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

---

6. ***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

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

---

7. ***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

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

---

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

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

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

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

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

---

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:

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

---

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

$$x_e = \frac{-(1-v/v_w)x_w}{(1-v/v_e)} = \frac{-[1-(1.34\text{ m/s})/(2.68\text{ m/s})](6.44\text{ km})}{1-(1.34\text{ m/s})/(0.447\text{ m/s})} = -0.81\text{ km}$$

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

---

11. SSM WWW ***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

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

---

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

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

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

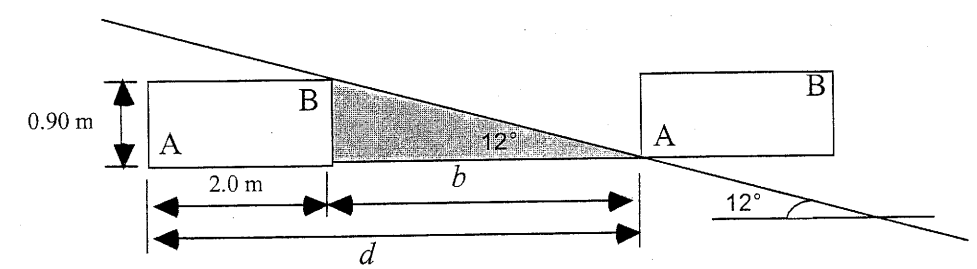
But $\left(\frac{t_{\text{North}}}{t_{\text{North}} + t_{\text{South}}}\right) = \frac{3}{4}$ and $\left(\frac{t_{\text{South}}}{t_{\text{North}} + t_{\text{South}}}\right) = \frac{1}{4}$. Therefore, we have that

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

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

---

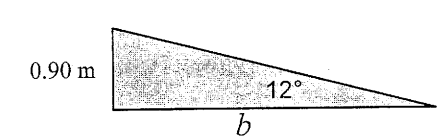
13. ***REASONING AND SOLUTION*** The upper edge of the wall will disappear after the train has traveled the distance d in the figure below.



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,

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

SOLUTION

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

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

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

$$a = \frac{\Delta v}{t} = \frac{+9.0 \text{ m/s}}{(1 \text{ day})\left(\dfrac{24 \text{ hr}}{1 \text{ day}}\right)\left(\dfrac{3600 \text{ s}}{1 \text{ hr}}\right)} = \boxed{+1.04\times10^{-4} \text{ m/s}^2}$$

---

18. ***REASONING*** We can use the definition of average acceleration $\bar{\mathbf{a}} = (\mathbf{v} - \mathbf{v_0})/(t - t_0)$ (Equation 2.4) to find the sprinter's final velocity $\mathbf{v}$ 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 $\bar{\mathbf{a}}$, 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 $\bar{\mathbf{a}} = +2.3$ m/s^2 Her velocity at the end of the 1.2-s period is

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

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

---

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

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

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

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

---

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

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

---

21. **SSM** ***REASONING AND SOLUTION*** The velocity of the automobile for each stage is given by Equation 2.4: $v = v_0 + at$. Therefore,

$$v_1 = v_0 + a_1 t = 0 \text{ m/s} + a_1 t \quad \text{and} \quad v_2 = v_1 + a_2 t$$

Since the magnitude of the car's velocity at the end of stage 2 is 2.5 times greater than it is at the end of stage 1, $v_2 = 2.5v_1$. Thus, rearranging the result for v_2, we find

$$a_2 = \frac{v_2 - v_1}{t} = \frac{2.5v_1 - v_1}{t} = \frac{1.5v_1}{t} = \frac{1.5(a_1 t)}{t} = 1.5a_1 = 1.5(3.0 \text{ m/s}^2) = \boxed{4.5 \text{ m/s}^2}$$

---

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

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

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

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

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

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:

$$x = \tfrac{1}{2}(v_0 + v)t = \tfrac{1}{2}(8.0 \text{ m/s} + 0 \text{ m/s})(5.0 \text{ s}) = \boxed{2.0 \times 10^1 \text{ m}}$$

---

29. SSM WWW ***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.

---

30. ***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

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

---

31. SSM WWW ***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

$$x = v_{\text{belt}} t_{\text{belt}} \qquad (1)$$

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

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

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

34. ***REASONING*** The entering car maintains a constant acceleration of $a_1 = 6.0\ \text{m/s}^2$ 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 $v = v_{01}$:

$$v_{10} = a_1 t_1 \tag{1}$$

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

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

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

$$x = v_{20}t \tag{3}$$

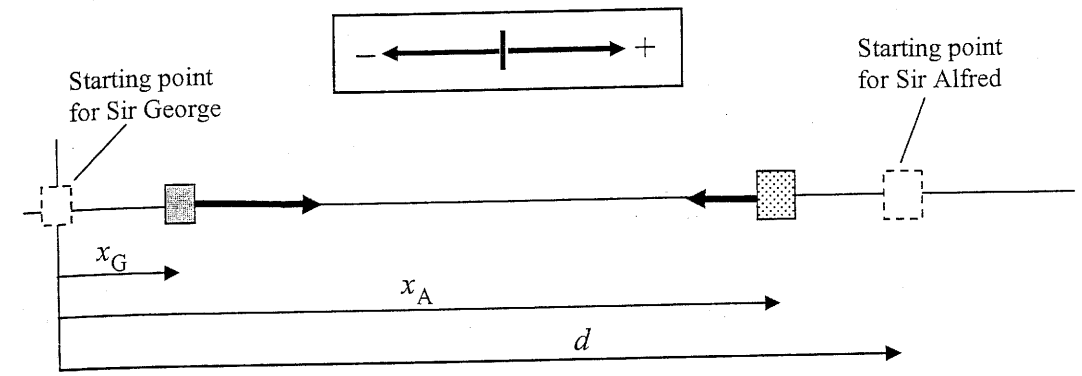
SOLUTION The displacement during the second interval is not required, so equating the right hand sides of Equations (2) and (3) eliminates x, leaving an equation that may be solved for the elapsed time t, which is now the only unknown quantity:

$$\begin{aligned} v_{10}t + \tfrac{1}{2}a_1 t^2 &= v_{20}t \\ v_{10}\cancel{t} + \tfrac{1}{2}a_1 t^{\cancel{2}} &= v_{20}\cancel{t} \\ \tfrac{1}{2}a_1 t &= v_{20} - v_{10} \\ t &= \frac{2\left(v_{20} - v_{10}\right)}{a_1} \end{aligned} \tag{4}$$

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

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

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)

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

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 $x_G = \dfrac{d}{1 - \dfrac{a_A}{a_G}}$.

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:

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

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 $v = v_{max}$:

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

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 $x_2 = L - \frac{v_{max}^2}{2a}$. Then, since the car is at its maximum speed, the acceleration is $a = 0$ m/s^2, and the displacement is

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

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

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

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

$\boxed{\text{Car B wins the race}}$ by 8.55 s - 8.33 s = $\boxed{0.22\text{ s}}$.

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43. $\boxed{\text{SSM}}$ ***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

$$y = v_0 t + \tfrac{1}{2}a_y t^2 = (-9.0\text{ m/s})(0.50\text{ s}) + \tfrac{1}{2}\left[(-9.80\text{ m/s}^2)(0.50\text{ s})^2\right] = -5.7\text{ m}$$

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

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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

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

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

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

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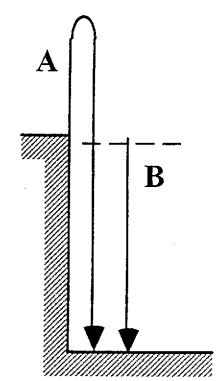
45. ***REASONING AND SOLUTION*** The figure at the right shows the paths taken by the pellets fired from gun **A** and gun **B**. The two paths differ by the extra distance covered by the pellet from gun **A** as it rises and falls back to the edge of the cliff. When it falls back to the edge of the 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.

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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 $\left(y = v_0 t + \frac{1}{2}at^2\right)$ to find the initial velocity v_0 of the ball.

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

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

---

47. ***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 $= 6.0 \times 10^{-2}$ 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, $\boxed{d_3 = 0.16\text{ m}}$.

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48. ***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

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

---

49. **SSM** ***REASONING AND SOLUTION*** Equation 2.8 can be used to determine the displacement that the ball covers as it falls halfway to the ground. Since the ball falls from rest, its initial velocity is zero. Taking down to be the negative direction, we have

$$y = v_0 t + \tfrac{1}{2}at^2 = \tfrac{1}{2}at^2 = \tfrac{1}{2}(-9.80\text{ m/s}^2)(1.2\text{ s})^2 = -7.1\text{ m}$$

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

---

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:

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

Solving for t shows that

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

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

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

---

86. ***REASONING AND SOLUTION*** The balls pass at a time t when both are at a position y above the ground. Applying Equation 2.8 to the ball that is dropped from rest, we have

$$y = 24\text{ m} + v_{01}t + \tfrac{1}{2}at^2 = 24\text{ m} + (0\text{ m/s})t + \tfrac{1}{2}at^2 \qquad (1)$$

Note that we have taken into account the fact that $y = 24$ m when $t = 0$ s in Equation (1). For the second ball that is thrown straight upward,

$$y = v_{02}t + \tfrac{1}{2}at^2 \qquad (2)$$

Equating Equations (1) and (2) for y yields

$$24\text{ m} + \tfrac{1}{2}at^2 = v_{02}t + \tfrac{1}{2}at^2 \qquad \text{or} \qquad 24\text{ m} = v_{02}t$$

Thus, the two balls pass at a time t, where

$$t = \frac{24\text{ m}}{v_{02}}$$

The initial speed v_{02} of the second ball is exactly the same as that with which the first ball hits the ground. To find the speed with which the first ball hits the ground, we take upward as the positive direction and use Equation 2.9 $\left(v^2 = v_0^2 + 2ay\right)$. Since the first ball is dropped from rest, we find that

$$v_{02} = v = \sqrt{2ay} = \sqrt{2(-9.80\text{ m/s}^2)(-24\text{ m})} = 21.7\text{ m/s}$$

Thus, the balls pass after a time

$$t = \frac{24\text{ m}}{21.7\text{ m/s}} = 1.11\text{ s}$$

At a time $t = 1.11$ s, the position of the first ball according to Equation (1) is

$$y = 24\text{ m} + \tfrac{1}{2}(-9.80\text{ m/s}^2)(1.11\text{ s})^2 = 24\text{ m} - 6.0\text{ m}$$

which is $\boxed{\text{6.0 m below the top of the cliff}}$.

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87. SSM ***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: $x_{car} = v_{car}t$. 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:

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

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

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

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

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

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

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

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

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

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

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

---

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

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