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 \( v^2 = v_0^2 + 2ax \), with \( v_0 = 0 \) m/s, the displacement is proportional to the square of the velocity.

13. (d) According to one of the equation of kinematics \( x = v_0t + \frac{1}{2}at^2 \), with \( v_0 = 0 \) m/s, 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 \( v = v_0 + at \) gives the answer directly, since the initial velocity, the final velocity, and the time are known.

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

17. (e) An equation of kinematics \( v^2 = v_0^2 + 2ax \) 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/s² 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 \( v^2 = v_0^2 + 2ax \), with \( v = 0 \) m/s, the launch speed \( v_0 \) is proportional to the square root of the maximum height.

21. (a) An equation of kinematics \( v = v_0 + at \) 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.
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 = **28 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

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

(2.1)

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

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

\[ = \frac{10.0 \times 10^3 \text{ m}}{4.27 \text{ m/s}} - \frac{10.0 \times 10^3 \text{ m}}{4.39 \text{ m/s}} = 64 \text{ s} \]

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

\[
\text{Displacement} = (27 \text{ m/s})t_{\text{North}} + (-17 \text{ m/s})t_{\text{South}}
\]

where \( t_{\text{North}} \) and \( t_{\text{South}} \) 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

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

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

---

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

\[
v_{0A} - v_{0B} = (4.0 \text{ m/s}^2 - 2.0 \text{ m/s}^2)(4 \text{ s}) = +8.0 \text{ m/s}
\]
The positive result indicates that motorcycle A was initially traveling faster.

27. **REASONING** We know the initial and final velocities of the blood, as well as its displacement. Therefore, Equation 2.9 \((v^2 - v_0^2 + 2ax)\) can be used to find the acceleration of the blood. The time it takes for the blood to reach its final velocity can be found by using Equation 2.7

\[
0 = \frac{x}{\frac{1}{2}(v_0 + v)}
\]

**SOLUTION**

a. The acceleration of the blood is

\[
a = \frac{v^2 - v_0^2}{2x} = \frac{(26 \text{ cm/s})^2 - (0 \text{ cm/s})^2}{2(2.0 \text{ cm})} = 1.7 \times 10^2 \text{ cm/s}^2
\]

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

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

28. **REASONING AND SOLUTION**

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

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

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

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

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

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

51. **REASONING AND SOLUTION**

a. \[ v^2 = v_0^2 + 2ay \]

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

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

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

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

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

52. **REASONING** Equation 2.9 \((v^2 = v_0^2 + 2ay)\) 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

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

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

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

Substituting Equation (2) into Equation (1) gives
\[ y_{\text{max}} = \frac{-v_0^2}{2a} = \frac{-2a(4.00 \text{ m})}{2a} = 5.33 \text{ m} \]

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 \( y = v_0 t + \frac{1}{2} at^2 \), 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

\[
\begin{align*}
\text{Upward moving stone:} & \quad y_{\text{up}} = v_{\text{up}}^0 t + \frac{1}{2} at^2 \\
\text{Downward moving stone:} & \quad y_{\text{down}} = v_{\text{down}}^0 t + \frac{1}{2} at^2
\end{align*}
\]

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 \( y_{\text{up}} \) is the displacement of the upward moving stone above the base of the cliff, \( y_{\text{down}} \) 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 \( y_{\text{down}} \) points in the negative direction. Substituting the two expressions for \( y_{\text{up}} \) and \( y_{\text{down}} \) into this equation gives
This equation can be solved for $t$ to show that the travel time to the crossing point is

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

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

$$y_{\text{up}} = v_{\text{up}}^2 t + \frac{1}{2} at^2 = v_{\text{up}} 0 \left( \frac{H}{v_{\text{up}} - v_{\text{down}}} \right) + \frac{1}{2} a \left( \frac{H}{v_{\text{up}} - v_{\text{down}}} \right)^2$$

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

$$= 2.46 \text{ m}$$

Thus, the crossing is located a distance of 2.46 m above the base of the cliff, which is below the halfway point of 3.00 m, as expected.

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

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

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

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

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

\[
\begin{align*}
  v_A &= \frac{10.0 \text{ km} - 40.0 \text{ km}}{1.5 \text{ h} - 0.0 \text{ h}} = -2.0 \times 10^1 \text{ km/h} \\
  v_B &= \frac{20.0 \text{ km} - 10.0 \text{ km}}{2.5 \text{ h} - 1.5 \text{ h}} = 1.0 \times 10^1 \text{ km/h} \\
  v_C &= \frac{40.0 \text{ km} - 20.0 \text{ km}}{3.0 \text{ h} - 2.5 \text{ h}} = 40 \text{ km/h}
\end{align*}
\]

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 $-9.80 \text{ m/s}^2$. 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

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

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

\[ a_1 = \frac{2.1 \text{ m/s}}{1.5 \text{ s}} = \frac{1.4 \text{ m/s}^2}{1.5 \text{ s}} \]