text{ m/s}) - (-27.0\text{ m/s})}{5.0\text{ s}} = \boxed{+0.80\text{ m/s}^2}$$

Since the acceleration is positive, it is in the opposite direction to the velocity and the car is slowing down or decelerating.

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15. ***REASONING*** The average acceleration $\left(\bar{a}\right)$ is defined by Equation 2.4 $\left(\bar{a} = \dfrac{v - v_0}{t - t_0}\right)$ as the change in velocity $\left(v - v_0\right)$ divided by the elapsed time $\left(t - t_0\right)$. The change in velocity is equal to the final velocity minus the initial velocity. Therefore, the change in velocity, and hence the acceleration, is positive if the final velocity is greater than the initial velocity. The acceleration is negative if the final velocity is less than the initial velocity. The acceleration is zero if the final and initial velocities are the same.

SOLUTION Equation 2.4 gives the average acceleration as

$$\bar{a} = \frac{v - v_0}{t - t_0}$$

a. The initial and final velocities are both +82 m/s, since the velocity is constant. The average acceleration is

$$\bar{a} = (82\text{ m/s} - 82\text{ m/s})/(t - t_0) = \boxed{0\text{ m/s}^2}$$

b. The initial velocity is +82 m/s, and the final velocity is –82 m/s. The average acceleration is

$$\bar{a} = (-82\text{ m/s} - 82\text{ m/s})/(12\text{ s}) = \boxed{-14\text{ m/s}^2}$$

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16. ***REASONING*** Although the planet follows a curved, two-dimensional path through space, this causes no difficulty here because the initial and final velocities for this period are in opposite directions. Thus, the problem is effectively a problem in one dimension only. Equation 2.4 $\left(\overline{\mathbf{a}} = \dfrac{\Delta \mathbf{v}}{\Delta t}\right)$ relates the change $\Delta \mathbf{v}$ in the planet's velocity to its average acceleration and the elapsed time Δt = 2.16 years. It will be convenient to convert the elapsed time to seconds before calculating the average acceleration.

SOLUTION
a. The net change in the planet's velocity is the final minus the initial velocity:

$$\Delta \mathbf{v} = \mathbf{v} - \mathbf{v}_0 = -18.5 \text{ km/s } - 20.9 \text{ km/s} = -39.4 \text{ km/s}$$

$$\Delta \mathbf{v} = \left(-39.4 \ \frac{\cancel{\text{km}}}{\text{s}}\right)\left(\frac{1000 \text{ m}}{1 \ \cancel{\text{km}}}\right) = \boxed{-3.94 \times 10^4 \text{ m/s}}$$

b. Although the planet's velocity changes by a large amount, the change occurs over a long time interval, so the average acceleration is likely to be small. Expressed in seconds, the interval is

$$\Delta t = \left(2.16 \ \cancel{\text{yr}}\right)\left(\frac{365 \ \cancel{\text{d}}}{1 \ \cancel{\text{yr}}}\right)\left(\frac{24 \ \cancel{\text{h}}}{1 \ \cancel{\text{d}}}\right)\left(\frac{60 \ \cancel{\text{min}}}{1 \ \cancel{\text{h}}}\right)\left(\frac{60 \text{ s}}{1 \ \cancel{\text{min}}}\right) = 6.81 \times 10^7 \text{ s}$$

Then the average acceleration is

$$\overline{\mathbf{a}} = \frac{\Delta \mathbf{v}}{\Delta t} = \frac{-3.94 \times 10^4 \text{ m/s}}{6.81 \times 10^7 \text{ s}} = \boxed{-5.79 \times 10^{-4} \text{ m/s}^2}$$

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17. ***REASONING*** Since the velocity and acceleration of the motorcycle point in the same direction, their numerical values will have the same algebraic sign. For convenience, we will choose them to be positive. The velocity, acceleration, and the time are related by Equation 2.4: $v = v_0 + at$.

SOLUTION

a. Solving Equation 2.4 for t we have

$$t = \frac{v - v_0}{a} = \frac{(+31 \text{ m/s}) - (+21 \text{ m/s})}{+2.5 \text{ m/s}^2} = \boxed{4.0 \text{ s}}$$

b. Similarly,

$$t = \frac{v - v_0}{a} = \frac{(+61 \text{ m/s}) - (+51 \text{ m/s})}{+2.5 \text{ m/s}^2} = \boxed{4.0 \text{ s}}$$

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18. ***REASONING*** We can use the definition of average acceleration $\overline{\mathbf{a}} = (\mathbf{v} - \mathbf{v_0})/(t - t_0)$ (Equation 2.4) to find the sprinter's final velocity **v** at the end of the acceleration phase, because her initial velocity ($\mathbf{v_0} = 0$ m/s , since she starts from rest), her average acceleration $\overline{\mathbf{a}}$, and the time interval $t - t_0$ are known.

SOLUTION
a. Since the sprinter has a constant acceleration, it is also equal to her average acceleration, so $\overline{\mathbf{a}} = +2.3\ \text{m/s}^2$ Her velocity at the end of the 1.2-s period is

$$\mathbf{v} = \mathbf{v_0} + \overline{\mathbf{a}}(t - t_0) = (0\ \text{m/s}) + (+2.3\ \text{m/s}^2)(1.2\ \text{s}) = \boxed{+2.8\ \text{m/s}}$$

b. Since her acceleration is zero during the remainder of the race, her velocity remains constant at $\boxed{+2.8\ \text{m/s}}$.

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19. ***REASONING*** When the velocity and acceleration vectors are in the same direction, the speed of the object increases in time. When the velocity and acceleration vectors are in opposite directions, the speed of the object decreases in time. (a) The initial velocity and acceleration are in the same direction, so the speed is increasing. (b) The initial velocity and acceleration are in opposite directions, so the speed is decreasing. (c) The initial velocity and acceleration are in opposite directions, so the speed is decreasing. (d) The initial velocity and acceleration are in the same direction, so the speed is increasing.

SOLUTION The final velocity v is related to the initial velocity v_0, the acceleration a, and the elapsed time t through Equation 2.4 ($v = v_0 + a\,t$). The final velocities and speeds for the four moving objects are:

a. $v = 12\ \text{m/s} + (3.0\ \text{m/s}^2)(2.0\ \text{s}) = 18\ \text{m/s}$. The final speed is $\boxed{18\ \text{m/s}}$.
b. $v = 12\ \text{m/s} + (-3.0\ \text{m/s}^2)(2.0\ \text{s}) = 6.0\ \text{m/s}$. The final speed is $\boxed{6.0\ \text{m/s}}$.
c. $v = -12\ \text{m/s} + (3.0\ \text{m/s}^2)(2.0\ \text{s}) = -6.0\ \text{m/s}$. The final speed is $\boxed{6.0\ \text{m/s}}$.
d. $v = -12\ \text{m/s} + (-3.0\ \text{m/s}^2)(2.0\ \text{s}) = -18\ \text{m/s}$. The final speed is $\boxed{18\ \text{m/s}}$.

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20. ***REASONING*** The fact that the emu is slowing down tells us that the acceleration and the velocity have opposite directions. Furthermore, since the acceleration remains the same in both parts of the motion, we can determine its value from the first part of the motion and then use it in the second part to determine the bird's final velocity at the end of the total 6.0-s time interval.

SOLUTION

a. The initial velocity of the emu is directed due north. Since the bird is slowing down, its acceleration must point in the opposite direction, or $\boxed{\text{due south}}$.

b. We assume that due north is the positive direction. With the data given for the first part of the motion, Equation 2.4 shows that the average acceleration is

$$\overline{\mathbf{a}} = \frac{\mathbf{v} - \mathbf{v}_0}{t - t_0} = \frac{(10.6 \text{ m/s}) - (13.0 \text{ m/s})}{4.0 \text{ s} - 0 \text{ s}} = -0.60 \text{ m/s}^2$$

The negative value for the acceleration indicates that it indeed points due south, which is the negative direction. Solving Equation 2.4 for the final velocity gives

$$\mathbf{v} = \mathbf{v}_0 + \overline{\mathbf{a}}\left(t - t_0\right) = +10.6 \text{ m/s} + \left(-0.60 \text{ m/s}^2\right)\left(2.0 \text{ s} - 0 \text{ s}\right) = +9.4 \text{ m/s}$$

Since this answer is positive, the bird's velocity after an additional 2.0 s is in the positive direction and is $\boxed{\text{9.4 m/s, due north}}$.

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21. ***REASONING AND SOLUTION*** The magnitude of the car's acceleration can be found from Equation 2.4 ($v = v_0 + at$) as

$$a = \frac{v - v_0}{t} = \frac{26.8 \text{ m/s} - 0 \text{ m/s}}{3.275 \text{ s}} = \boxed{8.18 \text{ m/s}^2}$$

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22. ***REASONING*** According to Equation 2.4, the average acceleration of the car for the first twelve seconds after the engine cuts out is

$$\overline{a}_1 = \frac{v_{1\text{f}} - v_{10}}{\Delta t_1} \qquad (1)$$

and the average acceleration of the car during the next six seconds is

$$\overline{a}_2 = \frac{v_{2\text{f}} - v_{20}}{\Delta t_2} = \frac{v_{2\text{f}} - v_{1\text{f}}}{\Delta t_2} \qquad (2)$$

The velocity $v_{1\text{f}}$ of the car at the end of the initial twelve-second interval can be found by solving Equations (1) and (2) simultaneously.

SOLUTION Dividing Equation (1) by Equation (2), we have

$$\frac{\bar{a}_1}{\bar{a}_2} = \frac{(v_{1f} - v_{10}) / \Delta t_1}{(v_{2f} - v_{1f}) / \Delta t_2} = \frac{(v_{1f} - v_{10}) \Delta t_2}{(v_{2f} - v_{1f}) \Delta t_1}$$

Solving for v_{1f}, we obtain

$$v_{1f} = \frac{\bar{a}_1 \Delta t_1 v_{2f} + \bar{a}_2 \Delta t_2 v_{10}}{\bar{a}_1 \Delta t_1 + \bar{a}_2 \Delta t_2} = \frac{(\bar{a}_1 / \bar{a}_2) \Delta t_1 v_{2f} + \Delta t_2 v_{10}}{(\bar{a}_1 / \bar{a}_2) \Delta t_1 + \Delta t_2}$$

$$v_{1f} = \frac{1.50(12.0\text{ s})(+28.0\text{ m/s}) + (6.0\text{ s})(+36.0\text{ m/s})}{1.50(12.0\text{ s}) + 6.0\text{ s}} = \boxed{+30.0\text{ m/s}}$$

---

23. ***REASONING AND SOLUTION*** Both motorcycles have the same velocity v at the end of the four second interval. Now

$$v = v_{0A} + a_A t$$

for motorcycle A and

$$v = v_{0B} + a_B t$$

for motorcycle B. Subtraction of these equations and rearrangement gives

$$v_{0A} - v_{0B} = (4.0\text{ m/s}^2 - 2.0\text{ m/s}^2)(4\text{ s}) = \boxed{+8.0\text{ m/s}}$$

The positive result indicates that motorcycle A was initially traveling faster.

---

24. ***REASONING AND SOLUTION*** The average acceleration of the basketball player is $\bar{a} = v / t$, so

$$x = \tfrac{1}{2}\bar{a}t^2 = \tfrac{1}{2}\left(\frac{6.0\text{ m/s}}{1.5\text{ s}}\right)(1.5\text{ s})^2 = \boxed{4.5\text{ m}}$$

---

25. SSM ***REASONING AND SOLUTION***

a. The magnitude of the acceleration can be found from Equation 2.4 ($v = v_0 + at$) as

$$a = \frac{v - v_0}{t} = \frac{3.0\text{ m/s} - 0\text{ m/s}}{2.0\text{ s}} = \boxed{1.5\text{ m/s}^2}$$

b. Similarly the magnitude of the acceleration of the car is

$$a = \frac{v - v_0}{t} = \frac{41.0\text{ m/s} - 38.0\text{ m/s}}{2.0\text{ s}} = \boxed{1.5\text{ m/s}^2}$$

c. Assuming that the acceleration is constant, the displacement covered by the car can be found from Equation 2.9 ($v^2 = v_0^{\,2} + 2ax$):

$$x = \frac{v^2 - v_0^2}{2a} = \frac{(41.0\text{ m/s})^2 - (38.0\text{ m/s})^2}{2(1.5\text{ m/s}^2)} = 79\text{ m}$$

Similarly, the displacement traveled by the jogger is

$$x = \frac{v^2 - v_0^2}{2a} = \frac{(3.0\text{ m/s})^2 - (0\text{ m/s})^2}{2(1.5\text{ m/s}^2)} = 3.0\text{ m}$$

Therefore, the car travels 79 m – 3.0 m = $\boxed{76\text{ m}}$ further than the jogger.

---

26. ***REASONING*** The average acceleration is defined by Equation 2.4 as the change in velocity divided by the elapsed time. We can find the elapsed time from this relation because the acceleration and the change in velocity are given.

SOLUTION

a. The time Δt that it takes for the VW Beetle to change its velocity by an amount $\Delta v = v - v_0$ is (and noting that 0.4470 m/s = 1 mi/h)

$$\Delta t = \frac{v - v_0}{a} = \frac{(60.0\text{ mi/h})\left(\frac{0.4470\text{ m/s}}{1\text{ mi/h}}\right) - 0\text{ m/s}}{2.35\text{ m/s}^2} = \boxed{11.4\text{ s}}$$

b. From Equation 2.4, the acceleration (in m/s^2) of the dragster is

$$a = \frac{v - v_0}{t - t_0} = \frac{(60.0\text{ mi/h})\left(\frac{0.4470\text{ m/s}}{1\text{ mi/h}}\right) - 0\text{ m/s}}{0.600\text{ s} - 0\text{ s}} = \boxed{44.7\text{ m/s}^2}$$

---

27. ***REASONING*** We know the initial and final velocities of the blood, as well as its displacement. Therefore, Equation 2.9 $\left(v^2 = v_0^2 + 2ax\right)$ can be used to find the acceleration

of the blood. The time it takes for the blood to reach it final velocity can be found by using Equation 2.7 $\left[t = \frac{x}{\frac{1}{2}(v_0 + v)}\right]$.

SOLUTION

a. The acceleration of the blood is

$$a = \frac{v^2 - v_0^2}{2x} = \frac{(26 \text{ cm/s})^2 - (0 \text{ cm/s})^2}{2(2.0 \text{ cm})} = \boxed{1.7\times10^2 \text{ cm/s}^2}$$

b. The time it takes for the blood, starting from 0 cm/s, to reach a final velocity of +26 cm/s is

$$t = \frac{x}{\frac{1}{2}(v_0 + v)} = \frac{2.0 \text{ cm}}{\frac{1}{2}(0 \text{ cm/s} + 26 \text{ cm/s})} = \boxed{0.15 \text{ s}}$$

---

28. ***REASONING AND SOLUTION***

a. From Equation 2.4, the definition of average acceleration, the magnitude of the average acceleration of the skier is

$$\bar{a} = \frac{v - v_0}{t - t_0} = \frac{8.0 \text{ m/s} - 0 \text{ m/s}}{5.0 \text{ s}} = \boxed{1.6 \text{ m/s}^2}$$

b. With x representing the displacement traveled along the slope, Equation 2.7 gives:

$$x = \tfrac{1}{2}(v_0 + v)t = \tfrac{1}{2}(8.0 \text{ m/s} + 0 \text{ m/s})(5.0 \text{ s}) = \boxed{2.0\times10^1 \text{ m}}$$

---

29. **SSM** ***REASONING AND SOLUTION*** The average acceleration of the plane can be found by solving Equation 2.9 $\left(v^2 = v_0^2 + 2ax\right)$ for a. Taking the direction of motion as positive, we have

$$a = \frac{v^2 - v_0^2}{2x} = \frac{(+6.1 \text{ m/s})^2 - (+69 \text{ m/s})^2}{2(+750 \text{ m})} = \boxed{-3.1 \text{ m/s}^2}$$

The minus sign indicates that the direction of the acceleration is opposite to the direction of motion, and the plane is slowing down.

---

30. ***REASONING*** At a constant velocity the time required for Secretariat to run the final mile is given by Equation 2.2 as the displacement (+1609 m) divided by the velocity. The actual time required for Secretariat to run the final mile can be determined from Equation 2.8, since

the initial velocity, the acceleration, and the displacement are given. It is the difference between these two results for the time that we seek.

SOLUTION According to Equation 2.2, with the assumption that the initial time is t_0 = 0 s, the run time at a constant velocity is

$$\Delta t = t - t_0 = t = \frac{\Delta x}{v} = \frac{+1609 \text{ m}}{+16.58 \text{ m/s}} = 97.04 \text{ s}$$

Solving Equation 2.8 $\left(x = v_0 t + \frac{1}{2}at^2\right)$ for the time shows that

$$t = \frac{-v_0 \pm \sqrt{v_0^2 - 4\left(\frac{1}{2}a\right)(-x)}}{2\left(\frac{1}{2}a\right)}$$

$$= \frac{-16.58 \text{ m/s} \pm \sqrt{(+16.58 \text{ m/s})^2 - 4\left(\frac{1}{2}\right)\left(+0.0105 \text{ m/s}^2\right)(-1609 \text{ m})}}{2\left(\frac{1}{2}\right)\left(+0.0105 \text{ m/s}^2\right)} = 94.2 \text{ s}$$

We have ignored the negative root as being unphysical. The acceleration allowed Secretariat to run the last mile in a time that was faster by

$$97.04 \text{ s} - 94.2 \text{ s} = \boxed{2.8 \text{ s}}$$

---

31. SSM ***REASONING*** The cart has an initial velocity of v_0 = +5.0 m/s, so initially it is moving to the right, which is the positive direction. It eventually reaches a point where the displacement is x = +12.5 m, and it begins to move to the left. This must mean that the cart comes to a momentary halt at this point (final velocity is v = 0 m/s), before beginning to move to the left. In other words, the cart is decelerating, and its acceleration must point opposite to the velocity, or to the left. Thus, the acceleration is negative. Since the initial velocity, the final velocity, and the displacement are known, Equation 2.9 $\left(v^2 = v_0^2 + 2ax\right)$ can be used to determine the acceleration.

SOLUTION Solving Equation 2.9 for the acceleration a shows that

$$a = \frac{v^2 - v_0^2}{2x} = \frac{(0 \text{ m/s})^2 - (+5.0 \text{ m/s})^2}{2(+12.5 \text{ m})} = \boxed{-1.0 \text{ m/s}^2}$$

---

32. ***REASONING*** At time t both rockets return to their starting points and have a displacement of zero. This occurs, because each rocket is decelerating during the first half of its journey.

However, rocket A has a smaller initial velocity than rocket B. Therefore, in order for rocket B to decelerate and return to its point of origin in the same time as rocket A, rocket B must have a deceleration with a greater magnitude than that for rocket A. Since we know that the displacement of each rocket is zero at time *t*, since both initial velocities are given, and since we seek information about the acceleration, we begin our solution with Equation 2.8, for it contains just these variables.

SOLUTION Applying Equation 2.8 to each rocket gives

$$x_A = v_{0A}t + \tfrac{1}{2}a_A t^2 \qquad x_B = v_{0B}t + \tfrac{1}{2}a_B t^2$$

$$0 = v_{0A}t + \tfrac{1}{2}a_A t^2 \qquad 0 = v_{0B}t + \tfrac{1}{2}a_B t^2$$

$$0 = v_{0A} + \tfrac{1}{2}a_A t \qquad 0 = v_{0B} + \tfrac{1}{2}a_B t$$

$$t = \frac{-2v_{0A}}{a_A} \qquad t = \frac{-2v_{0B}}{a_B}$$

The time for each rocket is the same, so that we can equate the two expressions for *t*, with the result that

$$\frac{-2v_{0A}}{a_A} = \frac{-2v_{0B}}{a_B} \quad \text{or} \quad \frac{v_{0A}}{a_A} = \frac{v_{0B}}{a_B}$$

Solving for a_B gives

$$a_B = \frac{a_A}{v_{0A}}v_{0B} = \frac{-15 \text{ m/s}^2}{5800 \text{ m/s}}(8600 \text{ m/s}) = \boxed{-22 \text{ m/s}^2}$$

As expected, the magnitude of the acceleration for rocket B is greater than that for rocket A.

---

33. ***REASONING*** The stopping distance is the sum of two parts. First, there is the distance the car travels at 20.0 m/s before the brakes are applied. According to Equation 2.2, this distance is the magnitude of the displacement and is the magnitude of the velocity times the time. Second, there is the distance the car travels while it decelerates as the brakes are applied. This distance is given by Equation 2.9, since the initial velocity, the acceleration, and the final velocity (0 m/s when the car comes to a stop) are given.

SOLUTION With the assumption that the initial position of the car is $x_0 = 0$ m, Equation 2.2 gives the first contribution to the stopping distance as

$$\Delta x_1 = x_1 = vt_1 = (20.0 \text{ m/s})(0.530 \text{ s})$$

Solving Equation 2.9 $\left(v^2 = v_0^2 + 2ax\right)$ for x shows that the second part of the stopping distance is

$$x_2 = \frac{v^2 - v_0^2}{2a} = \frac{(0\text{ m/s})^2 - (20.0\text{ m/s})^2}{2\left(-7.00\text{ m/s}^2\right)}$$

Here, the acceleration is assigned a negative value, because we have assumed that the car is traveling in the positive direction, and it is decelerating. Since it is decelerating, its acceleration points opposite to its velocity. The stopping distance, then, is

$$x_{\text{Stopping}} = x_1 + x_2 = (20.0\text{ m/s})(0.530\text{ s}) + \frac{(0\text{ m/s})^2 - (20.0\text{ m/s})^2}{2\left(-7.00\text{ m/s}^2\right)} = \boxed{39.2\text{ m}}$$

---

34. ***REASONING*** The entering car maintains a constant acceleration of a_1 = 6.0 m/s^2 from the time it starts from rest in the pit area until it catches the other car, but it is convenient to separate its motion into two intervals. During the first interval, lasting t_1 = 4.0 s, it accelerates from rest to the velocity v_{01} with which it enters the main speedway. This velocity is found from Equation 2.4 $\left(v = v_0 + at\right)$, with v_0 = 0 m/s, $a = a_1$, $t = t_1$, and $v = v_{01}$:

$$v_{10} = a_1 t_1 \qquad (1)$$

The second interval begins when the entering car enters the main speedway with velocity v_{01}, and ends when it catches up with the other car, which travels with a constant velocity v_{02} = 70.0 m/s. Since both cars begin and end the interval side-by-side, they both undergo the same displacement x during this interval. The displacement of each car is given by Equation 2.8 $\left(x = v_0 t + \frac{1}{2}at^2\right)$. For the accelerating car, $v_0 = v_{10}$, and $a = a_1$, so

$$x = v_{10}t + \tfrac{1}{2}a_1 t^2 \qquad (2)$$

For the other car, $v_0 = v_{02}$ and a = 0 m/s^2, and so Equation 2.8 yields

$$x = v_{20}t \qquad (3)$$

SOLUTION The displacement during the second interval is not required, so equating the right hand sides of Equations (2) and (3) eliminates x, leaving an equation that may be solved for the elapsed time t, which is now the only unknown quantity:

$$v_{10}t + \tfrac{1}{2}a_1 t^2 = v_{20}t$$

$$v_{10}\not{t} + \tfrac{1}{2}a_1 t^{\not{2}} = v_{20}\not{t}$$

$$\tfrac{1}{2}a_1 t = v_{20} - v_{10} \qquad (4)$$

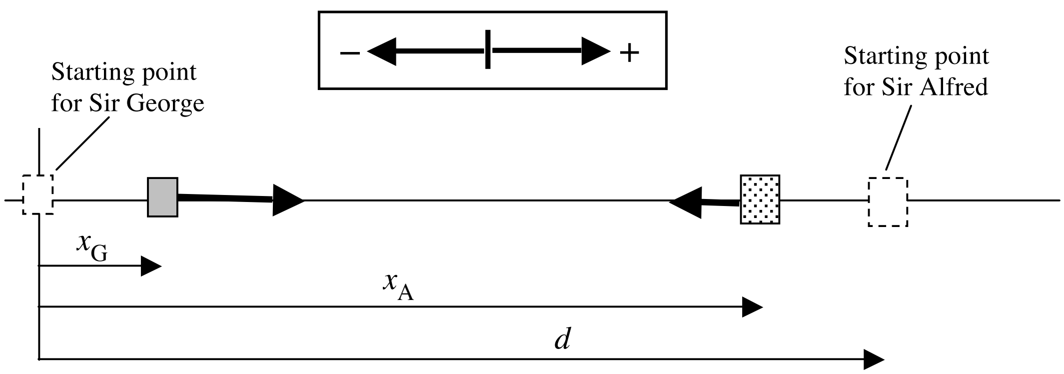
$$t = \frac{2\left(v_{20} - v_{10}\right)}{a_1}$$

Substituting Equation (1) for v_{10} into Equation (4), we find that

$$t = \frac{2\left(v_{20} - a_1 t_1\right)}{a_1} = \frac{2\left[70.0\,\text{m/s} - \left(6.0\ \text{m/s}^2\right)\left(4.0\ \text{s}\right)\right]}{\left(6.0\ \text{m/s}^2\right)} = \boxed{15\ \text{s}}$$

---

35. ***REASONING*** The drawing shows the two knights, initially separated by the displacement *d,* traveling toward each other. At any moment, Sir George's displacement is x_G and that of Sir Alfred is x_A. When they meet, their displacements are the same, so $x_G = x_A$.



According to Equation 2.8, Sir George's displacement as a function of time is

$$x_G = v_{0,G}t + \tfrac{1}{2}a_G t^2 = (0\ \text{m/s})t + \tfrac{1}{2}a_G t^2 = \tfrac{1}{2}a_G t^2 \qquad (1)$$

where we have used the fact that Sir George starts from rest $\left(v_{0,G} = 0\ \text{m/s}\right)$.

Since Sir Alfred starts from rest at $x = d$ at $t = 0$ s, we can write his displacement as (again, employing Equation 2.8)

$$x_A = d + v_{0,A}t + \tfrac{1}{2}a_A t^2 = d + (0\ \text{m/s})t + \tfrac{1}{2}a_A t^2 = d + \tfrac{1}{2}a_A t^2 \qquad (2)$$

Solving Equation 1 for t^2 $\left(t^2 = 2x_G / a_G\right)$ and substituting this expression into Equation 2 yields

$$x_A = d + \tfrac{1}{2} a_A \left(\frac{2x_G}{a_G} \right) = d + a_A \left(\frac{x_G}{a_G} \right) \tag{3}$$

Noting that $x_A = x_G$ when the two riders collide, we see that Equation 3 becomes

$$x_G = d + a_A \left(\frac{x_G}{a_G} \right)$$

Solving this equation for x_G gives $x_G = \dfrac{d}{1 - \dfrac{a_A}{a_G}}$.

SOLUTION Sir George's acceleration is positive $\left(a_G = +0.300 \text{ m/s}^2\right)$ since he starts from rest and moves to the right (the positive direction). Sir Alfred's acceleration is negative $\left(a_A = -0.200 \text{ m/s}^2\right)$ since he starts from rest and moves to the left (the negative direction). The displacement of Sir George is, then,

$$x_G = \frac{d}{1 - \dfrac{a_A}{a_G}} = \frac{88.0 \text{ m}}{1 - \dfrac{\left(-0.200 \text{ m/s}^2\right)}{\left(+0.300 \text{ m/s}^2\right)}} = \boxed{52.8 \text{ m}}$$

---

36. ***REASONING*** The players collide when they have the same x coordinate relative to a common origin. For convenience, we will place the origin at the starting point of the first player. From Equation 2.8, the x coordinate of each player is given by

$$x_1 = v_{01} t_1 + \tfrac{1}{2} a_1 t_1^2 = \tfrac{1}{2} a_1 t_1^2 \tag{1}$$

$$x_2 = d + v_{02} t_2 + \tfrac{1}{2} a_2 t_2^2 = d + \tfrac{1}{2} a_2 t_2^2 \tag{2}$$

where d = +48 m is the initial position of the second player. When $x_1 = x_2$, the players collide at time $t = t_1 = t_2$.

SOLUTION

a. Equating Equations (1) and (2) when $t = t_1 = t_2$, we have

$$\tfrac{1}{2} a_1 t^2 = d + \tfrac{1}{2} a_2 t^2$$

We note that a_1 = +0.50 m/s^2, while a_2 = –0.30 m/s^2, since the first player accelerates in the +x direction and the second player in the –x direction. Solving for t, we have

$$t = \sqrt{\frac{2d}{a_1 - a_2}} = \sqrt{\frac{2(48\text{ m})}{\left(0.50\text{ m/s}^2\right)-\left(-0.30\text{ m/s}^2\right)}} = \boxed{11\text{ s}}$$

b. From Equation (1),

$$x_1 = \tfrac{1}{2}a_1t_1^2 = \tfrac{1}{2}\left(0.50\text{ m/s}^2\right)(11\text{ s})^2 = \boxed{3.0\times10^1\text{ m}}$$

---

37. ***REASONING*** At a constant velocity the time required for the first car to travel to the next exit is given by Equation 2.2 as the magnitude of the displacement (2.5×10^3 m) divided by the magnitude of the velocity. This is also the travel time for the second car to reach the next exit. The acceleration for the second car can be determined from Equation 2.8, since the initial velocity, the displacement, and the time are known. This equation applies, because the acceleration is constant.

SOLUTION According to Equation 2.2, with the assumption that the initial time is t_0 = 0 s, the time for the first car to reach the next exit at a constant velocity is

$$\Delta t = t - t_0 = t = \frac{\Delta x}{v} = \frac{2.5\times10^3\text{ m}}{33\text{ m/s}} = 76\text{ s}$$

Remembering that the initial velocity v_0 of the second car is zero, we can solve Equation 2.8 $\left(x = v_0t + \frac{1}{2}at^2 = \frac{1}{2}at^2\right)$ for the acceleration to show that

$$a = \frac{2x}{t^2} = \frac{2(2.5\times10^3\text{ m})}{(76\text{ s})^2} = \boxed{0.87\text{ m/s}^2}$$

Since the second car's speed is increasing, this acceleration must be $\boxed{\text{in the same direction as the velocity}}$.

---

38. ***REASONING*** Let the total distance between the first and third sign be equal to 2d. Then, the time t_A is given by

$$t_A = \frac{d}{v_{55}} + \frac{d}{v_{35}} = \frac{d\left(v_{35}+v_{55}\right)}{v_{55}v_{35}} \qquad (1)$$

Equation 2.7 $\left[x=\frac{1}{2}\left(v_0+v\right)t\right]$ can be written as $t=2x/\left(v_0+v\right)$, so that

$$t_{\mathrm{B}}=\frac{2d}{v_{55}+v_{35}}+\frac{2d}{v_{35}+v_{25}}=\frac{2d\left[\left(v_{35}+v_{25}\right)+\left(v_{55}+v_{35}\right)\right]}{\left(v_{55}+v_{35}\right)\left(v_{35}+v_{25}\right)} \quad (2)$$

SOLUTION Dividing Equation (2) by Equation (1) and suppressing units for convenience, we obtain

$$\frac{t_{\mathrm{B}}}{t_{\mathrm{A}}}=\frac{2v_{55}v_{35}\left[\left(v_{35}+v_{25}\right)+\left(v_{55}+v_{35}\right)\right]}{\left(v_{55}+v_{35}\right)^2\left(v_{35}+v_{25}\right)}=\frac{2(55)(35)\left[(35+25)+(55+35)\right]}{(55+35)^2(35+25)}=\boxed{1.2}$$

---

39. ***REASONING*** Because the car is traveling in the $+x$ direction and decelerating, its acceleration is negative: $a = -2.70\ \mathrm{m/s^2}$. The final velocity for the interval is given ($v = +4.50$ m/s), as well as the elapsed time ($t = 3.00$ s). Both the car's displacement x and its initial velocity v_0 at the instant braking begins are unknown.

Compare the list of known kinematic quantities (v, a, t) to the equations of kinematics for constant acceleration: $v=v_0+at$ (Equation 2.4), $x=\frac{1}{2}\left(v_0+v\right)t$ (Equation 2.7), $x=v_0t+\frac{1}{2}at^2$ (Equation 2.8), and $v^2=v_0^2+2ax$ (Equation 2.9). None of these four equations contains all three known quantities and the desired displacement x, and each of them contains the initial velocity v_0. Since the initial velocity is neither known nor requested, we can combine two kinematic equations to eliminate it, leaving an equation in which x is the only unknown quantity.

SOLUTION For the first step, solve Equation 2.4 $\left(v=v_0+at\right)$ for v_0:

$$v_0=v-at \quad (1)$$

Substituting the expression for v_0 in Equation (1) into Equation 2.8 $\left(x=v_0t+\frac{1}{2}at^2\right)$ yields an expression for the car's displacement solely in terms of the known quantities v, a, and t:

$$x=\left(v-at\right)t+\tfrac{1}{2}at^2=vt-at^2+\tfrac{1}{2}at^2$$

$$x=vt-\tfrac{1}{2}at^2 \quad (2)$$

Substitute the known values of v, a, and t into Equation (2):

$$x = (+4.50 \text{ m/s})(3.00 \text{ s}) - \tfrac{1}{2}(-2.70 \text{ m/s}^2)(3.00 \text{ s})^2 = \boxed{+25.7 \text{ m}}$$

Note: Equation (2) can also be obtained by combining Equation (1) with Equation 2.7 $\left[x = \tfrac{1}{2}(v_0 + v)t\right]$, or, with more effort, by combining Equation (1) with Equation 2.9 $\left(v^2 = v_0^2 + 2ax\right)$.

---

40. ***REASONING AND SOLUTION*** As the plane decelerates through the intersection, it covers a total distance equal to the length of the plane plus the width of the intersection, so

$$x = 59.7 \text{ m} + 25.0 \text{ m} = 84.7 \text{ m}$$

The speed of the plane as it enters the intersection can be found from Equation 2.9. Solving Equation 2.9 for v_0 gives

$$v_0 = \sqrt{v^2 - 2ax} = \sqrt{(45.0 \text{ m})^2 - 2(-5.70 \text{ m/s}^2)(84.7 \text{ m})} = 54.7 \text{ m/s}$$

The time required to traverse the intersection can then be found from Equation 2.4. Solving Equation 2.4 for t gives

$$t = \frac{v - v_0}{a} = \frac{45.0 \text{ m/s} - 54.7 \text{ m/s}}{-5.70 \text{ m/s}^2} = \boxed{1.7 \text{ s}}$$

---

41. SSM ***REASONING*** As the train passes through the crossing, its motion is described by Equations 2.4 ($v = v_0 + at$) and 2.7 $\left[x = \tfrac{1}{2}(v + v_0)t\right]$, which can be rearranged to give

$$v - v_0 = at \qquad \text{and} \qquad v + v_0 = \frac{2x}{t}$$

These can be solved simultaneously to obtain the speed v when the train reaches the end of the crossing. Once v is known, Equation 2.4 can be used to find the time required for the train to reach a speed of 32 m/s.

SOLUTION Adding the above equations and solving for v, we obtain

$$v = \tfrac{1}{2}\left(at + \frac{2x}{t}\right) = \tfrac{1}{2}\left[(1.6 \text{ m/s}^2)(2.4 \text{ s}) + \frac{2(20.0 \text{ m})}{2.4 \text{ s}}\right] = 1.0 \times 10^1 \text{ m/s}$$

The motion from the end of the crossing until the locomotive reaches a speed of 32 m/s requires a time

$$t = \frac{v - v_0}{a} = \frac{32\text{ m/s} - 1.0\times10^1\text{ m/s}}{1.6\text{ m/s}^2} = \boxed{14\text{ s}}$$

---

42. ***REASONING*** Since the car is moving with a constant velocity, the displacement of the car in a time t can be found from Equation 2.8 with $a = 0$ m/s^2 and v_0 equal to the velocity of the car: $x_{\text{car}} = v_{\text{car}}t$. Since the train starts from rest with a constant acceleration, the displacement of the train in a time t is given by Equation 2.8 with $v_0 = 0$ m/s:

$$x_{\text{train}} = \tfrac{1}{2}a_{\text{train}}t^2$$

At a time t_1, when the car just reaches the front of the train, $x_{\text{car}} = L_{\text{train}} + x_{\text{train}}$, where L_{train} is the length of the train. Thus, at time t_1,

$$v_{\text{car}}t_1 = L_{\text{train}} + \tfrac{1}{2}a_{\text{train}}t_1^2 \qquad (1)$$

At a time t_2, when the car is again at the rear of the train, $x_{\text{car}} = x_{\text{train}}$. Thus, at time t_2

$$v_{\text{car}}t_2 = \tfrac{1}{2}a_{\text{train}}t_2^2 \qquad (2)$$

Equations (1) and (2) can be solved simultaneously for the speed of the car v_{car} and the acceleration of the train a_{train}.

SOLUTION

a. Solving Equation (2) for a_{train} we have

$$a_{\text{train}} = \frac{2v_{\text{car}}}{t_2} \qquad (3)$$

Substituting this expression for a_{train} into Equation (1) and solving for v_{car}, we have

$$v_{\text{car}} = \frac{L_{\text{train}}}{t_1\left(1 - \dfrac{t_1}{t_2}\right)} = \frac{92\text{ m}}{(14\text{ s})\left(1 - \dfrac{14\text{ s}}{28\text{ s}}\right)} = \boxed{13\text{ m/s}}$$

b. Direct substitution into Equation (3) gives the acceleration of the train:

$$a_{\text{train}} = \frac{2v_{\text{car}}}{t_2} = \frac{2\ (13\ \text{m/s})}{28\ \text{s}} = \boxed{0.93\ \text{m/s}^2}$$

---

43. SSM ***REASONING AND SOLUTION*** When air resistance is neglected, free fall conditions are applicable. The final speed can be found from Equation 2.9;

$$v^2 = v_0^2 + 2ay$$

where v_0 is zero since the stunt man falls from rest. If the origin is chosen at the top of the hotel and the upward direction is positive, then the displacement is y = –99.4 m. Solving for v, we have

$$v = -\sqrt{2ay} = -\sqrt{2(-9.80\ \text{m/s}^2)(-99.4\ \text{m})} = -44.1\ \text{m/s}$$

The speed at impact is the magnitude of this result or $\boxed{44.1\ \text{m/s}}$.

---

44. ***REASONING*** Because there is no effect due to air resistance, the rock is in free fall from its launch until it hits the ground, so that the acceleration of the rock is always −9.8 m/s^2, assuming upward to be the positive direction. In (a), we will consider the interval beginning at launch and ending 2.0 s later. In (b), we will consider the interval beginning at launch and ending 5.0 s later. Since the displacement isn't required, Equation 2.4 $(v = v_0 + at)$ suffices to solve both parts of the problem. The stone slows down as it rises, so we expect the speed in (a) to be larger than 15 m/s. The speed in (b) could be smaller than 15 m/s (the rock does not reach its maximum height) or larger than 15 m/s (the rock reaches its maximum height and falls back down below its height at the 2.0-s point).

SOLUTION

a. For the interval from launch to t = 2.0 s, the final velocity is v = 15 m/s, the acceleration is a = −9.8 m/s^2, and the initial velocity is to be found. Solving Equation 2.4 $(v = v_0 + at)$ for v_0 gives

$$v_0 = v - at = 15\ \text{m/s} - (-9.8\ \text{m/s}^2)(2.0\ \text{s}) = 35\ \text{m/s}$$

Therefore, at launch,

$$\text{Speed} = \boxed{35\ \text{m/s}}$$

b. Now we consider the interval from launch to t = 5.0 s. The initial velocity is that found in part (a), v_0 = 35 m/s. The final velocity is

$$v = v_0 + at = 35 \text{ m/s} + (-9.8 \text{ m/s}^2)(5.0 \text{ s}) = -14 \text{ m/s} \quad (2.4)$$

Instantaneous speed is the magnitude of the instantaneous velocity, so we drop the minus sign and find that

$$\text{Speed} = \boxed{14 \text{ m/s}}$$

---

45. ***REASONING AND SOLUTION*** In a time t the card will undergo a vertical displacement y given by

$$y = \tfrac{1}{2}at^2$$

where a = –9.80 m/s^2. When t = 60.0 ms = 6.0×10^{-2} s, the displacement of the card is 0.018 m, and the distance is the magnitude of this value or $\boxed{d_1 = 0.018 \text{ m}}$.

Similarly, when t = 120 ms, $\boxed{d_2 = 0.071 \text{ m}}$, and when t = 180 ms, $\boxed{d_3 = 0.16 \text{ m}}$.

---

46. ***REASONING***

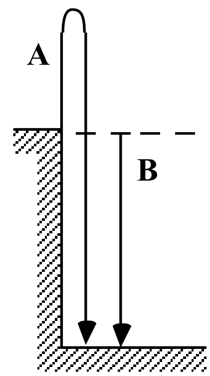
Assuming that air resistance can be neglected, the acceleration is the same for both the upward and downward parts, namely –9.80 m/s^2 (upward is the positive direction). Moreover, the displacement is y = 0 m, since the final and initial positions of the ball are the same. The time is given as t = 8.0 s. Therefore, we may use Equation 2.8 $\left(y = v_0\, t + \tfrac{1}{2}a\,t^2\right)$ to find the initial velocity v_0 of the ball.

SOLUTION Solving Equation 2.8 $\left(y = v_0\, t + \tfrac{1}{2}a\,t^2\right)$ for the initial velocity v_0 gives

$$v_0 = \frac{y - \tfrac{1}{2}a\,t^2}{t} = \frac{0 \text{ m} - \tfrac{1}{2}\left(-9.80 \text{ m/s}^2\right)\left(8.0 \text{ s}\right)^2}{8.0 \text{ s}} = \boxed{+39 \text{ m/s}}$$

---

47. ***REASONING AND SOLUTION*** The figure at the right shows the paths taken by the pellets fired from gun **A** and gun **B**. The two paths differ by the extra distance covered by the pellet from gun **A** as it rises and falls back to the edge of the cliff. When it falls back to the edge of the cliff, the pellet from gun A will have the same speed as the pellet fired from gun B, as Conceptual Example 15 discusses. Therefore, the flight time of pellet **A** will be greater than that of **B** by the amount of time that it takes for pellet **A** to cover the extra distance.



The time required for pellet **A** to return to the cliff edge after being fired can be found from Equation 2.4: $v = v_0 + at$. If "up" is taken as the positive direction then v_0 = +30.0 m/s and v = –30.0 m/s. Solving Equation 2.4 for t gives

$$t = \frac{v - v_0}{a} = \frac{(-30.0 \text{ m/s}) - (+30.0 \text{ m/s})}{-9.80 \text{ m/s}^2} = \boxed{6.12 \text{ s}}$$

Notice that this result is *independent* of the height of the cliff.

---

48. ***REASONING*** The initial velocity and the elapsed time are given in the problem. Since the rock returns to the same place from which it was thrown, its displacement is zero (y = 0 m). Using this information, we can employ Equation 2.8 $\left(y = v_0 t + \frac{1}{2}at^2\right)$ to determine the acceleration a due to gravity.

SOLUTION Solving Equation 2.8 for the acceleration yields

$$a = \frac{2(y - v_0 t)}{t^2} = \frac{2[0 \text{ m} - (+15 \text{ m/s})(20.0 \text{ s})]}{(20.0 \text{ s})^2} = \boxed{-1.5 \text{ m/s}^2}$$

---

49. SSM ***REASONING*** The initial velocity of the compass is +2.50 m/s. The initial position of the compass is 3.00 m and its final position is 0 m when it strikes the ground. The displacement of the compass is the final position minus the initial position, or y = –3.00 m. As the compass falls to the ground, its acceleration is the acceleration due to gravity, a = –9.80 m/s^2. Equation 2.8 $\left(y = v_0 t + \frac{1}{2}at^2\right)$ can be used to find how much time elapses before the compass hits the ground.

SOLUTION Starting with Equation 2.8, we use the quadratic equation to find the elapsed time.

$$t=\frac{-v_0 \pm \sqrt{v_0^2-4\left(\frac{1}{2}a\right)(-y)}}{2\left(\frac{1}{2}a\right)}=\frac{-(2.50\text{ m/s}) \pm \sqrt{(2.50\text{ m/s})^2-4\left(-4.90\text{ m/s}^2\right)\left[-(-3.00\text{ m})\right]}}{2\left(-4.90\text{ m/s}^2\right)}$$

There are two solutions to this quadratic equation, $t_1 = \boxed{1.08\text{ s}}$ and $t_2 = -0.568$ s. The second solution, being a negative time, is discarded.

---

50. ***REASONING*** The initial speed of the ball can be determined from Equation 2.9 $\left(v^2=v_0^2+2ay\right)$. Once the initial speed of the ball is known, Equation 2.9 can be used a second time to determine the height above the launch point when the speed of the ball has decreased to one half of its initial value.

SOLUTION When the ball has reached its maximum height, its velocity is zero. If we take upward as the positive direction, we have from Equation 2.9 that

$$v_0=\sqrt{v^2-2ay}=\sqrt{(0\text{ m/s})^2-2(-9.80\text{ m/s}^2)(16\text{ m})}=18\text{ m/s}$$

When the speed of the ball has decreased to one half of its initial value, $v=\frac{1}{2}v_0$, and Equation 2.9 gives

$$y=\frac{v^2-v_0^2}{2a}=\frac{(\frac{1}{2}v_0)^2-v_0^2}{2a}=\frac{v_0^2}{2a}\left(\frac{1}{4}-1\right)=\frac{(18\text{ m/s})^2}{2(-9.80\text{ m/s}^2)}\left(\frac{1}{4}-1\right)=\boxed{12\text{ m}}$$

---

51. ***REASONING AND SOLUTION***

a.
$$v^2=v_0^2+2ay$$

$$v=\pm\sqrt{(1.8\text{ m/s})^2+2\left(-9.80\text{ m/s}^2\right)(-3.0\text{ m})}=\pm 7.9\text{ m/s}$$

The minus is chosen, since the diver is now moving down. Hence, $\boxed{v=-7.9\text{ m/s}}$.

b. The diver's velocity is zero at his highest point. The position of the diver relative to the board is

$$y=-\frac{v_0^2}{2a}=-\frac{(1.8\text{ m/s})^2}{2\left(-9.80\text{ m/s}^2\right)}=0.17\text{ m}$$

The position above the water is 3.0 m + 0.17 m = $\boxed{3.2\text{ m}}$.

---

52. ***REASONING*** Equation 2.9 $\left(v^2 = v_0^2 + 2ay\right)$ can be used to determine the maximum height above the launch point, where the final speed is $v = 0 \text{ m/s}$. However, we will need to know the initial speed v_0, which can be determined via Equation 2.9 and the fact that $v = \frac{1}{2}v_0$ when $y = 4.00 \text{ m}$ (assuming upward to be the positive direction).

SOLUTION When the ball has reached its maximum height, we have $v = 0 \text{ m/s}$ and $y = y_{\text{max}}$, so that Equation 2.9 becomes

$$v^2 = v_0^2 + 2ay \qquad \text{or} \qquad (0 \text{ m/s})^2 = v_0^2 + 2ay_{\text{max}} \qquad \text{or} \qquad y_{\text{max}} = \frac{-v_0^2}{2a} \qquad (1)$$

Using Equation 2.9 and the fact that $v = \frac{1}{2}v_0$ when $y = 4.00 \text{ m}$ (assuming upward to be the positive direction), we find that

$$v^2 = v_0^2 + 2ay \qquad \text{or} \qquad \left(\tfrac{1}{2}v_0\right)^2 = v_0^2 + 2a(4.00 \text{ m}) \qquad \text{or} \qquad v_0^2 = \frac{2a(4.00 \text{ m})}{-(3/4)} \qquad (2)$$

Substituting Equation (2) into Equation (1) gives

$$y_{\text{max}} = \frac{-v_0^2}{2a} = \frac{-2a(4.00 \text{ m})/\left[-(3/4)\right]}{2a} = \boxed{5.33 \text{ m}}$$

---

53. SSM ***REASONING AND SOLUTION*** Since the balloon is released from rest, its initial velocity is zero. The time required to fall through a vertical displacement y can be found from Equation 2.8 $\left(y = v_0 t + \frac{1}{2}at^2\right)$ with $v_0 = 0 \text{ m/s}$. Assuming upward to be the positive direction, we find

$$t = \sqrt{\frac{2y}{a}} = \sqrt{\frac{2(-6.0 \text{ m})}{-9.80 \text{ m/s}^2}} = \boxed{1.1 \text{ s}}$$

---

54. ***REASONING*** Equation 2.9 $\left(v^2 = v_0^2 + 2ay\right)$ can be used to find out how far above the cliff's edge the pellet would have gone if the gun had been fired straight upward, provided that we can determine the initial speed imparted to the pellet by the gun. This initial speed can be found by applying Equation 2.9 to the downward motion of the pellet described in the problem statement.

SOLUTION If we assume that upward is the positive direction, the initial speed of the pellet is, from Equation 2.9,

$$v_0 = \sqrt{v^2 - 2ay} = \sqrt{(-27 \text{ m/s})^2 - 2(-9.80 \text{ m/s}^2)(-15 \text{ m})} = 20.9 \text{ m/s}$$

Equation 2.9 can again be used to find the maximum height of the pellet if it were fired straight up. At its maximum height, $v = 0$ m/s, and Equation 2.9 gives

$$y = \frac{-v_0^2}{2a} = \frac{-(20.9\text{ m/s})^2}{2(-9.80\text{ m/s}^2)} = \boxed{22\text{ m}}$$

---

55. ***REASONING*** The displacement y of the diver is equal to her average velocity $\bar{v}$ multiplied by the time t, or $y = \bar{v}t$. Since the diver has a constant acceleration (the acceleration due to gravity), her average velocity is equal to $\bar{v} = \frac{1}{2}(v_0 + v)$, where v_0 and v are, respectively, the initial and final velocities. Thus, according to Equation 2.7, the displacement of the diver is

$$y = \tfrac{1}{2}(v_0 + v)t \qquad (2.7)$$

The final velocity and the time in this expression are known, but the initial velocity is not. To determine her velocity at the beginning of the 1.20-s period (her initial velocity), we turn to her acceleration. The acceleration is defined by Equation 2.4 as the change in her velocity, $v - v_0$, divided by the elapsed time t: $a = (v - v_0)/t$. Solving this equation for the initial velocity v_0 yields

$$v_0 = v - at$$

Substituting this relation for v_0 into Equation 2.7, we obtain

$$y = \tfrac{1}{2}(v_0 + v)t = \tfrac{1}{2}(v - at + v)t = vt - \tfrac{1}{2}at^2$$

SOLUTION The diver's acceleration is that due to gravity, or $a = -9.80$ m/s^2. The acceleration is negative because it points downward, and this direction is the negative direction. The displacement of the diver during the last 1.20 s of the dive is

$$y = vt - \tfrac{1}{2}at^2 = (-10.1\text{ m/s})(1.20\text{ s}) - \tfrac{1}{2}(-9.80\text{ m/s}^2)(1.20\text{ s})^2 = \boxed{-5.06\text{ m}}$$

The displacement of the diver is negative because she is moving downward.

---

56. ***REASONING*** The ball is initially in free fall, then collides with the pavement and rebounds, which puts it into free fall again, until caught by the boy. We don't have enough information to analyze its collision with the pavement, but we're only asked to calculate the time it spends in the air, undergoing free-fall motion. The motion can be conveniently divided into three intervals: from release ($h_1 = 9.50$ m) to impact, from impact to the second highest point ($h_2 = 5.70$ m), and from the second highest point to $h_3 = 1.20$ m above the pavement. For each of the intervals, the acceleration is that due to gravity. For the first and last interval, the

ball's initial velocity is zero, so the time to fall a given distance can be found from Equation 2.8 $\left(y = v_0 t + \frac{1}{2}at^2\right)$.

The second interval begins at the pavement and ends at h_2, so the initial velocity isn't zero. However, the symmetry of free-fall motion is such that it takes the ball as much time to rise from the ground to a maximum height h_2 as it would take for a ball dropped from h_2 to fall to the pavement, so we can again use Equation 2.8 to find the duration of the second interval.

SOLUTION Taking upward as the positive direction, we have a = −9.80 m/s^2 for the acceleration in each of the three intervals. Furthermore, the initial velocity for each of the intervals is v_0 = 0 m/s. Remember, we are using symmetry to treat the second interval as if the ball were dropped from rest at a height of 5.70 m and fell to the pavement. Using Equation 2.8 $\left(y = v_0 t + \frac{1}{2}at^2\right)$, with v_0 = 0 m/s, we can solve for the time to find that

$$t = \sqrt{\frac{2y}{a}}$$

Applying this result to each interval gives the total time as

$$t_{total} = \underbrace{\sqrt{\frac{2(-9.50\text{ m})}{-9.80\text{ m/s}^2}}}_{1^{\text{st}}\text{ interval}} + \underbrace{\sqrt{\frac{2(-5.70\text{ m})}{-9.80\text{ m/s}^2}}}_{2^{\text{nd}}\text{ interval}} + \underbrace{\sqrt{\frac{2\left[-(5.70\text{ m}-1.20\text{ m})\right]}{-9.80\text{ m/s}^2}}}_{3^{\text{rd}}\text{ interval}} = \boxed{3.43\text{ s}}$$

Note that the displacement y for each interval is negative, because upward has been designated as the positive direction.

---

57. ***REASONING*** To calculate the speed of the raft, it is necessary to determine the distance it travels and the time interval over which the motion occurs. The speed is the distance divided by the time, according to Equation 2.1. The distance is 7.00 m – 4.00 m = 3.00 m. The time is the time it takes for the stone to fall, which can be obtained from Equation 2.8 $\left(y = v_0 t + \frac{1}{2}at^2\right)$, since the displacement y, the initial velocity v_0, and the acceleration a are known.

SOLUTION During the time t that it takes the stone to fall, the raft travels a distance of 7.00 m – 4.00 m = 3.00 m, and according to Equation 2.1, its speed is

$$\text{speed} = \frac{3.00\text{ m}}{t}$$

The stone falls downward for a distance of 75.0 m, so its displacement is $y = -75.0$ m, where the downward direction is taken to be the negative direction. Equation 2.8 can be used to find the time of fall. Setting $v_0 = 0$ m/s, and solving Equation 2.8 for the time t, we have

$$t = \sqrt{\frac{2y}{a}} = \sqrt{\frac{2(-75.0\text{ m})}{-9.80\text{ m/s}^2}} = 3.91\text{ s}$$

Therefore, the speed of the raft is

$$\text{speed} = \frac{3.00\text{ m}}{3.91\text{ s}} = \boxed{0.767\text{ m/s}}$$

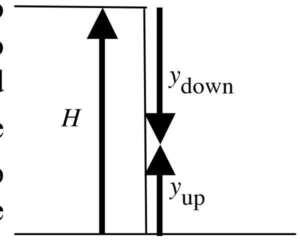
---

58. ***REASONING***
The stone that is thrown upward loses speed on the way up. The stone that is thrown downward gains speed on the way down. The stones cross paths below the point that corresponds to half the height of the cliff. To see why, consider where they would cross paths if they each maintained their initial speed as they moved. Then, they would cross paths exactly at the halfway point. However, the stone traveling upward begins immediately to lose speed, while the stone traveling downward immediately gains speed. Thus, the upward moving stone travels more slowly than the downward moving stone. Consequently, the stone thrown downward has traveled farther when it reaches the crossing point than the stone thrown upward.

The initial velocity v_0 is known for both stones, as is the acceleration a due to gravity. In addition, we know that at the crossing point the stones are at the same place at the same time t. Furthermore, the position of each stone is specified by its displacement y from its starting point. The equation of kinematics that relates the variables v_0, a, t and y is Equation 2.8 $\left(y = v_0 t + \frac{1}{2}at^2\right)$, and we will use it in our solution. In using this equation, we will assume upward to be the positive direction.

SOLUTION Applying Equation 2.8 to each stone, we have

$$\underbrace{y_{\text{up}} = v_0^{\text{up}}t + \tfrac{1}{2}at^2}_{\text{Upward moving stone}} \quad \text{and} \quad \underbrace{y_{\text{down}} = v_0^{\text{down}}t + \tfrac{1}{2}at^2}_{\text{Downward moving stone}}$$



In these expressions t is the time it takes for either stone to reach the crossing point, and a is the acceleration due to gravity. Note that y_{up} is the displacement of the upward moving stone above the base of the cliff, y_{down} is the displacement of the downward moving stone below the top of the cliff, and H is the displacement of the cliff-top above the base of the cliff, as the drawing shows. The distances above and below the crossing point must add to equal the height of the cliff, so we have

$$y_{\text{up}} - y_{\text{down}} = H$$

where the minus sign appears because the displacement y_{down} points in the negative direction. Substituting the two expressions for y_{up} and y_{down} into this equation gives

$$v_0^{\text{up}} t + \tfrac{1}{2}at^2 - \left(v_0^{\text{down}} t + \tfrac{1}{2}at^2\right) = H$$

This equation can be solved for t to show that the travel time to the crossing point is

$$t = \frac{H}{v_0^{\text{up}} - v_0^{\text{down}}}$$

Substituting this result into the expression from Equation 2.8 for y_{up} gives

$$y_{\text{up}} = v_0^{\text{up}} t + \tfrac{1}{2}at^2 = v_0^{\text{up}}\left(\frac{H}{v_0^{\text{up}} - v_0^{\text{down}}}\right) + \tfrac{1}{2}a\left(\frac{H}{v_0^{\text{up}} - v_0^{\text{down}}}\right)^2$$

$$= (9.00\text{ m/s})\left[\frac{6.00\text{ m}}{9.00\text{ m/s} - (-9.00\text{ m/s})}\right] + \tfrac{1}{2}\left(-9.80\text{ m/s}^2\right)\left[\frac{6.00\text{ m}}{9.00\text{ m/s} - (-9.00\text{ m/s})}\right]^2$$

$$= 2.46\text{ m}$$

Thus, the crossing is located a distance of $\boxed{2.46\text{ m}}$ above the base of the cliff, which is below the halfway point of 3.00 m, as expected.

---

59. SSM ***REASONING AND SOLUTION***

a. We can use Equation 2.9 to obtain the speed acquired as she falls through the distance H. Taking downward as the positive direction, we find

$$v^2 = v_0^2 + 2ay = (0\text{ m/s})^2 + 2aH \qquad \text{or} \qquad v = \sqrt{2aH}$$

To acquire a speed of twice this value or $2\sqrt{2aH}$, she must fall an additional distance H'. According to Equation 2.9 $\left(v^2 = v_0^2 + 2ay\right)$, we have

$$\left(2\sqrt{2aH}\right)^2 = \left(\sqrt{2aH}\right)^2 + 2aH' \qquad \text{or} \qquad 4(2aH) = 2aH + 2aH'$$

The acceleration due to gravity a can be eliminated algebraically from this result, giving

$$4H = H + H' \qquad \text{or} \qquad \boxed{H' = 3H}$$

b. In the previous calculation the acceleration due to gravity was eliminated algebraically. Thus, a value other than 9.80 m/s^2 would $\boxed{\text{not have affected the answer to part (a)}}$.

---

60. ***REASONING*** When the arrows reach their maximum heights, they come instantaneously to a halt, and the final speed of each arrow is zero. Using this fact, we will be able to determine the time it takes for each arrow to reach its maximum height. Knowing this time for the second arrow will allow us to determine its initial speed at launch.

SOLUTION The time required for the first arrow to reach its maximum height can be determined from Equation 2.4 ($v = v_0 + at$). Taking upward as the positive direction, we have

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

Note that the second arrow is shot 1.20 s after the first arrow. Therefore, since both arrows reach their maximum height at the same time, the second arrow reaches its maximum height

$$2.55\text{ s} - 1.20\text{ s} = 1.35\text{ s}$$

after being fired. The initial speed of the second arrow can then be found from Equation 2.4:

$$v_0 = v - at = 0\text{ m/s} - (-9.80\text{ m/s}^2)(1.35\text{ s}) = \boxed{13.2\text{ m/s}}$$

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61. **SSM** ***REASONING*** Once the man sees the block, the man must get out of the way in the time it takes for the block to fall through an additional 12.0 m. The velocity of the block at the instant that the man looks up can be determined from Equation 2.9. Once the velocity is known at that instant, Equation 2.8 can be used to find the time required for the block to fall through the additional distance.

SOLUTION When the man first notices the block, it is 14.0 m above the ground and its displacement from the starting point is $y = 14.0\text{ m} - 53.0\text{ m}$. Its velocity is given by Equation 2.9 $\left(v^2 = v_0^2 + 2ay\right)$. Since the block is moving down, its velocity has a negative value,

$$v = -\sqrt{v_0 + 2ay} = -\sqrt{(0\text{ m/s})^2 + 2(-9.80\text{ m/s}^2)(14.0\text{ m} - 53.0\text{ m})} = -27.7\text{ m/s}$$

The block then falls the additional 12.0 m to the level of the man's head in a time t which satisfies Equation 2.8:

$$y = v_0 t + \tfrac{1}{2}at^2$$

where $y = -12.0$ m and $v_0 = -27.7$ m/s. Thus, t is the solution to the quadratic equation

$$4.90t^2 + 27.7t - 12.0 = 0$$

where the units have been suppressed for brevity. From the quadratic formula, we obtain

$$t = \frac{-27.7 \pm \sqrt{(27.7)^2 - 4(4.90)(-12.0)}}{2(4.90)} = 0.40\text{ s} \quad \text{or} \quad -6.1\text{ s}$$

The negative solution can be rejected as nonphysical, and the time it takes for the block to reach the level of the man is $\boxed{0.40\text{ s}}$.

---

62. ***REASONING*** Once its fuel is gone, the rocket is in free fall, so its motion consists of two intervals of constant but different acceleration. We will take upward as the positive direction. From launch to engine burn-out, the acceleration is a_1 = +86.0 m/s^2, and the rocket's displacement is y_1. Its velocity at the end of the burn, v_1, is also the initial velocity for the second portion of its flight: engine burn-out to maximum altitude. During this second portion, the rocket slows down with the acceleration of gravity $a_2 = -9.80\text{ m/s}^2$ and undergoes an additional displacement of y_2 in reaching its maximum height. Its maximum altitude is the sum of these two vertical displacements: $h = y_1 + y_2$.

SOLUTION First we consider the time period t_1 = 1.70 s from the ignition of the engine until the fuel is gone. The rocket accelerates from v_0 = 0 m/s to $v = v_1$, rising a displacement y_1, as given by Equation 2.8 $\left(y = v_0 t + \tfrac{1}{2}at^2\right)$:

$$y_1 = v_0 t_1 + \tfrac{1}{2}a_1 t_1^2 = (0\text{ m/s})t_1 + \tfrac{1}{2}a_1 t_1^2 = \tfrac{1}{2}a_1 t_1^2 \qquad (1)$$

Equation 2.4 $\left(v = v_0 + at\right)$ gives its velocity v_1 at the instant the fuel runs out:

$$v_1 = v_0 + a_1 t_1 = 0\text{ m/s} + a_1 t_1 = a_1 t_1 \qquad (2)$$

From that moment onward, the second part of the rocket's motion is free fall ($a_2 = -9.80\text{ m/s}^2$). It takes a time t_2 for the rocket's velocity to decrease from $v_0 = v_1$ to $v_2 = 0$ m/s at its maximum altitude. We solve Equation 2.9 $\left(v^2 = v_0^2 + 2ay\right)$ to find its upward displacement y_2 during this time:

$$\left(0\text{ m/s}\right)^2 = v_1^2 + 2a_2 y_2 \quad \text{or} \quad y_2 = \frac{-v_1^2}{2a_2}$$

Substituting for v_1 from Equation (2), we find for y_2 that

$$y_2 = \frac{-\left(a_1 t_1\right)^2}{2a_2} \qquad (3)$$

Using Equations (1) and (3), we find that the rocket's maximum altitude, relative to the ground, is

$$h = y_1 + y_2 = \tfrac{1}{2}a_1 t_1^2 - \frac{\left(a_1 t_1\right)^2}{2a_2} = \tfrac{1}{2}a_1 t_1^2\left(1 - \frac{a_1}{a_2}\right)$$

Using the values given, we find that

$$h = \tfrac{1}{2}\left(86.0\text{ m/s}^2\right)\left(1.70\text{ s}\right)^2\left(1 - \frac{86.0\text{ m/s}^2}{-9.80\text{ m/s}^2}\right) = \boxed{1210\text{ m}}$$

---

63. ***REASONING*** To find the initial velocity $v_{0,2}$ of the second stone, we will employ Equation 2.8, $y = v_{0,2}t_2 + \tfrac{1}{2}at_2^2$. In this expression t_2 is the time that the second stone is in the air, and it is equal to the time t_1 that the first stone is in the air minus the time $t_{3.20}$ it takes for the first stone to fall 3.20 m:

$$t_2 = t_1 - t_{3.20}$$

We can find t_1 and $t_{3.20}$ by applying Equation 2.8 to the first stone.

SOLUTION To find the initial velocity $v_{0,2}$ of the second stone, we employ Equation 2.8, $y = v_{0,2}t_2 + \tfrac{1}{2}at_2^2$. Solving this equation for $v_{0,2}$ yields

$$v_{0,2} = \frac{y - \frac{1}{2}at_2^2}{t_2}$$

The time t_1 for the first stone to strike the ground can be obtained from Equation 2.8, $y = v_{0,1}t_1 + \frac{1}{2}at_1^2$. Noting that $v_{0,1}$ = 0 m/s since the stone is dropped from rest and solving this equation for t_1, we have

$$t_1 = \sqrt{\frac{2y}{a}} = \sqrt{\frac{2(-15.0\text{ m})}{-9.80\text{ m/s}^2}} = 1.75\text{ s} \qquad (1)$$

Note that the stone is falling down, so its displacement is negative (y = − 15.0 m). Also, its acceleration a is that due to gravity, so a = –9.80 m/s^2.

The time $t_{3.20}$ for the first stone to fall 3.20 m can also be obtained from Equation 1:

$$t_{3.20} = \sqrt{\frac{2y}{a}} = \sqrt{\frac{2(-3.20\text{ m})}{-9.80\text{ m/s}^2}} = 0.808\text{ s}$$

The time t_2 that the second stone is in the air is

$$t_2 = t_1 - t_{3.20} = 1.75\text{ s} - 0.808\text{ s} = 0.94\text{ s}$$

The initial velocity of the second stone is

$$v_{0,2} = \frac{y - \frac{1}{2}at_2^2}{t_2} = \frac{(-15.0\text{ m}) - \frac{1}{2}(-9.80\text{ m/s}^2)(0.94\text{ s})^2}{0.94\text{ s}} = \boxed{-11\text{ m/s}}$$

---

64. ***REASONING*** We assume that downward is the positive direction. The tile falls from rest, so its initial velocity v_0 is zero. The tile falls through a displacement y in going from the roof top to the top of the window. It is a value for y that we seek, and it can be obtained from $v_{\text{window}}^2 = v_0^2 + 2ay$ (Equation 2.9). In this expression v_0 = 0 m/s, and a is the acceleration due to gravity. The velocity v_{window} at the top of the window is not given, but it can be obtained from the time of 0.20 s that it takes the tile to pass the window.

SOLUTION Solving Equation 2.9 for y and using the fact that v_0 = 0 m/s gives

$$y = \frac{v_{\text{window}}^2 - v_0^2}{2a} = \frac{v_{\text{window}}^2}{2a} \qquad (1)$$

The tile travels an additional displacement $y_{\text{window}} = 1.6$ m in traversing the window in a time $t = 0.20$ s. These data can be used in $y_{\text{window}} = v_{\text{window}} t + \frac{1}{2} a t^2$ (Equation 2.8) to find the velocity v_{window} at the top of the window. Solving Equation 2.8 for v_{window} gives

$$v_{\text{window}} = \frac{2y_{\text{window}} - at^2}{2t} = \frac{2(1.6\text{ m}) - (9.80\text{ m/s}^2)(0.20\text{ s})^2}{2(0.20\text{ s})} = 7.0\text{ m/s}$$

Using this value for v_{window} in Equation (1), we obtain

$$y = \frac{v_{\text{window}}^2}{2a} = \frac{(7.0\text{ m/s})^2}{2(9.80\text{ m/s}^2)} = \boxed{2.5\text{ m}}$$

---

65. SSM ***REASONING*** The slope of a straight-line segment in a position-versus-time graph is the average velocity. The algebraic sign of the average velocity, therefore, corresponds to the sign of the slope.

SOLUTION

a. The slope, and hence the average velocity, is *positive* for segments *A* and *C*, *negative* for segment *B*, and *zero* for segment *D*.

b. In the given position-versus-time graph, we find the slopes of the four straight-line segments to be

$$v_A = \frac{1.25\text{ km} - 0\text{ km}}{0.20\text{ h} - 0\text{ h}} = \boxed{+6.3\text{ km/h}}$$

$$v_B = \frac{0.50\text{ km} - 1.25\text{ km}}{0.40\text{ h} - 0.20\text{ h}} = \boxed{-3.8\text{ km/h}}$$

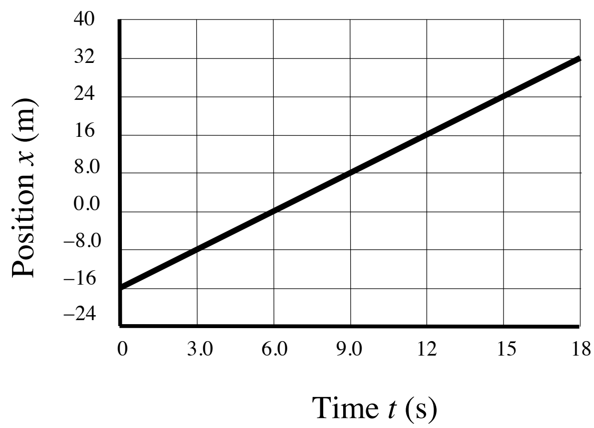
$$v_C = \frac{0.75\text{ km} - 0.50\text{ km}}{0.80\text{ h} - 0.40\text{ h}} = \boxed{+0.63\text{ km/h}}$$

$$v_D = \frac{0.75\text{ km} - 0.75\text{ km}}{1.00\text{ h} - 0.80\text{ h}} = \boxed{0\text{ km/h}}$$

---

66. ***REASONING*** On a position-versus-time graph, the velocity is the slope. Since the object's velocity is constant and it moves in the $+x$ direction, the graph will be a straight line with a positive slope, beginning at $x = -16$ m when $t = 0$ s. At $t = 18$ s, its position should be $x = -16\text{ m} + 48\text{ m} = +32$ m. Once the graph is constructed, the object's velocity is found by calculating the slope of the graph: $v = \dfrac{\Delta x}{\Delta t}$.

SOLUTION The position-versus-time graph for the motion is as follows:



The object's displacement is +48 m, and the elapsed time is 18 s, so its velocity is

$$v = \frac{\Delta x}{\Delta t} = \frac{+48\text{ m}}{18\text{ s}} = \boxed{+2.7\text{ m/s}}$$

---

67. ***REASONING AND SOLUTION*** The average acceleration for each segment is the slope of that segment.

$$a_\text{A} = \frac{40\text{ m/s} - 0\text{ m/s}}{21\text{ s} - 0\text{ s}} = \boxed{1.9\text{ m/s}^2}$$

$$a_\text{B} = \frac{40\text{ m/s} - 40\text{ m/s}}{48\text{ s} - 21\text{ s}} = \boxed{0\text{ m/s}^2}$$

$$a_\text{C} = \frac{80\text{ m/s} - 40\text{ m/s}}{60\text{ s} - 48\text{ s}} = \boxed{3.3\text{ m/s}^2}$$

---

68. ***REASONING*** The average velocity for each segment is the slope of the line for that segment.

SOLUTION Taking the direction of motion as positive, we have from the graph for segments A, B, and C,

$$v_A = \frac{10.0\text{ km} - 40.0\text{ km}}{1.5\text{ h} - 0.0\text{ h}} = \boxed{-2.0\times10^1\text{ km/h}}$$

$$v_B = \frac{20.0\text{ km} - 10.0\text{ km}}{2.5\text{ h} - 1.5\text{ h}} = \boxed{1.0\times10^1\text{ km/h}}$$

$$v_C = \frac{40.0\text{ km} - 20.0\text{ km}}{3.0\text{ h} - 2.5\text{ h}} = \boxed{40\text{ km/h}}$$

---

69. ***REASONING*** The slope of the position-time graph is the velocity of the bus. Each of the three segments of the graph is a straight line, so the bus has a different constant velocity for each part of the trip: v_A, v_B, and v_C . The slope of each segment may be calculated from Equation 2.2 $\left(v = \frac{\Delta x}{\Delta t}\right)$, where Δx is the difference between the final and initial positions of the bus and Δt is the elapsed time during each segment. The average acceleration of the bus is the change in its velocity divided by the elapsed time, as in Equation 2.4 $\left(\bar{a} = \frac{v - v_0}{\Delta t}\right)$. The trip lasts from t = 0 h (the initial instant on the graph) to t = 3.5 h (the final instant on the graph), so the total elapsed time is Δt = 3.5 h. The initial velocity of the bus is its velocity at t = 0, which is its constant velocity for segment A: $v_0 = v_A$. Similarly, the velocity of the bus at the last instant of segment C is its final velocity for the trip: $v = v_C$.

SOLUTION In using Equation 2.2 $\left(v = \frac{\Delta x}{\Delta t}\right)$ to calculate the slopes of segments A and C, any displacement Δx within a segment may be chosen, so long as the corresponding elapsed time Δt is used in the calculation. If the full displacements for each segment are chosen, then

$$v_A = \frac{\Delta x_A}{\Delta t_A} = \frac{24\text{ km} - 0\text{ km}}{1.0\text{ h} - 0\text{ h}} = 24\text{ km/h}$$

$$v_C = \frac{\Delta x_C}{\Delta t_C} = \frac{27\text{ km} - 33\text{ km}}{3.5\text{ h} - 2.2\text{ h}} = -5\text{ km/h}$$

Apply these results to Equation 2.4:

$$\bar{a} = \frac{v - v_0}{\Delta t} = \frac{(-5\text{ km/h}) - (24\text{ km/h})}{3.5\text{ h}} = \boxed{-8.3\text{ km/h}^2}$$

---

70. ***REASONING*** The runner is at the position $x = 0$ m when time $t = 0$ s; the finish line is 100 m away. During each ten-second segment, the runner has a constant velocity and runs

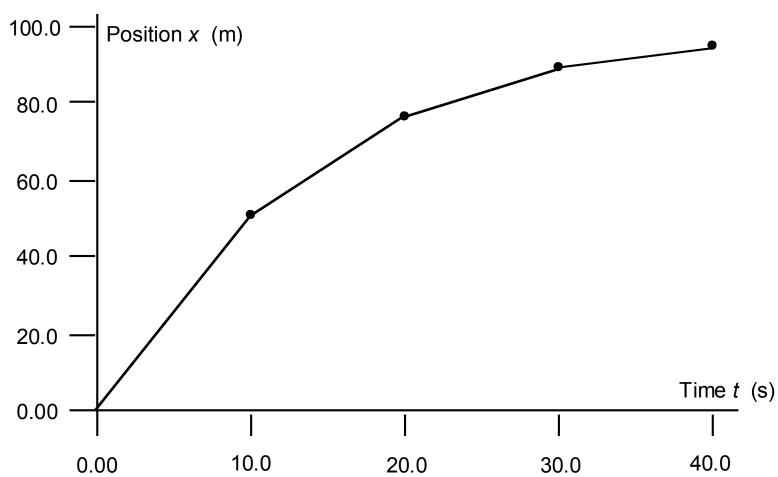
half the remaining distance to the finish line. The following table shows the first four segments of the motion:

Time Interval	**Change in Position**
$t = 0$ s → $t = 10.0$ s	$x = 0$ m → $x = 50.0$ m
$t = 10.0$ s → $t = 20.0$ s	$x = 50.0$ m → $x = 50.0$ m + 25.0 m = 75.0 m
$t = 20.0$ s → $t = 30.0$ s	$x = 75.0$ m → $x = 75.0$ m + 12.5 m = 87.5 m
$t = 30.0$ s → $t = 40.0$ s	$x = 87.5$ m → $x = 87.5$ m + 6.25 m = 93.8 m

This data can be used to construct the position-time graph. Since the runner has a constant velocity during each ten-second segment, we can find the velocity during each segment from the slope of the position-time graph for that segment.

SOLUTION

a. The following figure shows the position-time graph for the first forty seconds.



b. The slope of each segment of the position-time graph is calculated as follows:

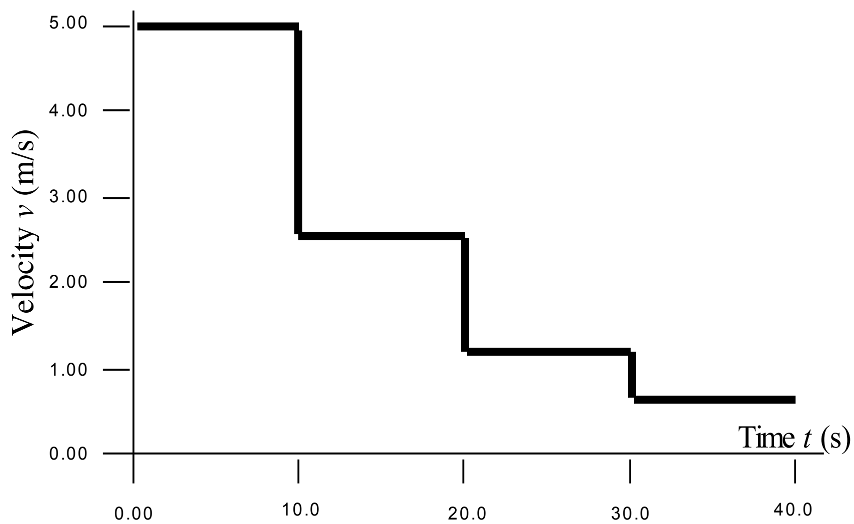
$[0.00 \text{ s to } 10.0 \text{ s}] \qquad v = \dfrac{\Delta x}{\Delta t} = \dfrac{50.0 \text{ m} - 0.00 \text{ m}}{10.0 \text{ s} - 0 \text{ s}} = 5.00 \text{ m/s}$

$[10.0 \text{ s to } 20.0 \text{ s}] \qquad v = \dfrac{\Delta x}{\Delta t} = \dfrac{75.0 \text{ m} - 50.0 \text{ m}}{20.0 \text{ s} - 10.0 \text{ s}} = 2.50 \text{ m/s}$

$[20.0 \text{ s to } 30.0 \text{ s}] \qquad v = \dfrac{\Delta x}{\Delta t} = \dfrac{87.5 \text{ m} - 75.0 \text{ m}}{30.0 \text{ s} - 20.0 \text{ s}} = 1.25 \text{ m/s}$

$[30.0 \text{ s to } 40.0 \text{ s}] \qquad v = \dfrac{\Delta x}{\Delta t} = \dfrac{93.8 \text{ m} - 87.5 \text{ m}}{40.0 \text{ s} - 30.0 \text{ s}} = 0.625 \text{ m/s}$

Therefore, the velocity-time graph is:



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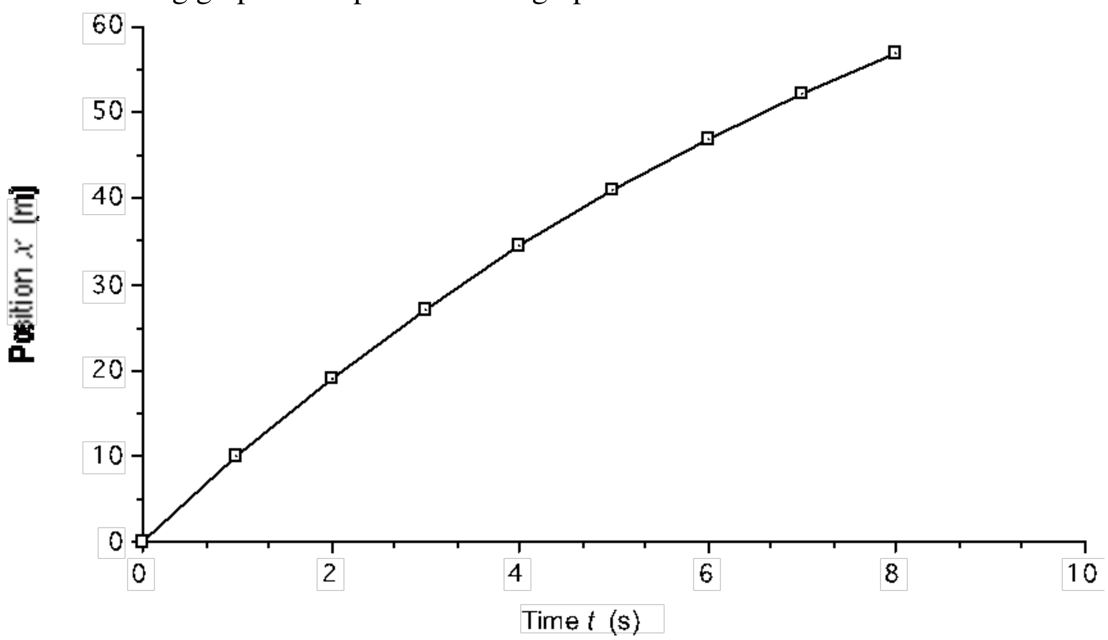
71. SSM ***REASONING*** The two runners start one hundred meters apart and run toward each other. Each runs ten meters during the first second and, during each second thereafter, each runner runs ninety percent of the distance he ran in the previous second. While the velocity of each runner changes from second to second, it remains constant during any one second.

SOLUTION The following table shows the distance covered during each second for one of the runners, and the position at the end of each second (assuming that he begins at the origin) for the first eight seconds.

Time t (s)	Distance covered (m)	Position x (m)

0.00		0.00
1.00	10.00	10.00
2.00	9.00	19.00
3.00	8.10	27.10
4.00	7.29	34.39
5.00	6.56	40.95
6.00	5.90	46.85
7.00	5.31	52.16
8.00	4.78	56.94

The following graph is the position-time graph constructed from the data in the table above.



a. Since the two runners are running toward each other in exactly the same way, they will meet halfway between their respective starting points. That is, they will meet at $x = 50.0$ m. According to the graph, therefore, this position corresponds to a time of $\boxed{6.6 \text{ s}}$.

b. Since the runners collide during the seventh second, the speed at the instant of collision can be found by taking the slope of the position-time graph for the seventh second. The speed of either runner in the interval from $t = 6.00$ s to $t = 7.00$ s is

$$v = \frac{\Delta x}{\Delta t} = \frac{52.16 \text{ m} - 46.85 \text{ m}}{7.00 \text{ s} - 6.00 \text{ s}} = 5.3 \text{ m/s}$$

Therefore, at the moment of collision, the speed of either runner is $\boxed{5.3 \text{ m/s}}$.

72. ***REASONING*** The average acceleration $(\bar{a})$ is defined by Equation 2.4 $\left(\bar{a}=\dfrac{v-v_0}{t-t_0}\right)$ as the change in velocity $(v-v_0)$ divided by the elapsed time $(t-t_0)$. The change in velocity is equal to the final velocity minus the initial velocity. Therefore, the change in velocity, and hence the acceleration, is positive if the final velocity is greater than the initial velocity. The acceleration is negative if the final velocity is less than the initial velocity. (a) The final velocity is greater than the initial velocity, so the acceleration will be positive. (b) The final velocity is less than the initial velocity, so the acceleration will be negative. (c) The final velocity is greater than the initial velocity (–3.0 m/s is greater than –6.0 m/s), so the acceleration will be positive. (d) The final velocity is less than the initial velocity, so the acceleration will be negative.

SOLUTION Equation 2.4 gives the average acceleration as

$$\bar{a}=\frac{v-v_0}{t-t_0}$$

Therefore, the average accelerations for the four cases are:

(a) $\bar{a}$ = (5.0 m/s – 2.0 m/s)/(2.0 s) = $\boxed{+1.5\ \text{m/s}^2}$

(b) $\bar{a}$ = (2.0 m/s – 5.0 m/s)/(2.0 s) = $\boxed{-1.5\ \text{m/s}^2}$

(c) $\bar{a}$ = [–3.0 m/s – (–6.0 m/s)]/(2.0 s) = $\boxed{+1.5\ \text{m/s}^2}$

(d) $\bar{a}$ = (–4.0 m/s – 4.0 m/s)/(2.0 s) = $\boxed{-4.0\ \text{m/s}^2}$

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73. **SSM** ***REASONING AND SOLUTION***

a. Once the pebble has left the slingshot, it is subject only to the acceleration due to gravity. Since the downward direction is negative, the acceleration of the pebble is $\boxed{-9.80\ \text{m/s}^2}$. The pebble is not decelerating. Since its velocity and acceleration both point downward, the magnitude of the pebble's velocity is increasing, not decreasing.

b. The displacement *y* traveled by the pebble as a function of the time *t* can be found from Equation 2.8. Using Equation 2.8, we have

$$y=v_0t+\tfrac{1}{2}a_yt^2=(-9.0\ \text{m/s})(0.50\ \text{s})+\tfrac{1}{2}\left[(-9.80\ \text{m/s}^2)(0.50\ \text{s})^2\right]=-5.7\ \text{m}$$

Thus, after 0.50 s, the pebble is $\boxed{5.7\ \text{m}}$ beneath the cliff-top.

---

74. ***REASONING*** In a race against el-Guerrouj, Bannister would run a distance given by his average speed times the time duration of the race (see Equation 2.1). The time duration of the race would be el-Guerrouj's winning time of 3:43.13 (223.13 s). The difference between Bannister's distance and the length of the race is el-Guerrouj's winning margin.

SOLUTION From the table of conversion factors on the page facing the front cover, we find that one mile corresponds to 1609 m. According to Equation 2.1, Bannister's average speed is

$$\text{Average speed} = \frac{\text{Distance}}{\text{Elapsed time}} = \frac{1609 \text{ m}}{239.4 \text{ s}}$$

Had he run against el-Guerrouj at this average speed for the 223.13-s duration of the race, he would have traveled a distance of

$$\text{Distance} = \text{Average speed} \times \text{Time} = \left(\frac{1609 \text{ m}}{239.4 \text{ s}}\right)(223.13 \text{ s})$$

while el-Guerrouj traveled 1609 m. Thus, el-Guerrouj would have won by a distance of

$$1609 \text{ m} - \left(\frac{1609 \text{ m}}{239.4 \text{ s}}\right)(223.13 \text{ s}) = \boxed{109 \text{ m}}$$

---

75. SSM ***REASONING*** Since the belt is moving with constant velocity, the displacement ($x_0 =$ 0 m) covered by the belt in a time t_{belt} is giving by Equation 2.2 (with x_0 assumed to be zero) as

$$x = v_{\text{belt}} t_{\text{belt}} \tag{1}$$

Since Clifford moves with constant acceleration, the displacement covered by Clifford in a time t_{Cliff} is, from Equation 2.8,

$$x = v_0 t_{\text{Cliff}} + \tfrac{1}{2} a t_{\text{Cliff}}^2 = \tfrac{1}{2} a t_{\text{Cliff}}^2 \tag{2}$$

The speed v_{belt} with which the belt of the ramp is moving can be found by eliminating x between Equations (1) and (2).

SOLUTION Equating the right hand sides of Equations (1) and (2), and noting that $t_{\text{Cliff}} = \tfrac{1}{4} t_{\text{belt}}$, we have

$$v_{\text{belt}} t_{\text{belt}} = \tfrac{1}{2} a \left(\tfrac{1}{4} t_{\text{belt}}\right)^2$$

$$v_{\text{belt}} = \tfrac{1}{32}a\,t_{\text{belt}} = \tfrac{1}{32}(0.37\text{ m/s}^2)(64\text{ s}) = \boxed{0.74\text{ m/s}}$$

---

76. ***REASONING*** The minimum time that a player must wait before touching the basketball is the time required for the ball to reach its maximum height. The initial and final velocities are known, as well as the acceleration due to gravity, so Equation 2.4 ($v = v_0 + at$) can be used to find the time.

SOLUTION Solving Equation 2.4 for the time yields

$$t = \frac{v - v_0}{a} = \frac{0\text{ m/s} - 4.6\text{ m/s}}{-9.8\text{ m/s}^2} = \boxed{0.47\text{ s}}$$

---

77. ***REASONING*** Average speed is the ratio of distance to elapsed time (Equation 2.1), so the elapsed time is distance divided by average speed. Both the average speed and the distance are given in SI base units, so the elapsed time will come out in seconds, which can then be converted to minutes (1 min = 60 s).

SOLUTION First, calculate the elapsed time Δt in seconds:

$$\Delta t = \frac{\text{Distance}}{\text{Average speed}} = \frac{1.5\text{ m}}{1.1\times10^{-2}\text{ m/s}} = 140\text{ s} \qquad (2.1)$$

Converting the elapsed time from seconds to minutes, we find that

$$\Delta t = (140\ \not{s})\left(\frac{1\text{ min}}{60\ \not{s}}\right) = \boxed{2.3\text{ min}}$$

---

78. ***REASONING*** The average acceleration is defined by Equation 2.4 as the change in velocity divided by the elapsed time. We can find the elapsed time from this relation because the acceleration and the change in velocity are given. Since the acceleration of the spacecraft is constant, it is equal to the average acceleration.

SOLUTION

a. The time Δt that it takes for the spacecraft to change its velocity by an amount $\Delta v = +2700$ m/s is

$$\Delta t = \frac{\Delta v}{a} = \frac{+2700\text{ m/s}}{+9.0\ \frac{\text{m/s}}{\text{day}}} = \boxed{3.0\times10^2\text{ days}}$$

b. Since 24 hr = 1 day and 3600 s = 1 hr, the acceleration of the spacecraft (in m/s^2) is

$$a = \frac{\Delta v}{t} = \frac{+9.0 \text{ m/s}}{(1 \text{ day})\left(\frac{24 \text{ hr}}{1 \text{ day}}\right)\left(\frac{3600 \text{ s}}{1 \text{ hr}}\right)} = \boxed{+1.04\times 10^{-4} \text{ m/s}^2}$$

---

79. ***REASONING*** The cheetah and its prey run the same distance. The prey runs at a constant velocity, so that its distance is the magnitude of its displacement, which is given by Equation 2.2 as the product of velocity and time. The distance for the cheetah can be expressed using Equation 2.8, since the cheetah's initial velocity (zero, since it starts from rest) and the time are given, and we wish to determine the acceleration. The two expressions for the distance can be equated and solved for the acceleration.

SOLUTION We begin by using Equation 2.2 and assuming that the initial position of the prey is $x_0 = 0$ m. The distance run by the prey is

$$\Delta x = x - x_0 = x = v_{\text{Prey}} t$$

The distance run by the cheetah is given by Equation 2.8 as

$$x = v_{0,\text{ Cheetah}} t + \tfrac{1}{2} a_{\text{Cheetah}} t^2$$

Equating the two expressions for x and using the fact that $v_{0,\text{ Cheetah}} = 0$ m/s, we find that

$$v_{\text{Prey}} t = \tfrac{1}{2} a_{\text{Cheetah}} t^2$$

Solving for the acceleration gives

$$a_{\text{Cheetah}} = \frac{2v_{\text{Prey}}}{t} = \frac{2(+9.0 \text{ m/s})}{3.0 \text{ s}} = \boxed{+6.0 \text{ m/s}^2}$$

---

80. ***REASONING AND SOLUTION*** The distance covered by the cab driver during the two phases of the trip must satisfy the relation

$$x_1 + x_2 = 2.00 \text{ km} \tag{1}$$

where x_1 and x_2 are the displacements of the acceleration and deceleration phases of the trip, respectively. The quantities x_1 and x_2 can be calculated from Equation 2.9 $\left(v^2 = v_0^2 + 2ax\right)$:

$$x_1 = \frac{v_1^2 - (0\text{ m/s})^2}{2a_1} = \frac{v_1^2}{2a_1} \quad \text{and} \quad x_2 = \frac{(0\text{ m/s})^2 - v_{02}^2}{2a_2} = -\frac{v_{02}^2}{2a_2}$$

with $v_{02} = v_1$ and $a_2 = -3a_1$. Thus,

$$\frac{x_1}{x_2} = \frac{v_1^2/(2a_1)}{-v_1^2/(-6a_1)} = 3$$

so that

$$x_1 = 3x_2 \qquad (2)$$

Combining (1) and (2), we have,

$$3x_2 + x_2 = 2.00\text{ km}$$

Therefore, $x_2 = 0.50\text{ km}$, and from Equation (1), $x_1 = 1.50\text{ km}$. Thus, the length of the acceleration phase of the trip is $x_1 = \boxed{1.50\text{ km}}$, while the length of the deceleration phase is $x_2 = \boxed{0.50\text{ km}}$.

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81. SSM ***REASONING*** Since the woman runs for a known distance at a known constant speed, we can find the time it takes for her to reach the water from Equation 2.1. We can then use Equation 2.1 to determine the total distance traveled by the dog in this time.

SOLUTION The time required for the woman to reach the water is

$$\text{Elapsed time} = \frac{d_\text{woman}}{v_\text{woman}} = \left(\frac{4.0\text{ km}}{2.5\text{ m/s}}\right)\left(\frac{1000\text{ m}}{1.0\text{ km}}\right) = 1600\text{ s}$$

In 1600 s, the dog travels a total distance of

$$d_\text{dog} = v_\text{dog}t = (4.5\text{ m/s})(1600\text{ s}) = \boxed{7.2\times10^3\text{ m}}$$

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82. ***REASONING*** When the second-place cyclist catches the leader, the displacement x_2nd of the second-place cyclist is 10.0 m greater than the displacement x_leader of the leader, so $x_\text{2nd} = x_\text{leader} + 10.0$ m. The initial velocity and acceleration of the second-place cyclist are known ($v_0 = +9.50$ m/s, $a = +1.20$ m/s^2), as well as those of the leader ($v_0 = +11.10$ m/s, $a = 0.00$ m/s^2). Note that the leader has zero acceleration, since his velocity is constant.

Equation 2.8 may be used to provide a relationship between these variables and the displacement x.

SOLUTION Substituting Equation 2.8 into each side of the relation $x_{2nd} = x_{leader} + 10.0$ m, we have that

$$\underbrace{v_0 t + \tfrac{1}{2} a t^2}_{x_{2nd}} = \underbrace{v_0 t + \tfrac{1}{2} a t^2}_{x_{leader}} + 10.0 \text{ m}$$

$$(9.50 \text{ m/s})t + \tfrac{1}{2}(1.20 \text{ m/s}^2)t^2 = (11.10 \text{ m/s})t + \tfrac{1}{2}(0.00 \text{ m/s}^2)t^2 + 10.0 \text{ m}$$

Rearranging the terms of this equation so it is in quadratic form, we have

$$\tfrac{1}{2}(1.20 \text{ m/s}^2)t^2 - (1.60 \text{ m/s})t - 10.0 \text{ m} = 0$$

This equation can be solved using the quadratic formula, with the result that $t = \boxed{5.63 \text{ s}}$.

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83. ***REASONING*** The time t_{trip} to make the entire trip is equal to the time t_{cart} that the golfer rides in the golf cart plus the time t_{walk} that she walks; $t_{trip} = t_{cart} + t_{walk}$. Therefore, the time that she walks is

$$t_{walk} = t_{trip} - t_{cart} \qquad (1)$$

The average speed $\bar{v}_{trip}$ for the entire trip is equal to the total distance, $x_{cart} + x_{walk}$, she travels divided by the time to make the entire trip (see Equation 2.1);

$$\bar{v}_{trip} = \frac{x_{cart} + x_{walk}}{t_{trip}}$$

Solving this equation for t_{trip} and substituting the resulting expression into Equation 1 yields

$$t_{walk} = \frac{x_{cart} + x_{walk}}{\bar{v}_{trip}} - t_{cart} \qquad (2)$$

The distance traveled by the cart is $x_{cart} = \bar{v}_{cart} t_{cart}$, and the distance walked by the golfer is $x_{walk} = \bar{v}_{walk} t_{walk}$. Substituting these expressions for x_{cart} and x_{walk} into Equation 2 gives

$$t_{walk} = \frac{\bar{v}_{cart} t_{cart} + \bar{v}_{walk} t_{walk}}{\bar{v}_{trip}} - t_{cart}$$

The unknown variable t_{walk} appears on both sides of this equation. Algebraically solving for this variable gives

$$t_{\text{walk}} = \frac{\bar{v}_{\text{cart}} t_{\text{cart}} - \bar{v}_{\text{trip}} t_{\text{cart}}}{\bar{v}_{\text{trip}} - \bar{v}_{\text{walk}}}$$

SOLUTION The time that the golfer spends walking is

$$t_{\text{walk}} = \frac{\bar{v}_{\text{cart}} t_{\text{cart}} - \bar{v}_{\text{trip}} t_{\text{cart}}}{\bar{v}_{\text{trip}} - \bar{v}_{\text{walk}}} = \frac{(3.10 \text{ m/s})(28.0 \text{ s}) - (1.80 \text{ m/s})(28.0 \text{ s})}{(1.80 \text{ m/s}) - (1.30 \text{ m/s})} = \boxed{73 \text{ s}}$$

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84. ***REASONING*** The definition of average velocity is given by Equation 2.2 as the displacement divided by the elapsed time. When the velocity is constant, as it is for car A, the average velocity is the same as the constant velocity. We note that, since both displacement and time are the same for each car, this equation gives the same value for car B's average velocity and car A's constant velocity.

Since the acceleration of car B is constant, we know that its average velocity is given by Equation 2.6 as $\bar{v}_B = \frac{1}{2}(v_B + v_{B0})$, where v_B is the final velocity and $v_{B0} = 0$ m/s is the initial velocity (car B starts from rest). Thus, we can use Equation 2.6 to find the final velocity.

Car B's constant acceleration can be calculated from Equation 2.4 ($v_B = v_{B0} + a_B t$), which is one of the equations of kinematics and gives the acceleration as $[a_B = (v_B - v_{B0})/t]$. Since car B starts from rest, we know that $v_{B0} = 0$ m/s. Furthermore, t is given. Therefore, calculation of the acceleration a_B requires that we use the value calculated for the final velocity v_B.

SOLUTION

a. According to Equation 2.2, the velocity of car A is the displacement L divided by the time t. Thus, we obtain

$$v_A = \frac{L}{t} = \frac{460 \text{ m}}{210 \text{ s}} = \boxed{2.2 \text{ m/s}}$$

b. The average velocity of car B is given by Equation 2.6 as $\bar{v}_B = \frac{1}{2}(v_B + v_{B0})$, where v_B is the final velocity and v_{B0} is the initial velocity. Solving for the final velocity and using the fact that car B starts from rest ($v_{B0} = 0$ m/s) gives

$$v_B = 2\bar{v}_B - v_{B0} = 2\bar{v}_B \qquad (1)$$

As discussed in the ***REASONING***, the average velocity of car B is equal to the constant velocity of car A. Substituting this result into Equation (1), we find that

$$v_B = 2\bar{v}_B = 2v_A = 2(2.2 \text{ m/s}) = \boxed{4.4 \text{ m/s}}$$

c. Solving Equation 2.4 ($v_B = v_{B0} + a_B t$) for the acceleration shows that

$$a_B = \frac{v_B - v_{B0}}{t} = \frac{4.4 \text{ m/s} - 0 \text{ m/s}}{210 \text{ s}} = \boxed{0.021 \text{ m/s}^2}$$

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85. ***REASONING*** We choose due north as the positive direction. Our solution is based on the fact that when the police car catches up, both cars will have the same displacement, relative to the point where the speeder passed the police car. The displacement of the speeder can be obtained from the definition of average velocity given in Equation 2.2, since the speeder is moving at a constant velocity. During the 0.800-s reaction time of the policeman, the police car is also moving at a constant velocity. Once the police car begins to accelerate, its displacement can be expressed as in Equation 2.8 $\left(x = v_0 t + \frac{1}{2}at^2\right)$, because the initial velocity v_0 and the acceleration a are known and it is the time t that we seek. We will set the displacements of the speeder and the police car equal and solve the resulting equation for the time t.

SOLUTION Let t equal the time during the accelerated motion of the police car. Relative to the point where he passed the police car, the speeder then travels a time of t + 0.800 s before the police car catches up. During this time, according to the definition of average velocity given in Equation 2.2, his displacement is

$$x_{\text{Speeder}} = v_{\text{Speeder}}(t + 0.800 \text{ s}) = (42.0 \text{ m/s})(t + 0.800 \text{ s})$$

The displacement of the police car consists of two contributions, the part due to the constant-velocity motion during the reaction time and the part due to the accelerated motion. Using Equation 2.2 for the contribution from the constant-velocity motion and Equation 2.9 for the contribution from the accelerated motion, we obtain

$$x_{\text{Police car}} = \underbrace{v_{0,\text{ Police car}}(0.800 \text{ s})}_{\substack{\text{Constant velocity motion,} \\ \text{Equation 2.2}}} + \underbrace{v_{0,\text{ Police car}}t + \tfrac{1}{2}at^2}_{\substack{\text{Accelerated motion,} \\ \text{Equation 2.8}}}$$

$$= (18.0 \text{ m/s})(0.800 \text{ s}) + (18.0 \text{ m/s})t + \tfrac{1}{2}(5.00 \text{ m/s}^2)t^2$$

Setting the two displacements equal we obtain

$$\underbrace{(42.0 \text{ m/s})(t + 0.800 \text{ s})}_{\text{Displacement of speeder}} = \underbrace{(18.0 \text{ m/s})(0.800 \text{ s}) + (18.0 \text{ m/s})t + \tfrac{1}{2}(5.00 \text{ m/s}^2)t^2}_{\text{Displacement of police car}}$$

Rearranging and combining terms gives this result in the standard form of a quadratic equation:

$$\left(2.50\text{ m/s}^2\right)t^2-(24.0\text{ m/s})t-19.2\text{ m}=0$$

Solving for t shows that

$$t=\frac{-(-24.0\text{ m/s})\pm\sqrt{(-24.0\text{ m/s})^2-4\left(2.50\text{ m/s}^2\right)(-19.2\text{ m})}}{2\left(2.50\text{ m/s}^2\right)}=10.3\text{ s}$$

We have ignored the negative root, because it leads to a negative value for the time, which is unphysical. The total time for the police car to catch up, including the reaction time, is

$$0.800\text{ s}+10.3\text{ s}=\boxed{11.1\text{ s}}$$

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86. ***REASONING AND SOLUTION*** We measure the positions of the balloon and the pellet relative to the ground and assume up to be positive. The balloon has no acceleration, since it travels at a constant velocity v_B, so its displacement in time t is v_Bt. Its position above the ground, therefore, is

$$y_B=H_0+v_Bt$$

where H_0 = 12 m. The pellet moves under the influence of gravity (a = –9.80 m/s^2), so its position above the ground is given by Equation 2.8 as

$$y_P=v_0t+\tfrac{1}{2}at^2$$

But $y_P=y_B$ at time t, so that

$$v_0t+\tfrac{1}{2}at^2=H_0+v_Bt$$

Rearranging this result and suppressing the units gives

$$\tfrac{1}{2}at^2+\left(v_0-v_B\right)t-H_0=\tfrac{1}{2}(-9.80)t^2+(30.0-7.0)t-12.0=0$$

$$4.90t^2-23.0t+12.0=0$$

$$t=\frac{23.0\pm\sqrt{23.0^2-4(4.90)(12.0)}}{2(4.90)}=4.09\text{ s}\quad\text{or}\quad 0.602\text{ s}$$

Substituting each of these values in the expression for y_B gives

$$y_B = 12.0 \text{ m} + (7.0 \text{ m/s})(4.09 \text{ s}) = \boxed{41 \text{ m}}$$

$$y_B = 12.0 \text{ m} + (7.0 \text{ m/s})(0.602 \text{ s}) = \boxed{16 \text{ m}}$$

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87. SSM ***REASONING*** Since 1 mile = 1609 m, a quarter-mile race is $L = 402$ m long. If a car crosses the finish line before reaching its maximum speed, then there is only one interval of constant acceleration to consider. We will first determine whether this is true by calculating the car's displacement x_1 while accelerating from rest to top speed from Equation 2.9 $\left(v^2 = v_0^2 + 2ax\right)$, with $v_0 = 0$ m/s and $v = v_{\text{max}}$:

$$v_{\text{max}}^2 = (0 \text{ m/s})^2 + 2ax_1 \quad \text{or} \quad x_1 = \frac{v_{\text{max}}^2}{2a} \tag{1}$$

If $x_1 > L$, then the car crosses the finish line before reaching top speed, and the total time for its race is found from Equation 2.8 $\left(x = v_0 t + \frac{1}{2}at^2\right)$, with $x = L$ and $v_0 = 0$ m/s:

$$L = (0 \text{ m/s})t + \tfrac{1}{2}at^2 = \tfrac{1}{2}at^2 \quad \text{or} \quad t = \sqrt{\frac{2L}{a}} \tag{2}$$

On the other hand, if a car reaches its maximum speed before crossing the finish line, the race divides into two intervals, each with a different constant acceleration. The displacement x_1 is found as given in Equation (1), but the time t_1 to reach the maximum speed is most easily found from Equation 2.4 $(v = v_0 + at)$, with $v_0 = 0$ m/s and $v = v_{\text{max}}$:

$$v_{\text{max}} = 0 \text{ m/s} + at_1 \quad \text{or} \quad t_1 = \frac{v_{\text{max}}}{a} \tag{3}$$

The time t_2 that elapses during the rest of the race is found by solving Equation 2.8 $\left(x = v_0 t + \frac{1}{2}at^2\right)$. Let $x_2 = L - x_1$ represent the displacement for this part of the race. With the aid of Equation (1), this becomes $x_2 = L - \dfrac{v_{\text{max}}^2}{2a}$. Then, since the car is at its maximum speed, the acceleration is $a = 0$ m/s^2, and the displacement is

$$x_2 = v_{\text{max}} t_2 + \tfrac{1}{2}\left(0 \text{ m/s}^2\right)t_2^2 = v_{\text{max}} t_2 \quad \text{or} \quad t_2 = \frac{x_2}{v_{\text{max}}} = \frac{L - \dfrac{v_{\text{max}}^2}{2a}}{v_{\text{max}}} = \frac{L}{v_{\text{max}}} - \frac{v_{\text{max}}}{2a} \tag{4}$$

Using this expression for t_2 and Equation (3) for t_1 gives the total time for a two-part race:

$$t = t_1 + t_2 = \frac{v_{\max}}{a} + \left(\frac{L}{v_{\max}} - \frac{v_{\max}}{2a} \right) = \frac{L}{v_{\max}} + \frac{v_{\max}}{2a} \qquad (5)$$

SOLUTION First, we use Equation (1) to determine whether either car finishes the race while accelerating:

Car A $$x_1 = \frac{v_{\max}^2}{2a} = \frac{(106 \text{ m/s})^2}{2(11.0 \text{ m/s}^2)} = 511 \text{ m}$$

Car B $$x_1 = \frac{v_{\max}^2}{2a} = \frac{(92.4 \text{ m/s})^2}{2(11.6 \text{ m/s}^2)} = 368 \text{ m}$$

Therefore, car A finishes the race before reaching its maximum speed, but car B has 402 m − 368 m = 34 m to travel at its maximum speed. Equation (2) gives the time for car A to reach the finish line as

Car A $$t = \sqrt{\frac{2L}{a}} = \sqrt{\frac{2(402 \text{ m})}{11.0 \text{ m/s}^2}} = 8.55 \text{ s}$$

Equation (5) gives the time for car B to reach the finish line as

Car B $$t = \frac{L}{v_{\max}} + \frac{v_{\max}}{2a} = \frac{402 \text{ m}}{92.4 \text{ m/s}} + \frac{92.4 \text{ m/s}}{2(11.6 \text{ m/s}^2)} = 8.33 \text{ s}$$

Car B wins the race by 8.55 s − 8.33 s = 0.22 s.

88. ***REASONING AND SOLUTION*** During the first phase of the acceleration,

$$a_1 = \frac{v}{t_1}$$

During the second phase of the acceleration,

$$v = (3.4\text{ m/s}) - (1.1\text{ m/s}^2)(1.2\text{ s}) = 2.1\text{ m/s}$$

Then

$$a_1 = \frac{2.1\text{ m/s}}{1.5\text{ s}} = \boxed{1.4\text{ m/s}^2}$$

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89. SSM ***REASONING*** When the jet is accelerating, its velocity is changing. The displacement of the jet during a given time interval is equal to the product of its average velocity during that interval and the time, the average velocity being equal to one-half the sum of the jet's initial and final velocities (Equation 2.7). The initial and final velocities are known, but the time is not. However, the time can be determined from a knowledge of the jet's acceleration.

SOLUTION The displacement x of the jet is given by Equation 2.7:

$$x = \frac{1}{2}(v_0 + v)t,$$

where the initial (v_0) and final velocities (v) are known. The time t is not given in the problem, but can be written in terms of the acceleration from Equation 2.4:

$$a = \frac{v - v_0}{t}$$

Solving for t yields the following: $t = \dfrac{v - v_0}{a}$. We can now substitute this result into Equation 2.7: $x = \dfrac{1}{2}(v_0 + v)t = \dfrac{1}{2}(v_0 + v)\left(\dfrac{v - v_0}{a}\right) = \dfrac{v^2 - v_0^2}{2a}$.

Using the values given in the problem, we find the displacement of the jet to be:

$$x = \frac{v^2 - v_0^2}{2a} = \frac{(+62\text{ m/s})^2 - (0\text{ m/s})^2}{2(+31\text{ m/s}^2)} = \boxed{+62\text{ m}}$$

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90. ***CONCEPTS*** **(i)** Since her speed is increasing, the acceleration vector must point in the same direction as the velocity vector, which points in the negative *y* direction. Thus the acceleration is <u>negative</u>.

(ii) Since her speed is decreasing, the acceleration vector must point opposite to the velocity vector. Since the velocity vector points in the negative *y* direction, the acceleration vector must point in the positive *y* direction. Thus the acceleration is <u>positive</u>.

CALCULATIONS **(a)** Since the skydiver is moving in the negative *y* direction, her initial velocity is $v_0 = -16$ m/s and her final velocity is $v = -28$ m/s. Her average acceleration $\overline{a}$ is the change in velocity divided by the elapsed time:

$$\overline{a} = \frac{v - v_0}{t} = \frac{-28 \text{ m/s} - (-16 \text{ m/s})}{1.5 \text{ s}} = \boxed{-8.0 \text{ m/s}^2}$$

As expected, her average acceleration is negative. Note that her acceleration is not that due to gravity (-9.8 m/s^2) because of air resistance.

(b) Now the skydiver is slowing down, but still falling along the negative *y* direction. Her initial and final velocities are $v_0 = -48$ m/s and $v = -26$ m/s, respectively. The average acceleration for this phase of the motion is

$$\overline{a} = \frac{v - v_0}{t} = \frac{-26 \text{ m/s} - (-48 \text{ m/s})}{11 \text{ s}} = \boxed{+2.0 \text{ m/s}^2}$$

Now, as anticipated, her average acceleration is positive.

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91. SSM ***CONCEPTS*** **(i)** Because the dragster has an acceleration of 40.0 m/s^2, its velocity changes by 40.0 m/s during each second of the travel. Therefore, *since the dragster starts from rest*, the velocity is 40.0 m/s at the end of the first second, 2×40.0 m/s at the end of the second second, 3×40.0 m/s at the end of the third second, and so on. Thus, <u>when the time doubles, the velocity also doubles</u>. (Be sure to note that this is only true if the initial velocity is equal to zero.)

(ii) The displacement of the dragster is equal to its average velocity multiplied by the elapsed time. The average velocity $\overline{v}$ is just one-half the sum of the initial and final velocities, or $\overline{v} = \frac{1}{2}(v_0 + v)$. Since the initial velocity is zero, $v_0 = 0$ m/s and the average velocity is just one-half the final velocity, or $\overline{v} = \frac{1}{2}v$. However, as we have seen, the final velocity is proportional to the elapsed time, since when the time doubles, the final velocity also doubles. Therefore, the displacement, being the product of the average velocity and the time, is proportional to the time squared, or t^2. Consequently, as the time doubles, the displacement does not double, but <u>increases by a factor of four</u>. (Again, this is the case since the initial velocity is equal to zero.)

CALCULATIONS **(a)** According to Equation 2.4, the final velocity v, the initial velocity v_0, the acceleration a, and the elapsed time t are related by $v = v_0 + at$. The final velocities at the two times are:

$$[t = 2.0\text{ s}] \qquad v = v_0 + at = 0\text{ m/s} + \left(40.0\text{ m/s}^2\right)\left(2.0\text{ s}\right) = \boxed{80\text{ m/s}}$$

$$[t = 4.0\text{ s}] \qquad v = v_0 + at = 0\text{ m/s} + \left(40.0\text{ m/s}^2\right)\left(4.0\text{ s}\right) = \boxed{160\text{ m/s}}$$

We see that the velocity doubles when the time doubles, as expected.

(b) The displacement x is equal to the average velocity multiplied by the time, so

$$x = \underbrace{\tfrac{1}{2}\left(v_0 + v\right)}_{\text{Average velocity}} t = \tfrac{1}{2}vt$$

where we have used the fact that $v_0 = 0$ m/s. According to Equation 2.4, the final velocity is related to the acceleration by $v = v_0 + at$, or $v = at$, since $v_0 = 0$ m/s. Therefore, the displacement can be written as $x = \tfrac{1}{2}vt = \tfrac{1}{2}(at)t = \tfrac{1}{2}at^2$. The displacements at the two times are then

$$[t = 2.0\text{ s}] \qquad x = \tfrac{1}{2}at^2 = \tfrac{1}{2}\left(40.0\text{ m/s}^2\right)\left(2.0\text{ s}\right)^2 = \boxed{80\text{ m}}$$

$$[t = 4.0\text{ s}] \qquad x = \tfrac{1}{2}at^2 = \tfrac{1}{2}\left(40.0\text{ m/s}^2\right)\left(4.0\text{ s}\right)^2 = \boxed{320\text{ m}}$$

As predicted, the displacement at $t = 4.0$ s is four times that at $t = 2.0$ s.
