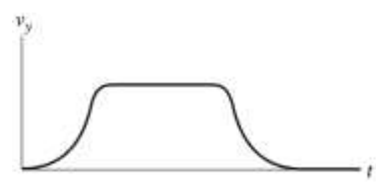
2

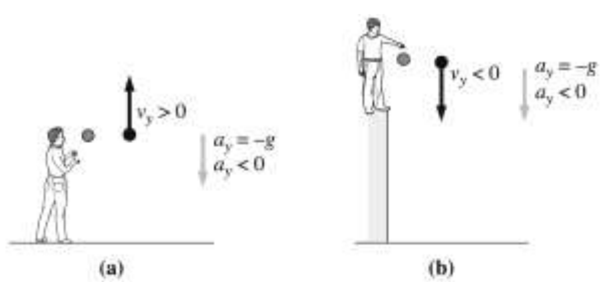
MOTION IN ONE DIMENSION

Q2.1. Reason: The elevator must speed up from rest to cruising velocity. In the middle will be a period of constant velocity, and at the end a period of slowing to a rest.
The graph must match this description. The value of the velocity is zero at the beginning, then it increases, then, during the time interval when the velocity is constant, the graph will be a horizontal line. Near the end the graph will decrease and end at zero.



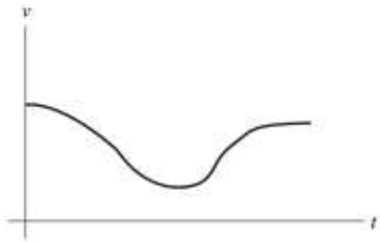
Assess: After drawing velocity-versus-time graphs (as well as others), stop and think if it matches the physical situation, especially by checking end points, maximum values, places where the slope is zero, etc. This one passes those tests.

Q2.2. Reason: (a) The sign conventions for velocity are in Figure 2.7. The sign conventions for acceleration are in Figure 2.27. Positive velocity in vertical motion means an object is moving upward. Negative acceleration means the acceleration of the object is downward. Therefore the upward velocity of the object is decreasing. An example would be a ball thrown upward, before it starts to fall back down. Since it's moving upward, its velocity is positive. Since gravity is acting on it and the acceleration due to gravity is always downward, its acceleration is negative.
(b) To have a negative vertical velocity means that an object is moving downward. The acceleration due to gravity is always downward, so it is always negative. An example of a motion where both velocity and acceleration are negative would be a ball dropped from a height during its downward motion. Since the acceleration is in the same direction as the velocity, the velocity is increasing.



Assess: For vertical displacement, the convention is that upward is positive and downward is negative for both velocity and acceleration.

Q2.3. Reason: Where the rings are far apart the tree is growing rapidly. It appears that the rings are quite far apart near the center (the origin of the graph), then get closer together, then farther apart again.

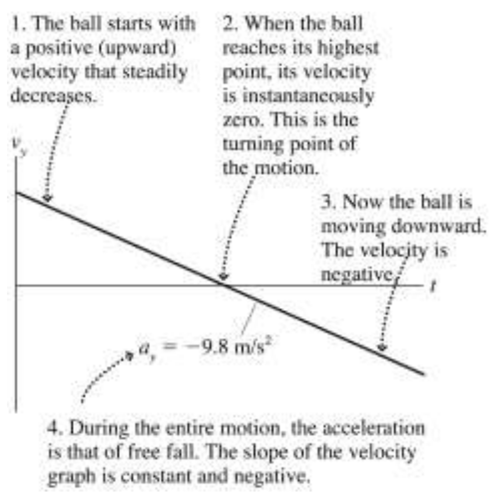


Assess: After drawing velocity-versus-time graphs (as well as others), stop and think if it matches the physical situation, especially by checking end points, maximum values, places where the slope is zero, etc. This one passes those tests.

Q2.4. Reason: Call "up" the positive direction. Also assume that there is no air resistance. This assumption is probably not true (unless the rock is thrown on the moon), but air resistance is a complication that will be addressed later, and for small, heavy items like rocks no air resistance is a pretty good assumption if the rock isn't going too fast.

To be able to draw this graph without help demonstrates a good level of understanding of these concepts. The velocity graph will not go up and down as the rock does—that would be a graph of the position. Think carefully about the velocity of the rock at various points during the flight.

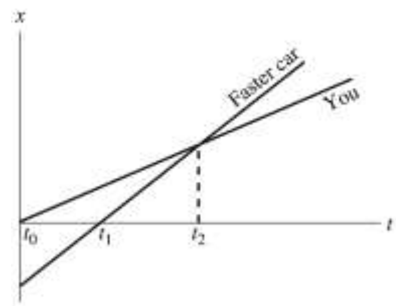
At the instant the rock leaves the hand it has a large positive (up) velocity, so the value on the graph at $t = 0$ needs to be a large positive number. The velocity decreases as the rock rises, but the velocity arrow would still point up. So the graph is still above the t axis, but decreasing. At the tippy-top the velocity is zero; that corresponds to a point on the graph where it crosses the t axis. Then as the rock descends with increasing velocity (in the negative, or down, direction), the graph continues below the t axis. It may not have been totally obvious before, but this graph will be a *straight line* with a negative slope.



Assess: Make sure that the graph touches or crosses the t axis whenever the velocity is zero. In this case, that is only when it reaches the top of its trajectory and the velocity vector is changing direction from up to down.

It is also worth noting that this graph would be more complicated if we were to include the time at the beginning when the rock is being accelerated by the hand. Think about what that would entail.

Q2.5. Reason: Let $t_0 = 0$ be when you pass the origin. The other car will pass the origin at a later time t_1 and passes you at time t_2.



Assess: The slope of the position graph is the velocity, and the slope for the faster car is steeper.

Q2.6. Reason: The plot shows the $x-$ component of the velocity as a function of time, not the position as a function of time. When the lines A and B cross, this indicates that two objects have the same $x-$ component of their velocity at that moment, not that they are in the same position. Of course, since we do not know where the objects started, it would be possible for the two objects to also be passing each other at that instant, there is simply no reason to think that based on the plot. So, Zach's statement might technically be correct, but it does not capture any of the relevant features of the plot. So we reject his example.

Let us ignore the fact that people often refer to the vertical direction as *y*, and assume that Victoria has chosen to call the vertical direction *x* (which is fine, just unconventional). The slope of either line indicates the change in velocity over time, in the *x* direction, which is called the acceleration in the *x* direction a_x. When a rock is thrown, once it leaves a person's hand gravity is always accelerating it downward. The vertical component of velocity may be upward or downward, but the acceleration is always downward. Line A has a positive acceleration and line B has a negative acceleration. It is not possible for these to both describe rocks in flight. We also reject Victoria's example.

Assess: An example of a scenario to accompany the plot would be: Car A was rolling backwards, but is now rolling forward and speeding up. Car B was moving forward, but slowed down and is now going in reverse. As Car A sped up and Car B slowed down, at one point they had the same speed.

Q2.7. Reason: A predator capable of running at a great speed while not being capable of large accelerations could overtake slower prey that were capable of large accelerations, given enough time. However, it may not be as effective as surprising and grabbing prey that are capable of higher acceleration. For example, prey could escape if the safety of a burrow were nearby. If a predator were capable of larger accelerations than its prey, while being slower in speed than the prey, it would have a greater chance of surprising and grabbing prey, quickly, though prey might outrun it if given enough warning.

Assess: Consider the horse-man race discussed in the text.

Q2.8. Reason: We will neglect air resistance, and thus assume that the ball is in free fall.

(a) $-g$ After leaving your hand the ball is traveling up but slowing, therefore the acceleration is down (*i.e.*, negative).

(b) $-g$ At the very top the velocity is zero, but it had previously been directed up and will consequently be directed down, so it is changing direction (*i.e.*, accelerating) down.

(c) $-g$ Just before hitting the ground it is going down (velocity is down) and getting faster; this also constitutes an acceleration down.

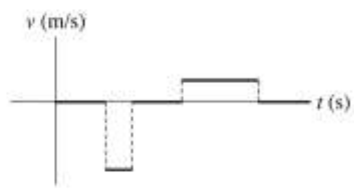
Assess: As simple as this question is, it is sure to illuminate a student's understanding of the difference between velocity and acceleration. Students would be wise to dwell on this question until it makes complete sense.

Q2.9. Reason: Consider the ball thrown upward. The path from Janelle's hand to its peak is symmetric to the path back from the peak to Janelle's hand. That means that whatever the initial upward speed was, when the ball returns and passes Janelle on its way down, it will have that same speed, just directed downward now. From that moment on, the trip down to Michael is exactly the same as for the ball thrown downward. Thus the two balls will be moving at the same speed when they reach Michael.

Assess: The ball initially thrown downward will certainly reach Michael first. But we are not asked about the time required or the average velocity. We are only asked about the speed at the moment the balls reach Michael. So this makes sense.

Q2.10. Reason: (a) Sirius the dog starts at about 1 m west of a fire hydrant (the hydrant is the $x = 0$ m position) and walks toward the east at a constant speed, passing the hydrant at $t = 1.5$ s. At $t = 4$ s Sirius encounters his faithful friend Fido 2 m east of the hydrant and stops for a 6-second barking hello-and-smell. Remembering some important business, Sirius breaks off the conversation at t = 10 s and sprints back to the hydrant, where he stays for 4 s and then leisurely pads back to his starting point.
(b) Sirius is at rest during segments B (while chatting with Fido) and D (while at the hydrant). Notice that the graph is a horizontal line while Sirius is at rest.
(c) Sirius is moving to the right whenever x is increasing. That is only during segment A. Don't confuse something going right on the graph (such as segments C and E) with the object physically moving to the right (as in segment A). Just because t is increasing doesn't mean x is.
(d) The speed is the magnitude of the slope of the graph. Both segments C and E have negative slope, but C's slope is steeper, so Sirius has a greater speed during segment C than during segment E.
Assess: We stated our assumption (that the origin is at the hydrant) explicitly. During segments B and D time continues to increase but the position remains constant; this corresponds to zero velocity.

Q2.11. Reason: There are five different segments of the motion, since the lines on the position-versus-time graph have different slopes between five different time periods.
(a) A fencer is initially still. To avoid his opponent's lunge, the fencer jumps backwards very quickly. He remains still for a few seconds. The fencer then begins to advance slowly on his opponent.
(b) Referring to the velocities obtained in part (a), the velocity-versus-time graph would look like the following diagram.



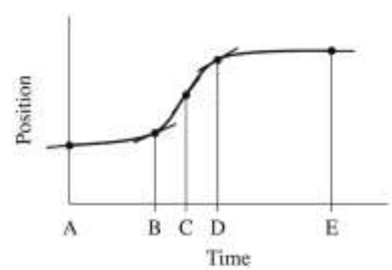
Assess: Velocity is given by the slope of lines on position-versus-time graphs. See Conceptual Example 2.1 and the discussion that follows.

Q2.12. Reason: (a) A's speed is greater at $t = 1$ s. The slope of the tangent to B's curve at $t = 1$ s is smaller than the slope of A's line.
(b) A and B have the same speed just before $t = 3$ s. At that time, the slope of the tangent to the curve representing B's motion is equal to the slope of the line representing A's motion.
Assess: The fact that B's curve is always *above* A's doesn't really matter. The respective *slopes* matter, not how high on the graph the curves are.

Q2.13. Reason: (a) D. The steepness of the tangent line is greatest at D.
(b) C, D, E. Motion to the left is indicated by a decreasing segment on the graph.
(c) C. The speed corresponds to the steepness of the tangent line, so the question can be re-cast as "Where is the tangent line getting steeper (either positive or negative slope, but getting steeper)?" The slope at B is zero and is greatest at D, so it must be getting steeper at C.
(d) A, E. The speed corresponds to the steepness of the tangent line, so the question can be re-cast as "Where is the tangent line getting less steep (either positive or negative slope, but getting less steep)?"
(e) B. Before B the object is moving right and after B it is moving left.
Assess: It is amazing that we can get so much information about the velocity (and even about the acceleration) from a position-versus-time graph. Think about this carefully. Notice also that the object is at rest (to the left of the origin) at point F.

Q2.14. Reason: (a) For the velocity to be constant, the velocity-versus-time graph must have zero slope. Looking at the graph, there are three time intervals where the graph has zero slope: segment A, segment D and segment F.
(b) For an object to be speeding up, the magnitude of the velocity of the object must be increasing. When the slope of the lines on the graph is nonzero, the object is accelerating and therefore changing speed.
Consider segment B. The velocity is positive while the slope of the line is negative. Since the velocity and acceleration are in opposite directions, the object is slowing down. At the start of segment B, we can see the velocity is +2 m/s, while at the end of segment B the velocity is 0 m/s.
During segment E the slope of the line is positive which indicates positive acceleration, but the velocity is negative. Since the acceleration and velocity are in opposite directions, the object is slowing here also. Looking at the graph at the beginning of segment E the velocity is –2 m/s, which has a magnitude of 2 m/s. At the end of segment E the velocity is 0 m/s, so the object has slowed down.
Consider segment C. Here the slope of the line is negative and the velocity is negative. The velocity and acceleration are in the same direction so the object is speeding up. The object is gaining velocity in the negative direction. At the beginning of that segment the velocity is 0 m/s, and at the end the velocity is –2 m/s, which has a magnitude of 2 m/s.
(c) In the analysis for part (b), we found that the object is slowing down during segments B and E.
(d) An object standing still has zero velocity. The only time this is true on the graph is during segment F, where the line has zero slope, and is along $v = 0$ m/s. The velocity is also zero for an instant at time $t = 5$ s between segments B and C.
(e) For an object to be moving to the right, the convention is that the velocity is positive. In terms of the graph, positive values of velocity are above the time axis. The velocity is positive for segments A and B. The velocity must also be greater than zero. Segment F represents a velocity of 0 m/s.
Assess: The slope of the velocity graph is the acceleration graph.

Q2.15. Reason: This graph shows a curved position-versus-time line. Since the graph is curved the motion is *not* uniform. The instantaneous velocity, or the velocity at any given instant of time, is the slope of a line tangent to the graph at that point in time. Consider the graph below, where tangents have been drawn at each labeled time.



Comparing the slope of the tangents at each time in the figure above, the speed of the car is greatest at time C.
Assess: Instantaneous velocity is given by the slope of a line tangent to a position-versus-time curve at a given instant of time. This is also demonstrated in Conceptual Example 2.4.

Q2.16. Reason: C. Negative, negative; since the slope of the tangent line is negative at both 1 and 2.
Assess: The car's position at 2 is at the origin, but it is traveling to the left and therefore has negative velocity in this coordinate system.

Q2.17. Reason: The velocity of an object is given by the physical slope of the line on the position-versus-time graph. Since the graph has constant slope, the velocity is constant. We can calculate the slope by using Equation 2.1, choosing any two points on the line since the velocity is constant. In particular, at $t_1 = 0$ s the position is $x_1 = 5$ m. At time $t_2 = 3$ s the position is $x_2 = 15$ m. The points on the line can be read to two significant figures.
The velocity is

$$v = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{15\text{ m} - 5\text{ m}}{3\text{ s} - 0\text{ s}} = \frac{10\text{ m}}{3\text{ s}} = +3.3\text{ m/s}$$

The correct choice is C.
Assess: Since the slope is positive, the value of the position is increasing with time, as can be seen from the graph.

Q2.18. Reason: We are asked to find the largest of four accelerations, so we compute all four from Equation 2.8:

$$a_x = \frac{\Delta v_x}{\Delta t}$$

A $a_x = \dfrac{10 \text{ m/s}}{5.0 \text{ s}} = 2.0 \text{ m/s}^2$

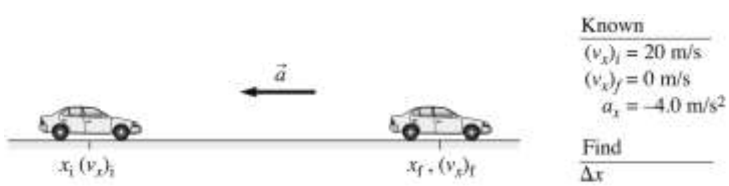
B $a_x = \dfrac{5.0 \text{ m/s}}{2.0 \text{ s}} = 2.5 \text{ m/s}^2$

C $a_x = \dfrac{20 \text{ m/s}}{7.0 \text{ s}} = 2.9 \text{ m/s}^2$

D $a_x = \dfrac{3.0 \text{ m/s}}{1.0 \text{ s}} = 3.0 \text{ m/s}^2$

The largest of these is the last, so the correct choice is D.
Assess: A large final speed, such as in choices A and C, does not necessarily indicate a large acceleration.

Q2.19. Reason: The initial velocity is 20 m/s. Since the car comes to a stop, the final velocity is 0 m/s. We are given the acceleration of the car, and need to find the stopping distance. See the pictorial representation, which includes a list of values below.



An equation that relates acceleration, initial velocity, final velocity, and distance is Equation 2.13.

$$(v_x)_f^2 = (v_x)_i^2 + 2a_x\Delta x$$

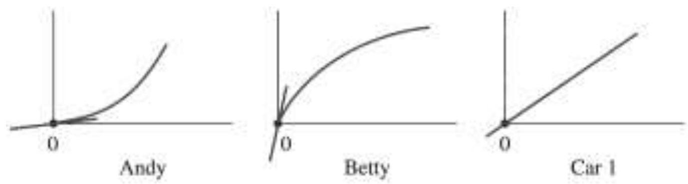
Solving for Δx,

$$\Delta x = \frac{(v_x)_f^2 - (v_x)_i^2}{2a_x} = \frac{(0 \text{ m/s})^2 - (20 \text{ m/s})^2}{2(-4.0 \text{ m/s}^2)} = 50 \text{ m}$$

The correct choice is D.
Assess: We are given initial and final velocities and acceleration. We are asked to find a displacement, so Equation 2.13 is an appropriate equation to use.

Q2.20. Reason: This is not a hard question once we remember that the displacement is the area under the velocity-versus-time graph. The scales on all three graphs are the same, so simple visual inspection will attest that Betty traveled the furthest since there is more area under her graph. The correct choice is B.
Assess: It is important to verify that the scales on the axes on all the graphs are the same before trusting such a simple visual inspection.
In the same vein, it is important to realize that although all three cars end up at the same speed (40 m/s), they do not end up at the same place (assuming they started at the same position); this is nothing more than reiterating what was said in the Reason step above. On a related note, check the accelerations: Andy’s acceleration was small to begin with but growing toward the end, Betty’s was large at first and decreased toward the end, and Carl’s acceleration was constant over the 5.0 s. Mentally tie this all together.

Q2.21. Reason: The slope of the tangent to the velocity-versus-time graph gives the acceleration of each car. At time $t = 0$ s the slope of the tangent to Andy's velocity-versus-time graph is very small. The slope of the tangent to the graph at the same time for Carl is larger. However, the slope of the tangent in Betty's case is the largest of the three. So Betty had the greatest acceleration at $t = 0$ s. See the figure below.



The correct choice is B.
Assess: Acceleration is given by the slope of the tangent to the curve in a velocity-versus-time graph at a given time.

Q2.22. Reason: Both balls are in free fall (neglecting air resistance) once they leave the hand, and so they will have the same acceleration. Therefore, the slopes of their velocity-versus-time graphs must be the same (*i.e.*, the graphs must be parallel). That eliminates choices B and C. Ball 1 has positive velocity on the way up, while ball 2 never goes up or has positive velocity; therefore, choice A is correct.
Assess: Examine the other choices. In choice B ball 1 is going up faster and faster while ball 2 is going down faster and faster. In choice C ball 1 is going up the whole time but speeding up during the first part and slowing down during the last part; ball 2 is going down faster and faster. In choice D ball 2 is released from rest (as in choice A), but ball 1 is thrown down so that its velocity at $t = 0$ is already some non-zero value down; thereafter both balls have the same acceleration and are in free fall.

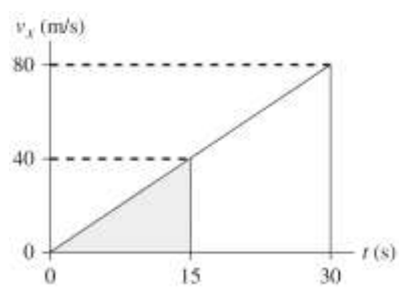
Q2.23. Reason: There are two ways to approach this problem, and both are educational. Using algebra, first calculate the acceleration of the larger plane.

$$a = \frac{\Delta v}{\Delta t} = \frac{80 \text{ m/s}}{30 \text{ s}} = 2.667 \text{ m/s}^2$$

Then use that acceleration to figure how far the smaller plane goes before reading 40 m/s.

$$(v_x)_\text{f}^2 = (v_x)_\text{i}^2 + 2a_x\Delta x \Rightarrow \Delta x = \frac{(v_x)_\text{f}^2 - (v_x)_\text{i}^2}{2a_x} = \frac{(40 \text{ m/s})^2}{2(2.667 \text{ m/s}^2)} = 300 \text{ m}$$

So choice A is correct.
The second method is graphical. Make a velocity vs. time graph; the slope of the straight line is the same for both planes. We see that the smaller plane reaches 40 m/s in half the time that the larger plane took to reach 80 m/s. And we see that the area under the smaller triangle is ¼ the area under the larger triangle. Since the area under the velocity vs. time graph is the distance then the distance the small plane needs is ¼ the distance the large plane needs.



Assess: It seems reasonable that a smaller plane would need only ¼ the distance to take off as a large plane.

Q2.24. **Reason:** The dots from time 0 to 9 seconds indicate a direction of motion to the right. The dots are getting closer and closer. This indicates that the object is moving to the right and slowing down. From 9 to 16 seconds, the object remains at the same position, so it has no velocity. From 16 to 23 seconds, the object is moving to the left. Its velocity is constant since the dots are separated by identical distances.
The velocity-versus-time graph that matches this motion closest is B.
Assess: The slope of the line in a velocity-versus-time graph gives an object's acceleration.

Q2.25. **Reason:** Let us call the vertically upward direction $+y$. We can determine the initial velocity by using Equation 2.13, with the minor adjustment of changing the subscripts from x to y. Then we have

$$(v_y)_\mathrm{f}^2 = (v_y)_\mathrm{i}^2 + 2a_y\Delta y \Rightarrow (v_y)_\mathrm{i} = \pm\sqrt{(v_y)_\mathrm{f}^2 - 2a_y\Delta y} = \pm\sqrt{(2.8\text{ m/s}) - 2(-9.8\text{ m/s})(3.8\text{ m})} = \pm 9.1\text{ m/s}$$

Clearly, since the ball was thrown upward, we want the positive answer. So the correct answer is C.
Assess: It makes sense that the initial upward component of velocity would have to be greater in magnitude than the final.

Q2.26. **Reason:** We can solve this in two steps. First, we can use Equation 2.12 to determine the acceleration of the car. Then we can use that acceleration to determine the time required to travel 30 m. The difference in time required to drive 30 m and to drive the initial 15 m will be the time required to drive the second 15 m. Let us call the direction of motion $+x$. The acceleration is given by

$$\Delta x = (v_x)_\mathrm{i}\Delta t + \frac{1}{2}a_x(\Delta t)^2 \Rightarrow a_x = \frac{2\Delta x}{(\Delta t)^2} = \frac{2(15\text{ m})}{(2.4\text{ s})^2} = 5.21\text{ m/s}^2$$

Here, we have used the fact that the car started from rest. Now we consider the entire 30 m trip, and use the acceleration we just found:

$$\Delta x = (v_x)_\mathrm{i}\Delta t + \frac{1}{2}a_x(\Delta t)^2 \Rightarrow \Delta t = \sqrt{\frac{2\Delta x}{a_x}} = \sqrt{\frac{2(30\text{ m})}{(5.21\text{m/s}^2)}} = 3.39\text{ s}$$

The entire 30 m takes 3.39 s, and the first 15 m took 2.4 s. This means the second 15 m segment takes 1.0 s. The correct answer is A.
Assess: It makes sense that the second 15 m segment takes less time than the first 15 m segment, since the car already had gotten up to speed .

Q2.27. **Reason:** By definition the acceleration in the x direction is the rate of change of the velocity in the x direction. This means

$$a_x = \Delta v_x / \Delta t = \frac{(v_x)_\mathrm{f} - (v_x)_\mathrm{i}}{t_\mathrm{f} - t_\mathrm{i}} = \frac{(15\text{ m/s}) - (5\text{ m/s})}{(4\text{ s}) - (0\text{ s})} = 2.5\text{ m/s}^2.$$

The correct answer is B.

Assess: Since the slope is positive, we expect a positive acceleration. The magnitude is also reasonable for the components of velocity given.

Q2.28. **Reason:** We can solve this with a straightforward application of Equation 2.13. One can easily obtain the acceleration from the slope, and this was the goal of Q2.27. The result is $a_x = 2.5\text{ m/s}^2$; see the solution to Q2.27 for details.

$$(v_x)_\mathrm{f}^2 = (v_x)_\mathrm{i}^2 + 2a_x\Delta x \Rightarrow \Delta x = \frac{(v_x)_\mathrm{f}^2 - (v_x)_\mathrm{i}^2}{2a_x} = \frac{(15\text{ m/s})_\mathrm{f}^2 - (5\text{ m/s})_\mathrm{i}^2}{2(2.5\text{ m/s}^2)} = 40\text{ m}$$

The correct answer is C.

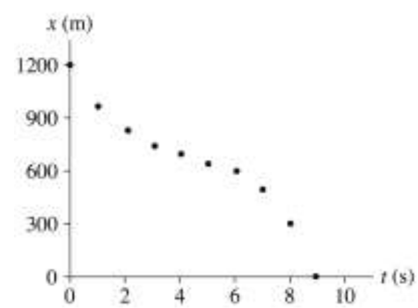
Assess: The speed is never less than 5 m/s, so the distance traveled must be greater than $(5 \text{ m/s})(4 \text{ s}) = 20 \text{ m}.$ The speed is never greater than 15 m/s, so the distance traveled must be less than $(15 \text{ m/s})(4 \text{ s}) = 60 \text{ m}.$ Our answer lies directly between these limits, and is therefore very reasonable.

Problems

P2.1. Strategize: The dots represent positions after fixed time intervals.
Prepare: The car is traveling to the left toward the origin, so its position decreases with increase in time.
Solve: (a)

Time *t* (s)	Position *x* (m)
0	1200
1	975
2	825
3	750
4	700
5	650
6	600
7	500
8	300
9	0

(b)



Assess: A car's motion traveling down a street can be represented at least three ways: a motion diagram, position-versus-time data presented in a table (part (a)), and a position-versus-time graph (part (b)).

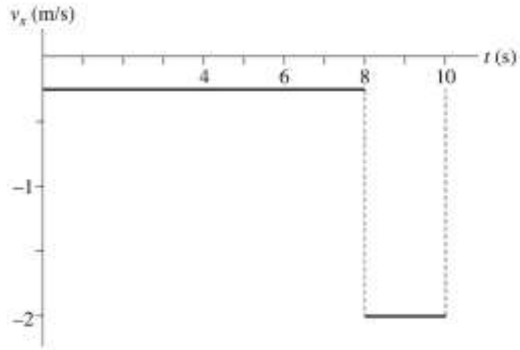
P2.2. Strategize: Review our sign conventions.
Prepare: Position to the right of or above origin is positive, but to the left of or below origin is negative. Velocity is positive for motion to the right and for upward motion, but it is negative for motion to the left and for downward motion.

Solve:

Diagram	Position	Velocity
(a)	Negative	Positive
(b)	Negative	Negative
(c)	Positive	Negative

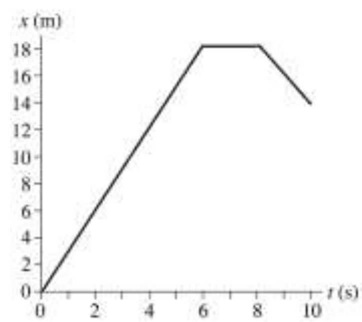
P2.3. Strategize: This is a position vs. time graph, so the x component of velocity is given by the slope.
Prepare: The position graph has a shallow (negative) slope for the first 8 s, and then the slope increases.
Solve:
(a) The change in slope comes at 8 s, so that is how long the dog moved at the slower speed.

(b)



Assess: We expect the sneaking up phase to be longer than the spring phase, so this looks like a realistic situation.

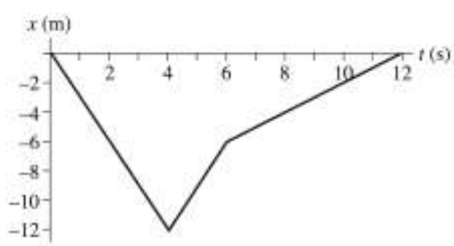
P2.4. Strategize: To get a position from a velocity graph we count the area under the curve.
Prepare: We expect to draw a line on our position graph that has a positive slope whenever the x component of velocity is positive, and a negative slope when the x component of velocity is negative.
Solve:
(a)



(b) We need to count the area under the velocity graph (area below the x-axis is subtracted). There are 18 m of area above the axis and 4 m of area below. $18\text{ m} - 4\text{ m} = 14\text{ m}.$

Assess: These numbers seem reasonable; a mail carrier could back up 4 m. It is also important that the problem state what the position is at $t = 0,$ or we wouldn't know how high to draw the position graph.

P2.5. Strategize: We want to produce a position vs. time plot in which the slope of x vs. t yields the v_x vs. t plot we are given.
Prepare: To get a position from a velocity graph we count the area under the curve.
Solve:
(a)



(b) We need to count the area under the velocity graph (area below the *x*-axis is subtracted). There are 12 m of area below the axis and 12 m of area above. $12\text{ m} - 12\text{ m} = 0\text{ m}.$

(c) A football player runs left at 3 m/s for 4 s, then cuts back to the right at 3 m/s for 2 s, then walks (continuing to the right) back to the starting position.

Assess: We note an abrupt change of velocity from 3 m/s left to 3 m/s right at 4 s. It is also important that the problem state what the position is at $t = 0$, or we wouldn't know how high to draw the position graph.

P2.6. Strategize: This problem can be broken down into steps during which the velocity is constant, such that (during any step) the relationship between displacement, velocity and time is simple.

Prepare: Let us call east the positive x direction. During any period when the velocity is constant, we can use $v_x = \Delta x / \Delta t.$ We are told the time for the 5 minute stop, and for the 20 minute trip with the wind. We can use this to calculate the distance that Dylan covers, and then the time required for the return. Finally, we will add the times from each segment to obtain a total time.

Solve: For the first part of the trip, when Dylan rides with the wind, we have:

$$v_x = \Delta x / \Delta t \Rightarrow \Delta x = v_x \Delta t = \left(\frac{15\text{ mi}}{60\text{ min}}\right)(20\text{ min}) = 5.0\text{ mi}$$

Dylan must cover this same distance during the return trip, but this time he will be moving in the $-x$ direction (meaning both the displacement in x and the x component of velocity will be negative). We have:

$$v_x = \Delta x / \Delta t \Rightarrow \Delta t = \Delta x / v_x = (-5.0\text{ mi}) / \left(\frac{-10\text{ mi}}{60\text{ min}}\right) = 30\text{ min}$$

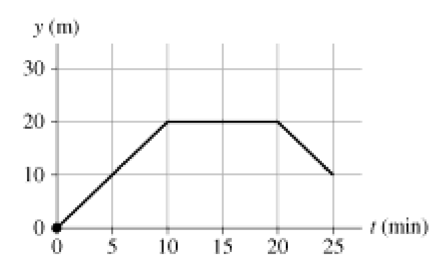
The total time is then the sum of the 20 min, 5 min, and 30 min segments, or 55 minutes.

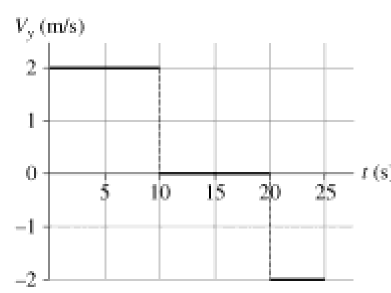
Assess: It makes sense that the return trip takes 10 minutes longer than the first leg of the trip, since the wind is blowing against Dylan for the return trip.

P2.7. Strategize: We want to indicate position relative to the ground on the vertical axis of one plot, and time on the horizontal axis.

Prepare: We assume the speed is roughly constant when the elevator is moving. We start with the position plot, and then we can determine the components of the velocity from the slope.

Solve: The entire trip takes 24 s and 10 s are spent stopped. So the motion takes a total of 14 s. If we assume the elevator has the same speed when going upward as it does downward, then the total distance of 7 floors (5 up and then 2 down) corresponds to 2 s per floor. Thus, we expect it took 10 s to get up to the fifth floor, and then 4 s to go back down to the third floor. Clearly, the slope of this plot is either ± 2 m/s or 0 m/s. This allows us to complete the velocity vs. time plot as well.





Assess: Note that the sign of the velocity is accurately reflected in the slope of the position vs. time plot.

P2.8. Strategize: The slope of the position-versus-time graph at every point gives the velocity at that point.
Prepare: Referring to Figure P2.8, the graph has a distinct slope and hence distinct velocity in the time intervals: from $t = 0$ to $t = 20$ s; from 20 s to 30 s; and from 30 s to 40 s.
Solve: The slope at $t = 10$ s is

$$v = \frac{\Delta x}{\Delta t} = \frac{100\text{ m} - 50\text{ m}}{20\text{ s}} = 2.5\text{ m/s}$$

The slope at $t = 25$ s is

$$v = \frac{100\text{ m} - 100\text{ m}}{10\text{ s}} = 0\text{ m/s}$$

The slope at $t = 35$ s is

$$v = \frac{0\text{ m} - 100\text{ m}}{10\text{ s}} = -10\text{ m/s}$$

Assess: As expected a positive slope gives a positive velocity and a negative slope yields a negative velocity.

P2.9. Strategize: Ignoring air resistance, the horizontal component of the velocity should be constant.
Prepare: Assume that the ball travels in a horizontal line at a constant v_x. It doesn't really, but if it is a line drive then it is a fair approximation.

$$\text{time} = \frac{\text{distance}}{\text{speed}} = \frac{60\text{ ft}}{95\ \frac{\text{mi}}{\text{h}}}\left(\frac{1\text{ mi}}{5280\text{ ft}}\right)\left(\frac{60\text{ min}}{1\text{ h}}\right)\left(\frac{60\text{ s}}{1\text{ min}}\right) = 0.43\text{ s}$$

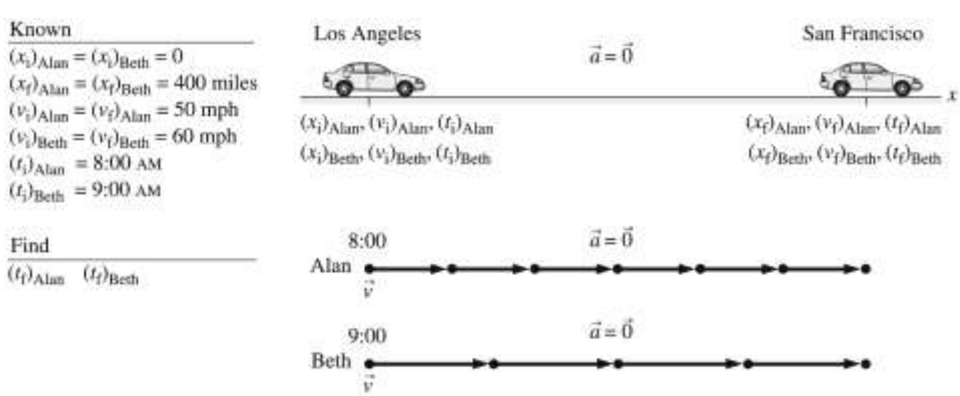
Assess: Just under a half second is reasonable for a major league pitch.

P2.10. Strategize: Ignoring air resistance, the horizontal component of the velocity should be constant.
Prepare: Assume that the ball travels in a horizontal line at a constant v_x. It doesn't really, but if it is a line drive then it is a fair approximation.
Solve:

$$\Delta t = \frac{\Delta x}{v_x} = \frac{43\text{ ft}}{100\text{ mi/h}}\left(\frac{1\text{ mi}}{5280\text{ ft}}\right)\left(\frac{3600\text{ s}}{1\text{ h}}\right) = 0.29\text{ s}$$

Assess: This is a short but reasonable time for a fastball to get from the mound to home plate.

P2.11. Strategize: We assume both drivers maintain a steady speed.
Prepare: A visual overview of Alan's and Beth's motion that includes a pictorial representation, a motion diagram, and a list of values is shown below. Our strategy is to calculate and compare Alan's and Beth's time of travel from Los Angeles to San Francisco.



Solve: Beth and Alan are moving at a constant speed, so we can calculate the time of arrival as follows:

$$v = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i} \Rightarrow t_f = t_i + \frac{x_f - x_i}{v}$$

Using the known values identified in the pictorial representation, we find

$$(t_f)_{\text{Alan}} = (t_i)_{\text{Alan}} + \frac{(x_f)_{\text{Alan}} - (x_i)_{\text{Alan}}}{v} = 8{:}00\ \text{AM} + \frac{400\ \text{mile}}{50\ \text{miles/hour}} = 8{:}00\ \text{AM} + 8\ \text{hr} = 4{:}00\ \text{PM}$$

$$(t_f)_{\text{Beth}} = (t_i)_{\text{Beth}} + \frac{(x_f)_{\text{Beth}} - (x_i)_{\text{Beth}}}{v} = 9{:}00\ \text{AM} + \frac{400\ \text{mile}}{60\ \text{miles/hour}} = 9{:}00\ \text{AM} + 6.67\ \text{hr} = 3{:}40\ \text{PM}$$

(a) Beth arrives first.
(b) Beth has to wait 20 minutes for Alan.
Assess: Times of the order of 7 or 8 hours are reasonable in the present problem.

P2.12. Strategize: This problem involves constant-velocity motion.
Prepare: Assume that Richard only speeds on the 125 mi stretch of the interstate. We then need to compute the times that correspond to two different speeds for that given distance. Rearrange Equation 1.1 to produce

$$\text{time} = \frac{\text{distance}}{\text{speed}}$$

Solve: At the speed limit:

$$\text{time}_1 = \frac{125\ \text{mi}}{65\ \text{mi/h}}\left(\frac{60\ \text{min}}{1\ \text{h}}\right) = 115.4\ \text{min}$$

At the faster speed:

$$\text{time}_2 = \frac{125\ \text{mi}}{70\ \text{mi/h}}\left(\frac{60\ \text{min}}{1\ \text{h}}\right) = 107.1\ \text{min}$$

By subtracting we see that Richard saves 8.3 min.
Assess: Breaking the law to save 8.3 min is normally not worth it; Richard's parents can wait 8 min.
Notice how the hours (as well as the miles) cancel in the equations.

P2.13. Strategize: Since each runner is running at a steady pace, they both are traveling with a constant speed.
Prepare: Each runner must travel the same distance to finish the race. We assume they are traveling uniformly. We can calculate the time it takes each runner to finish using Equation 2.1.
Solve: The first runner finishes in

$$\Delta t_1 = \frac{\Delta x}{(v_x)_1} = \frac{5.00\ \text{km}}{12.0\ \text{km/h}} = 0.417\ \text{h}$$

Converting to minutes, this is $(0.417\ \text{h})\left(\frac{60\ \text{min}}{1\ \text{h}}\right) = 25.0\ \text{min}$

For the second runner

$$\Delta t_2 = \frac{\Delta x}{(v_x)_2} = \frac{5.00\ \text{km}}{14.5\ \text{km/h}} = 0.345\ \text{h}$$

Converting to seconds, this is

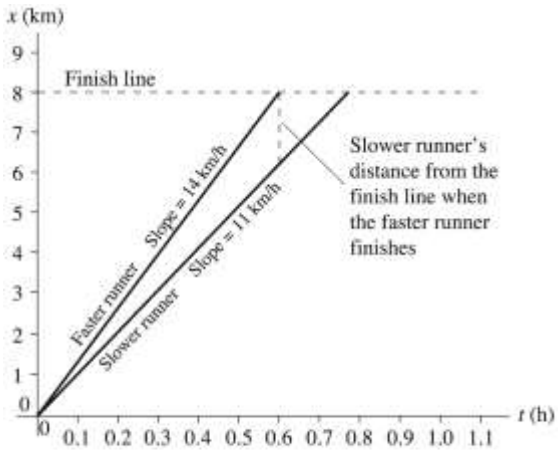
$$(0.345\ \text{h})\left(\frac{60\ \text{min}}{1\ \text{h}}\right) = 20.7\ \text{min}$$

The time the second runner waits is 25.0 min – 20.7 min = 4.3 min
Assess: For uniform motion, velocity is given by Equation 2.1.

P2.14. Strategize: This problem involves constant-velocity motion.
Prepare: We'll do this problem in multiple steps. Rearrange Equation 1.1 to produce

$$\text{time} = \frac{\text{distance}}{\text{speed}}$$

Use this to compute the time the faster runner takes to finish the race; then use $\text{distance} = \text{speed}´\ \text{time}$ to see how far the slower runner has gone in that amount of time. Finally, subtract that distance from the 8.00 km length of the race to find out how far the slower runner is from the finish line.



Solve: The faster runner finishes in

$$t = \frac{8.00\ \text{km}}{14.0\ \text{km/h}} = 0.571\ \text{h}$$

In that time the slower runner runs $d = (11.0\ \text{km/h})´\ (0.571\ \text{h}) = 6.29\ \text{km}$.
This leaves the slower runner $8.00\ \text{km} -\ 6.29\ \text{km} = 1.71\ \text{km}$ from the finish line as the faster runner crosses the line.
Assess: The slower runner will not even be in sight of the faster runner when the faster runner crosses the line.
We did not need to convert hours to seconds because the hours cancelled out of the last equation. Notice we kept 3 significant figures, as indicated by the original data.

P2.15. Strategize: This is a position vs. time plot, and we are asked for the top speed. So we are interested in the maximum slope in the given plot.
Prepare: The slope of the path traced by the dots in the position vs. time plot is initially somewhat inclined, but then increases after the first two seconds. After that point near the two second mark (which we approximate as 1.9 s), the slope appears fairly constant. We can take this larger, sustained slope as the maximum speed.
Solve: Since the speed after the dot at 1.9 s mark appears roughly constant, we can use the expression for the average speed over that interval:

$$v_{x,\text{av}} = \frac{\Delta x}{\Delta t} = \frac{x_\text{f} - x_\text{i}}{t_\text{f} - t_\text{i}} = \frac{(100\ \text{m}) - (10\ \text{m})}{(9.5\ \text{s}) - (1.9\ \text{s})} = 12\ \text{m/s}$$

Assess: This is extremely fast. One can perform a simple check by noting that the average time for the entire run is $(100\ \text{m})/(9.5\ \text{s}) = 11\ \text{m/s}$. So the fact that we got a slightly higher speed for Usain Bolt's maximum speed is reasonable.

P2.16. Strategize: Since she is running at a steady pace, this is a constant-velocity problem.

Prepare: Assume v_x is constant so the ratio $\frac{\Delta x}{\Delta t}$ is also constant.

Solve:

(a)

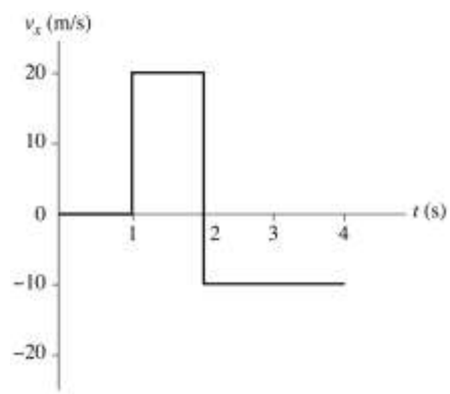
$$\frac{100\text{ m}}{18\text{ s}} = \frac{400\text{ m}}{\Delta t} \Rightarrow \Delta t = 18\text{ s}\left(\frac{400\text{ m}}{100\text{ m}}\right) = 72\text{ s}$$

(b)

$$\frac{100\text{ m}}{18\text{ s}} = \frac{1.0\text{ mi}}{\Delta t} \Rightarrow \Delta t = 18\text{s}\left(\frac{1.0\text{ mi}}{100\text{ m}}\right)\left(\frac{1609\text{ m}}{1.0\text{ mi}}\right) = 290\text{ s} = 4.8\text{ min}$$

Assess: This pace does give about the right answer for the time required to run a mile for a good marathoner.

P2.17. Strategize: In this problem the velocity is changing, but we can determine v_x at a given time by looking at the slope of the x vs. t graph.
Prepare: The graph in Figure P2.17 shows distinct slopes in the time intervals: 0 – 1 s, 1 s – 2 s, and 2 s – 4 s. We can thus obtain the velocity values from this graph using $v = \Delta x/\Delta t$.
Solve: (a)



(b) There is only one turning point. At t = 2 s the velocity changes from +20 m/s to −10 m/s, thus reversing the direction of motion. At t = 1 s, there is an abrupt change in motion from rest to +20 m/s, but there is no reversal in motion.
Assess: As shown above in (a), a positive slope must give a positive velocity and a negative slope must yield a negative velocity.

P2.18. Strategize: The distance traveled is the area under the v_y graph.

Prepare: Since the graph of v_y vs. t is linear in each region, calculating the area under the line is simple.

Solve:

(a) The area of a triangle is $\frac{1}{2}BH$.

$$\Delta y = \text{area} = \frac{1}{2}BH = \frac{1}{2}(0.20\text{ s})(0.75\text{ m/s}) = 7.5\text{ cm}$$

(b) We estimate the distance from the heart to the brain to be about 30 cm.

$$\Delta t = \frac{\Delta y}{v_y} = \frac{30\text{ cm}}{7.5\text{ cm/beat}} = 4.0\text{ beats}$$

Assess: Four beats seems reasonable. There is some doubt that we are justified using two significant figures here.

P2.19. Strategize: Displacement is given by the area under the a velocity vs. time graph.
Prepare: In this case, the displacement is equal to the area under the velocity graph between t_i and t_f. We can find the car's final position from its initial position and the area.
Solve: (a) Using the equation $x_f = x_i$ + area of the velocity graph between t_i and t_f,

$$x_{2\text{ s}} = 10\text{ m} + \text{area of trapezoid between 0 s and 2 s}$$
$$= 10\text{ m} + \frac{1}{2}(12\text{ m/s} + 4\text{ m/s})(2\text{ s}) = 26\text{ m}$$
$$x_{3\text{ s}} = 10\text{ m} + \text{area of triangle between 0 s and 3 s}$$
$$= 10\text{ m} + \frac{1}{2}(12\text{ m/s})(3\text{ s}) = 28\text{ m}$$
$$x_{4\text{ s}} = x_{3\text{ s}} + \text{area between 3 s and 4 s}$$
$$= 28\text{ m} + \frac{1}{2}(-4\text{ m/s})(1\text{ s}) = 26\text{ m}$$

(b) The car reverses direction at $t = 3$ s, because its velocity becomes negative.
Assess: The car starts at $x_i = 10$ m at $t_i = 0$. Its velocity decreases as time increases, is zero at $t = 3$ s, and then becomes negative. The slope of the velocity-versus-time graph is negative which means the car's acceleration is negative and a constant. From the acceleration thus obtained and given velocities on the graph, we can also use kinematic equations to find the car's position at various times.

P2.20. Strategize: This is an estimation problem, so a range of answers may be acceptable. v_x is given by the slope of the x vs. graph.
Prepare: To make the estimates from the graph we need to read the slopes from the graph. Lightly pencil in straight lines tangent to the graph at $t = 2$ s and $t = 4$ s. Then pick a pair of points on each line to compute the rise and the run.
Solve:
(a)

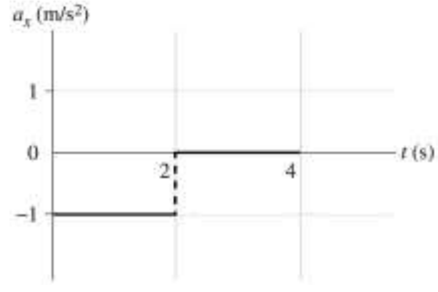
$$v_x = \frac{200\text{ m}}{4\text{ s} - 1\text{ s}} = 67\text{ m/s}$$

(b)

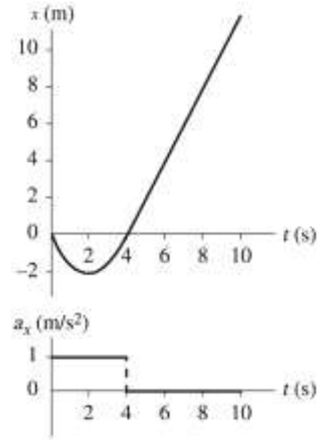
$$v_x = \frac{400\text{ m}}{5\text{ s} - 2\text{ s}} = 130\text{ m/s}$$

Assess: The speed is increasing, which is indeed what the graph tells us. These are reasonable numbers for a drag racer.

P2.21. Strategize: The graph in Figure P2.21 shows the horizontal component of velocity as a function of time. We know the acceleration is the rate of change of the velocity. So we can determine the acceleration using the slope of this graph.
Prepare: We will use $a_x = \Delta v_x/\Delta t$. A linear decrease in velocity from $t = 0$ s to $t = 2$ s implies a constant negative acceleration. On the other hand, a constant velocity between $t = 2$ s and $t = 4$ s means zero acceleration.
Solve:

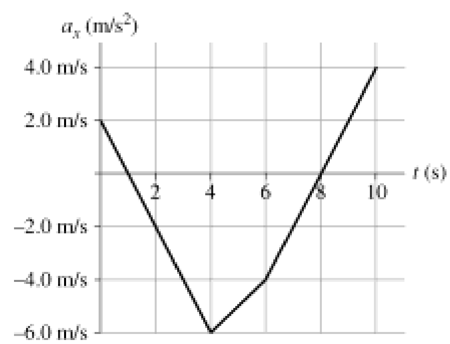


P2.22. **Strategize:** Figure P2.22 shows the horizontal component of the velocity. We know the displacement in the horizontal direction is the area under this curve, and acceleration in the horizontal direction is the given by the slope of this graph.
Prepare: To determine the displacement at a time *t*, we calculate the area between the velocity line and the time axis up to that time. To determine the horizontal component of the acceleration, we use $a_x = \Delta v_x / \Delta t.$
Solve: **(a)**



(b) From the acceleration versus *t* graph above, *ax* at *t* = 3.0 s is +1 m/s^2.
Assess: Because the velocity was negative at first, the train was moving left. There is a turning point at 2 s.

P2.23. **Strategize:** Acceleration is the rate of change of velocity. We must draw a velocity vs. time graph in which the slope at a given point is equal to the value of the acceleration in the plot above.
Prepare: We are told the initial speed of the object is 2.0 m/s. We can simply start drawing a line from that point with the appropriate slope, changing slopes at the appropriate times.
Solve:



Assess: We can check our answer by calculating the velocity after a certain time and seeing if it matches the graph. Let us check the lowest point, which on our graph is –6.0 m/s and occurs at 4 s. Using Equation 2.11, we have $(v_x)_\text{f} = (v_x)_\text{i} + a_x\Delta t = (2.0\text{ m/s}) + (-2.0\text{ m/s}^2)(4\text{ s}) = -6.0\text{ m/s},$ which is consistent.

P2.24. **Strategize:** Acceleration is given by the slope of the velocity vs. time graph.
Prepare: We calculate the acceleration from the rise and the run for each straight line segment.
Solve: Speeding up:

$$a_y = \frac{\mathrm{D}v_y}{\mathrm{D}t} = \frac{0.75\text{ m/s}}{0.05\text{ s}} = 15\text{ m/s}^2$$

Slowing down:

$$a_y = \frac{\Delta v_y}{\Delta t} = \frac{-0.75 \text{ m/s}}{0.15 \text{ s}} = -5 \text{ m/s}^2$$

Assess: Indeed the slope looks three time steeper in the first segment than in the second. These are pretty large accelerations.

P2.25. Strategize: From a velocity-versus-time graph we find the acceleration by computing the slope.
Prepare: We will compute the slope of each straight-line segment in the graph.

$$a_x = \frac{(v_x)_\text{f} - (v_x)_\text{i}}{t_\text{f} - t_\text{i}}$$

The trickiest part is reading the values off of the graph.
Solve: (a)

$$a_x = \frac{5.5 \text{ m/s} - 0.0 \text{ m/s}}{0.9 \text{ s} - 0.0 \text{ s}} = 6.1 \text{ m/s}^2$$

(b)

$$a_x = \frac{9.3 \text{ m/s} - 5.5 \text{ m/s}}{2.4 \text{ s} - 0.9 \text{ s}} = 2.5 \text{ m/s}^2$$

(c)

$$a_x = \frac{10.9 \text{ m/s} - 9.3 \text{ m/s}}{3.5 \text{ s} - 2.4 \text{ s}} = 1.5 \text{ m/s}^2$$

Assess: This graph is difficult to read to more than one significant figure. I did my best to read a second significant figure but there is some estimation in the second significant figure.
It takes Carl Lewis almost 10 s to run 100 m, so this graph covers only the first third of the race. Were the graph to continue, the slope would continue to decrease until the slope is zero as he reaches his (fastest) cruising speed.
Also, if the graph were continued out to the end of the race, the area under the curve should total 100 m.

P2.26. Strategize: In reality, biological systems rarely move with constant acceleration. But we will assume constant acceleration over this very short time interval.
Prepare: Use the definition of acceleration. Also, 60 ms = 0.060 s.
Solve:

$$a_y = \frac{\Delta v_y}{\Delta t} = \frac{3.7 \text{ m/s}}{0.060 \text{ s}} = 62 \text{ m/s}^2$$

Assess: Frogs are quite impressive! Humans can’t jump with this kind of acceleration.

P2.27. Strategize: We will assume constant accelerations for both animals.
Prepare: We can calculate acceleration from Equation 2.8:
Solve: For the gazelle:

$$(a_x) = \left(\frac{\Delta v_x}{\Delta t}\right) = \frac{13 \text{ m/s}}{3.0 \text{ s}} = 4.3 \text{ m/s}^2$$

For the lion:

$$(a_x) = \left(\frac{\Delta v_x}{\Delta t}\right) = \frac{9.5 \text{ m/s}}{1.0 \text{ s}} = 9.5 \text{ m/s}^2$$

For the trout:

$$(a_x) = \left(\frac{\Delta v_x}{\Delta t}\right) = \frac{2.8\text{ m/s}}{0.12\text{ s}} = 23\text{ m/s}^2$$

The trout is the animal with the largest acceleration.
Assess: A lion would have an easier time snatching a gazelle than a trout.

P2.28. Strategize: We will assume constant acceleration, such that we can use kinematic equations.
Prepare: Acceleration is the rate of change of velocity.

$$a_x = \frac{\Delta v_x}{\Delta t}$$

Where $\Delta v_x = 4.0$ m/s and $\Delta t = 0.11$ s.
We will then use that acceleration to compute the final position after the strike:

$$x_\text{f} = \frac{1}{2}a_x(\Delta t)^2$$

where we are justified in using the special case because $(v_x)_\text{i} = 0.0$ m/s and $x_\text{i} = 0$ m.
Solve: (a)

$$a_x = \frac{\Delta v_x}{\Delta t} = \frac{4.0\text{ m/s}}{0.11\text{ s}} = 36\text{ m/s}^2$$

(b)

$$x_\text{f} = \frac{1}{2}a_x(\Delta t)^2 = \frac{1}{2}(36\text{ m/s}^2)(0.11\text{ s})^2 = 0.22\text{ m}$$

Assess: The answer is remarkable but reasonable. The pike strikes quickly and so is able to move 0.22 m in 0.11 s, even starting from rest. The seconds squared cancel in the last equation.

P2.29. Strategize: This problem consists of unit conversion, and application of the definition of acceleration. Note that since the acceleration is constant, we are also free to use kinematic equations.
Prepare: First, we will convert units:

$$60\frac{\text{miles}}{\text{hour}} \times \frac{1\text{ hour}}{3600\text{ s}} \times \frac{1609\text{ m}}{1\text{ mile}} = 26.8\text{ m/s}$$

We also note that $g = 9.8$ m/s^2. Because the car has constant acceleration, we can use kinematic equations.
Solve: (a) For initial velocity $v_\text{i} = 0$, final velocity $v_\text{f} = 26.8$ m/s, and $\Delta t = 10$ s, we can find the acceleration using

$$v_\text{f} = v_\text{i} + a\Delta t \Rightarrow a = \frac{v_\text{f} - v_\text{i}}{\Delta t} = \frac{(26.8\text{ m/s} - 0\text{ m/s})}{10\text{ s}} = 2.68\text{ m/s}^2 \approx 2.7\text{ m/s}^2$$

(b) The fraction is $a/g = 2.68/9.8 = 0.273$. So a is 27% of g, or 0.27 g.
(c) The displacement is calculated as follows:

$$x_\text{f} - x_\text{i} = v_\text{i}\Delta t + \frac{1}{2}a(\Delta t)^2 = \frac{1}{2}a(\Delta t)^2 = 134\text{ m} = 440\text{ feet}$$

Assess: A little over tenth of a mile displacement in 10 s is physically reasonable.

P2.30. Strategize: We will assume acceleration is constant, such that we can use kinematic equations.
Prepare: Fleas are amazing jumpers; they can jump several times their body height—something we cannot do.
We assume constant acceleration so we can use the kinematic equations. The last of the three relates the three variables we are concerned with in part (a): speed, distance (which we know), and acceleration (which we want).

$$(v_y)_f^2 = (v_y)_i^2 + 2a_y \Delta y$$

In part (b) we use Equation 2.11 because it relates the initial and final velocities and the acceleration (which we know) with the time interval (which we want).

$$(v_y)_f = (v_y)_i + a_y \Delta t$$

Part (c) is about the phase of the jump *after* the flea reaches takeoff speed and leaves the ground. So now it is $(v_y)_i$, that is 1.0 m/s instead of $(v_y)_f$. And the acceleration is not the same as in part (a)—it is now $-g$ (with the positive direction up) since we are ignoring air resistance. We do not know the time it takes the flea to reach maximum height, so we employ Equation 2.13 again because we know everything in that equation except Δy.
Solve: (a) Use $(v_y)_i = 0.0\ \text{m/s}$ and rearrange Equation 2.13.

$$a_y = \frac{(v_y)_f^2}{2\Delta y} = \frac{(1.0\ \text{m/s})^2}{2(0.50\ \text{mm})}\left(\frac{1000\ \text{mm}}{1\ \text{m}}\right) = 1000\ \text{m/s}^2$$

(b) Having learned the acceleration from part **(**a**)** we can now rearrange Equation 2.12 to find the time it takes to reach takeoff speed. Again use $(v_y)_i = 0.0\ \text{m/s}$.

$$\Delta t = \frac{(v_y)_f}{a_y} = \frac{1.0\ \text{m/s}}{1000\ \text{m/s}^2} = .0010\ \text{s}$$

Assess: Just over 5 cm is pretty good considering the size of a flea. It is about 10–20 times the size of a typical flea. Check carefully to see that each answer ends up in the appropriate units.

P2.31. Strategize: This is a question about acceleration and how it relates to other kinematic quantities. We will assume the large acceleration is constant, such that we can make use of kinematic equations.
Reason: We can use Equation 2.11 to relate acceleration to initial and final speeds. To relate the acceleration and time to distance covered, we can use the initial velocity from part (a) and Equation 2.13. Let us call the initial direction of motion the $+x$ direction, such that the acceleration will be in the $-x$ direction.
Solve: The maximum initial speed would require the maximum allowed time to stop. So we assume $\Delta t = 30$ ms. Then

$$(v_x)_f = (v_x)_i + a_x\Delta t \Rightarrow (v_x)_i = (v_x)_f - a_x\Delta t = (0\ \text{m/s}) - \left(-(50)(9.8\ \text{m/s}^2)\right)(30\times10^{-3}\ \text{s}) = 14.7\ \text{m/s}$$

We would report our answer to part (a) as 15 m/s. We have kept an extra digit above for use in part (b).
To determine the minimum distance, we again assume that all 30 ms of allowable time are used in the stopping process, and we use the initial velocity from part (a), such that we can write

$$(v_x)_f^2 = (v_x)_i^2 + 2a_x\Delta x \Rightarrow \Delta x = \frac{(v_x)_f^2 - (v_x)_i^2}{2a_x} = \frac{(0\ \text{m/s})^2 - (14.7\ \text{m/s})^2}{2\left(-(50)(9.8\ \text{m/s}^2)\right)} = 0.22\ \text{m}$$

Assess: The maximum initial speed we found is around 33 mph. This means that going from full speed to a full stop in 30 ms could be fatal if the initial speed is greater than around 33 mph. Of course, seatbelts, airbags, and crumple zones in cars are designed to increase the distance over which the humans in the car stop to considerably more than 0.22 m. This way humans can survive head-on collisions starting from even greater speeds.

P2.32. Strategize: Let us assume the acceleration is constant over the intervals described.
Prepare: We'll do this in parts, first computing the acceleration after the congestion.
Solve:

$$a = \frac{\Delta v}{\Delta t} = \frac{12.0 \text{ m/s} - 5.0 \text{ m/s}}{8.0 \text{ s}} = \frac{7.0 \text{ m/s}}{8.0 \text{ s}}$$

Now use the same acceleration to find the new velocity.

$$v_{\text{f}} = v_{\text{i}} + a\Delta t = 12.0 \text{ m/s} + \left(\frac{7.0}{8.0} \text{ m/s}^2\right)(16 \text{ s}) = 26 \text{ m/s}$$

Assess: The answer is a reasonable 58 mph.

P2.33. Strategize: Because the skier slows steadily, her acceleration is a constant during the glide and we can use the kinematic equations.
Prepare: We can use Equation 2.13 to determine the unknown acceleration.
Solve: Since we know the skier's initial and final speeds and the width of the patch over which she decelerates, we will use

$$v_{\text{f}}^2 = v_{\text{i}}^2 + 2a(x_{\text{f}} - x_{\text{i}})$$
$$\Rightarrow a = \frac{v_{\text{f}}^2 - v_{\text{i}}^2}{2(x_{\text{f}} - x_{\text{i}})} = \frac{(6.0 \text{ m/s})^2 - (8.0 \text{ m/s})^2}{2(5.0 \text{ m})} = -2.8 \text{ m/s}^2$$

The magnitude of this acceleration is 2.8 m/s^2.
Assess: A deceleration of 2.8 m/s^2 or 6.3 mph/s is reasonable.

P2.34. Strategize: We will assume constant acceleration of both planes, such that we can use the kinematic equations of motion.
Prepare: The kinematic equation that relates velocity, acceleration, and distance is $(v_x)_{\text{f}}^2 = (v_x)_{\text{i}}^2 + 2a_x\Delta x$. Solve for Δx.

$$\Delta x = \frac{(v_x)_{\text{f}}^2 - (v_x)_{\text{i}}^2}{2a_x}$$

Note that $(v_x)_{\text{i}}^2 = 0$ for both planes.
Solve: The accelerations are same, so they cancel.

$$\frac{\Delta x_{\text{jet}}}{\Delta x_{\text{prop}}} = \frac{\left(\frac{(v_x)_{\text{f}}^2}{2a_x}\right)_{\text{jet}}}{\left(\frac{(v_x)_{\text{f}}^2}{2a_x}\right)_{\text{prop}}} = \frac{\left((v_x)_{\text{f}}\right)_{\text{jet}}^2}{\left((v_x)_{\text{f}}\right)_{\text{prop}}^2} = \frac{\left((2v_x)_{\text{f}}\right)_{\text{prop}}^2}{\left((v_x)_{\text{f}}\right)_{\text{prop}}^2} = 4 \Rightarrow \Delta x_{\text{jet}} = 4\Delta x_{\text{prop}} = 4(1/4 \text{ mi}) = 1 \text{ mi}$$

Assess: It seems reasonable to need a mile for a passenger jet to take off.

P2.35. Strategize: Because the car slows steadily, the deceleration is a constant and we can use the kinematic equations of motion under constant acceleration.
Prepare: We look for an equation in which we know all but one variable, and find that we can solve this using Equation 2.13.
Solve: Since we know the car's initial and final speeds and the width of the patch over which she decelerates, we will use

$$v_{\text{f}}^2 = v_{\text{i}}^2 + 2a(x_{\text{f}} - x_{\text{i}})$$
$$\Rightarrow a = \frac{v_{\text{f}}^2 - v_{\text{i}}^2}{2(x_{\text{f}} - x_{\text{i}})} = \frac{(0 \text{ m/s})^2 - (90 \text{ m/s})^2}{2(110 \text{ m})} = -37 \text{ m/s}^2$$

The magnitude of this acceleration is 37 m/s^2.
Assess: A deceleration of 37 m/s^2 is impressive; it is almost 4 *g*s.

P2.36. Strategize: Although this problem does not involve constant acceleration throughout the entire time shown, the acceleration is constant on intervals.
Prepare: We recall that displacement is equal to area under the velocity graph between t_i and t_f, and acceleration is the slope of the velocity-versus-time graph.
Solve: (a) Using the equation, $x_f = x_i$ + area under the velocity-versus-time graph between t_i and t_f we have,

$$x \text{ (at } t = 1 \text{ s)} = x \text{ (at } t = 0 \text{ s)} + \text{area between } t = 0 \text{ s and } t = 1 \text{ s} = 0.0 \text{ m} + (4 \text{ m/s})(1 \text{ s}) = 4.0 \text{ m}$$

Reading from the velocity-versus-time graph, v_x (at t = 1 s) = 4.0 m/s. Also, a_x = slope = $\Delta v/\Delta t = 0 \text{ m/s}^2$.
(b)

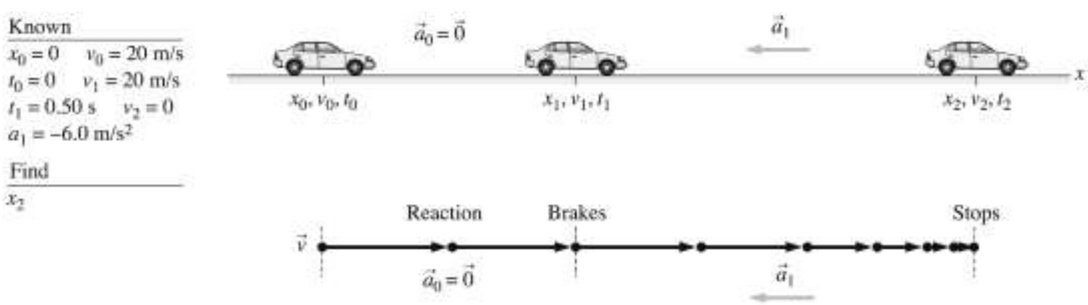
$$\begin{aligned} x(\text{at } t = 3.0 \text{ s}) &= x(\text{at } t = 0 \text{ s}) + \text{area between } t = 0 \text{ s and } t = 3 \text{ s} \\ &= 0.0 \text{ m} + 4 \text{ m/s} \times 2 \text{ s} + 2 \text{ m/s} \times 1 \text{ s} + (1/2) \times 2 \text{ m/s} \times 1 \text{ s} = 11.0 \text{ m} \end{aligned}$$

Reading from the graph, v_x (t = 3 s) = 2 m/s. The acceleration is

$$a_x(t = 3 \text{ s}) = \text{slope} = \frac{v_x(\text{at } t = 4 \text{ s}) - v_x(\text{at } t = 2 \text{ s})}{2 \text{ s}} = -2.0 \text{ m/s}^2$$

Assess: Due to the negative slope of the velocity graph between 2 s and 4 s, a negative acceleration was expected.

P2.37. Strategize: Let us assume the acceleration of the car is constant.
Prepare: A visual overview of the car's motion that includes a pictorial representation, a motion diagram, and a list of values is shown below. We label the car's motion along the x-axis. For the driver's maximum (constant) deceleration, kinematic equations are applicable. This is a two-part problem. We will first find the car's displacement during the driver's reaction time when the car's deceleration is zero. Then we will find the displacement as the car is brought to rest with maximum deceleration.



Solve: During the reaction time when $a_0 = 0$, we can use

$$\begin{aligned} x_1 &= x_0 + v_0(t_1 - t_0) + \frac{1}{2}a_0(t_1 - t_0)^2 \\ &= 0 \text{ m} + (20 \text{ m/s})(0.50 \text{ s} - 0 \text{ s}) + 0 \text{ m} = 10 \text{ m} \end{aligned}$$

During deceleration,

$$v_2^2 = v_1^2 + 2a_1(x_2 - x_1) \qquad 0 = (20 \text{ m/s})^2 + 2(-6.0 \text{ m/s}^2)(x_2 - 10 \text{ m}) \Rightarrow x_2 = 43 \text{ m}$$

She has 50 m to stop, so she can stop in time.
Assess: While driving at 20 m/s or 45 mph, a reaction time of 0.5 s corresponds to a distance of 33 feet or only two lengths of a typical car. Keep a safe distance while driving!

P2.38. Strategize: During the phase of constant acceleration, we can use kinematic equations, and during the subsequent phase of no acceleration, we can again use kinematic equations. But we cannot apply kinematic equations across both phases, since the acceleration changes in between.

Prepare: Do this in two parts. First compute the distance traveled during the acceleration phase and what speed it reaches. Then compute the additional distance traveled at that constant speed.
Solve: During the acceleration phase, since $(v_x)_\mathrm{i} = 0$ and $x_\mathrm{i} = 0$,

$$x_\mathrm{f} = \frac{1}{2}a_x(\Delta t)^2 = \frac{1}{2}(250\ \mathrm{m/s^2})(20\ \mathrm{ms})^2 = 0.05\ \mathrm{m} = 5.0\ \mathrm{cm}$$

We also compute the speed it attains.

$$v_x = a_x\Delta t = (250\ \mathrm{m/s^2})(20\ \mathrm{ms}) = 5.0\ \mathrm{m/s}$$

Now the distance traveled at a constant speed of $5.0\ \mathrm{m/s}$.

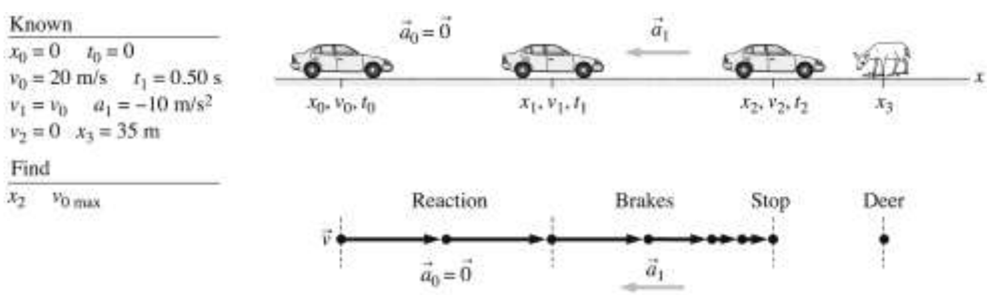
$$\Delta x = v_x\Delta t = (5.0\ \mathrm{m/s})(30\ \mathrm{ms}) = 0.15\ \mathrm{m} = 15\ \mathrm{cm}$$

Now add the two distances to get the total.

$$\Delta x_\mathrm{total} = 5.0\ \mathrm{cm} + 15\ \mathrm{cm} = 20\ \mathrm{cm}$$

Assess: A 20-cm-long tongue is impressive, but possible.

P2.39. Strategize: We will assume that you achieve the maximum magnitude of acceleration possible, and that this acceleration is constant.
Prepare: A visual overview of your car's motion that includes a pictorial representation, a motion diagram, and a list of values is shown below. We label the car's motion along the *x*-axis. For maximum (constant) deceleration of your car, kinematic equations hold. This is a two-part problem. We will first find the car's displacement during your reaction time when the car's deceleration is zero. Then we will find the displacement as you bring the car to rest with maximum deceleration.



Solve: (a) To find x_2, we first need to determine x_1. Using $x_1 = x_0 + v_0(t_1 - t_0)$, we get $x_1 = 0$ m + (20 m/s) (0.50 s – 0 s) = 10 m. Now, with $a_1 = 10$ m/s^2, $v_2 = 0$ and $v_1 = 20$ m/s, we can use

$$v_2^2 = v_1^2 + 2a_1(x_2 - x_1) \Rightarrow 0\ \mathrm{m^2/s^2} = (20\ \mathrm{m/s})^2 + 2(-10\ \mathrm{m/s^2})(x_2 - 10\ \mathrm{m}) \Rightarrow x_2 = 30\ \mathrm{m}$$

The distance between you and the deer is $(x_3 - x_2)$ or (35 m – 30 m) = 5 m.
(b) Let us find $v_{0\,\max}$ such that $v_2 = 0$ m/s at $x_2 = x_3 = 35$ m. Using the following equation,

$$v_2^2 - v_{0\,\max}^2 = 2a_1(x_2 - x_1) \Rightarrow 0\ \mathrm{m^2/s^2} - v_{0\,\max}^2 = 2(-10\ \mathrm{m/s^2})(35\ \mathrm{m} - x_1)$$

Also, $x_1 = x_0 + v_{0\,\max}\,(t_1 - t_0) = v_{0\,\max}\,(0.50\ \mathrm{s} - 0\ \mathrm{s}) = (0.50\ \mathrm{s})v_{0\,\max}$. Substituting this expression for x_1 in the above equation yields

$$-v_{0\,\max}^2 = (-20\ \mathrm{m/s^2})[35\ \mathrm{m} - (0.50\ \mathrm{s})\,v_{0\,\max}] \Rightarrow v_{0\,\max}^2 + (10\ \mathrm{m/s})v_{0\,\max} - 700\ \mathrm{m^2/s^2} = 0$$

The solution of this quadratic equation yields $v_{0\,\max} = 22$ m/s. (The other root is negative and unphysical for the present situation.)
Assess: An increase of speed from 20 m/s to 22 m/s is very reasonable for the car to cover an additional distance of 5 m with a reaction time of 0.50 s and a deceleration of 10 m/s^2.

P2.40. Strategize: Here we must relate acceleration to other kinematic variables like distance and velocity. Let us assume that the acceleration during the compression of the bag is constant, such that we can use kinematic equations.
Prepare: We are given initial and final vertical components of the velocity, as well as the distance of the compression. Equation 2.13 allows us to solve for the acceleration. Let us choose the vertically upward direction to be $+y$.

Solve: Applying Equation 2.13, and paying special attention to the signs of quantities like the compression, we find

$$(v_y)_f^2 = (v_y)_i^2 + 2a_y\Delta y \Rightarrow a_y = \frac{(v_y)_f^2 - (v_y)_i^2}{2\Delta y} = \frac{(0\text{ m/s})^2 - (-6.0\text{ m/s})^2}{2(-0.12\text{ m})} = 150\text{ m/s}^2$$

We are asked to report this in units of g, so we divide by 9.8 m/s^2 to obtain $a_y = 15g$.

Assess: This is much less than the particularly dangerous of $60g$ given in the text.

P2.41. Strategize: We will assume constant acceleration, such that we can use kinematic equations.
Prepare: Call the point where the motorcycle started the origin.
Solve:
(a)

$$a = \frac{\Delta v}{\Delta t} \Rightarrow \Delta t = \frac{\Delta v}{a} = \frac{80\text{ km/h}}{8.0\text{ m/s}^2}\left(\frac{1\text{ h}}{3600\text{ s}}\right)\left(\frac{1000\text{ m}}{1\text{ km}}\right) = 2.78\text{ s} \approx 2.8\text{ s}$$

(b) Compute the distance traveled in 10 s for each vehicle.

For the car: $\Delta x = v\Delta t = (80\text{ km/h})(2.78\text{ s})\left(\frac{1\text{ h}}{3600\text{ s}}\right)\left(\frac{1000\text{ m}}{1\text{ km}}\right) = 61.7\text{ m}$

For the motorcycle: $\Delta x = \frac{1}{2}a(\Delta t)^2 = \frac{1}{2}(8.0\text{ m/s}^2)(2.78\text{ s})^2 = 30.7\text{ m}$

The difference is the distance between the motorcycle and the car at that time. 61.7 m – 30.7 m = 31 m
Assess: The motorcycle will never catch up if it never exceeds the speed of the car.

P2.42. Strategize: In this problem we will use the slope of a velocity vs. time graph to determine acceleration, and other kinematic variables. The acceleration is assumed to be approximately constant for this insect.
Prepare: We can answer part (a) by using Equation 2.11, which is equivalent to determining the slope of a velocity vs. time graph in the case of a constant acceleration. We can then use Equation 2.12 to determine the distance covered by the insect.
Solve: **(a)** The acceleration is given by

$$a_y = \frac{(v_y)_f - (v_y)_i}{\Delta t} = \frac{(0.90\text{ m/s}) - (0\text{ m/s})}{(5.0\times10^{-3}\text{ s})} = 1.8\times10^2\text{ m/s}^2$$

(b) The distance can be determined by

$$\Delta y = (v_y)_i\Delta t + \frac{1}{2}a_y(\Delta t)^2 = (0\text{ m/s})(5\times10^{-3}\text{ m/s}) + \frac{1}{2}(180\text{ m/s}^2)(5\times10^{-3}\text{ m/s})^2 = 2.3\times10^{-3}\text{ m}$$

Assess: The distance covered is very reasonable for an insect in the process of jumping.

P2.43. Strategize: During the acceleration phase, acceleration is constant, and we can use kinematic equations. Once the acceleration drops to zero, acceleration will once again be constant, and we can apply kinematic equations over the phase of constant velocity. But we cannot apply kinematic equations from the beginning of the dash to the end, since acceleration changes in between.
Prepare: Use Equation 2.11 to find the acceleration.

$$v_x = a_x t_1 \qquad \text{where } v_0 = 0 \text{ and } t_0 = 0$$

$$a_x = \frac{v_x}{t_1} = \frac{11.2\text{ m/s}}{2.14\text{ s}} = 5.23\text{ m/s}^2$$

Solve: The distance traveled during the acceleration phase will be

$$\begin{aligned}\Delta x &= \frac{1}{2}a_x(\Delta t)^2\\ &= \frac{1}{2}(5.23\ \text{m/s}^2)(2.14\ \text{s})^2\\ &= 12.0\ \text{m}\end{aligned}$$

The distance left to go at constant velocity is $100\ \text{m} - 12.0\ \text{m} = 88.0\ \text{m}$. The time this takes at the top speed of 11.2 m/s is

$$\Delta t = \frac{\Delta x}{v_x} = \frac{88.0\ \text{m}}{11.2\ \text{m/s}} = 7.86\ \text{s}$$

The total time is $2.14\ \text{s} + 7.86\ \text{s} = 10.0\ \text{s}$.

Assess: This is indeed about the time it takes a world-class sprinter to run 100 m (the world record is a bit under 9.8 s). Compare the answer to this problem with the accelerations given in Problem 2.25 for Carl Lewis.

P2.44. Strategize: In this problem we consider hoverflies falling under the influence of gravity, which yields a constant acceleration. Thus we can use kinematic equations.

Prepare: The hoverflies are released from rest. We can find the distance they would cover if they fell only under the influence of gravity (no wing flapping) using Equation 2.12 and inserting the specified time of 200 ms. For part (b), we can use the same equation again. Only this time we will insert a known distance we want the hoverflies to cover and solve for the time.

Solve: For part (a): $\Delta y = (v_y)_i \Delta t + \frac{1}{2}a_y(\Delta t)^2 = (0\ \text{m/s})(0.200\ \text{s}) + \frac{1}{2}(-9.8\ \text{m/s}^2)(0.200\ \text{s})^2 = -0.20\ \text{m}$. So the hoverflies would have fallen 20 cm in the first 200 ms.

For part (b) $\Delta y = (v_y)_i \Delta t + \frac{1}{2}a_y(\Delta t)^2 \Rightarrow \Delta y = \frac{1}{2}a_y(\Delta t)^2$ since the hoverflies are dropped, not thrown with some initial velocity. Then $\Delta t = \sqrt{\frac{2\Delta y}{a_y}} = \sqrt{\frac{2(-0.40\ \text{m})}{(-9.8\ \text{m/s}^2)}} = 0.29\ \text{s}$ or 290 ms.

Assess: The result from (b) explains why only some hoverflies avoided hitting the bottom when began flying after 200 ms, since the entire fall takes only 290 ms.

P2.45. Strategize: This problem involves freefall, in which the acceleration is constant. Thus, we can use the kinematic equations.

Prepare: The bill must drop its own length in freefall.

Solve:

$$\Delta y = \frac{1}{2}g(\Delta t)^2 \Rightarrow \Delta t = \sqrt{\frac{2\Delta y}{g}} = \sqrt{\frac{2(0.16\ \text{m})}{9.8\ \text{m/s}^2}} = 0.18\ \text{s}$$

Assess: This is less than the typical 0.25 s reaction time, so most people miss the bill.

P2.46. Strategize: This problem involves freefall, in which the acceleration is constant. Thus, we can use the kinematic equations.

Prepare: We will assume that, as stated in the chapter, the bill is held at the top, and the other person's fingers are bracketing the bill at the bottom.

Call the initial position of the top of the bill the origin, $y_0 = 0.0\ \text{m}$, and, for convenience, call the down direction positive.

In free fall the acceleration a_y will be 9.8 m/s^2.

The length of the bill will be Δy, the distance the top of the bill can fall from rest in 0.25 s.

Solve:

$$y_{\text{f}} = \frac{1}{2}a_y(\Delta t)^2 = \frac{1}{2}(9.8\,\text{m/s}^2)(0.25\,\text{s})^2 = 0.31\,\text{m}$$

Assess: This is about twice as long as real bills are (they are really 15.5 cm long), so if a typical reaction time is 0.25 s, then almost no one would catch one in this manner. To catch a bill as small as real bills, one would need a reaction time of 0.13 s.

P2.47. Strategize: This problem involves freefall, in which the acceleration is constant. Thus, we can use the kinematic equations.
Prepare: Use kinematic equations for constant acceleration. Assume the gannet is in free fall during the dive.
Solve:

$$(v_y)_{\text{f}}^2 = (v_y)_{\text{i}}^2 + 2g\Delta y \Rightarrow \Delta y = \frac{(v_y)_{\text{f}}^2}{2g} = \frac{(32\text{ m/s})^2}{2(9.8\text{ m/s}^2)} = 52\text{ m}$$

Assess: 52 meters seems a reasonable height from which to begin the dive.

P2.48. Strategize: Once the trout leaves the water, it is subject to acceleration due to gravity only. The acceleration is constant, so we can use kinematic equations.
Prepare: In order to find the maximum height, we can use Equation 2.13. We recognize that at the maximum height the vertical component of the velocity is momentarily zero. Let us call the vertically upward direction $+y$. For part (b), we must consider that the maximum height may be greater than 1.8 m. That means the trout will rise to its maximum height and then fall back to 1.8 m.
Solve: (a) To find the maximum height, we write

$$\left(v_y\right)_{\text{f}}^2 = \left(v_y\right)_{\text{i}}^2 + 2a_y\Delta y \Rightarrow \Delta y = \frac{\left(v_y\right)_{\text{f}}^2 - \left(v_y\right)_{\text{i}}^2}{2a_y} \Rightarrow \Delta y_{\text{max}} = \frac{\left(0\text{ m/s}\right)^2 - \left(8.0\text{ m/s}\right)^2}{2\left(-9.8\text{ m/s}^2\right)} = 3.3\text{ m.}$$

(b) One way of finding the time required to reach a height of 1.8 m is to use Equation 2.12 and solve the quadratic equation for time:

$$0 = -\Delta y + \left(v_y\right)_{\text{i}}\Delta t + \frac{1}{2}a_y\left(\Delta t\right)^2 \Rightarrow \Delta t = \frac{-\left(v_y\right)_{\text{i}} \pm \sqrt{\left(v_y\right)_{\text{i}}^2 + 2\Delta y a_y}}{a_y}$$

$$\Delta t = \frac{-\left(8.0\text{ m/s}\right) \pm \sqrt{\left(8.0\text{ m/s}\right)^2 + 2\left(1.8\text{ m}\right)\left(-9.8\text{ m/s}^2\right)}}{\left(-9.8\text{ m/s}^2\right)} = 0.27\text{ s or }1.4\text{ s}$$

Clearly the trout rises past a height of 1.8 m before reaching its maximum height and falling back to a height of 1.8 m. Hence, we want the later of the two times that the trout reaches this height: 1.4 s.
Assess: This a reasonable time of flight for a fish jumping out of the water.

P2.49. Strategize: Two objects are in freefall. We must determine where they meet. Since the acceleration is constant during freefall, we can use kinematic equations.
Prepare: We will need to describe the motion of the acrobat and the ball, for which we will use subscripts A and B, respectively. Let us call the vertically upward direction $+y$. To determine when the acrobat catches the ball, we must determine when the two objects have the same vertical positions. We can use Equation 2.12 to describe the change in position of each object. In order for them to meet, we require $\Delta y_{\text{A}} = \Delta y_{\text{B}} + \left(9.0\text{ m}\right)$. That is, however much the ball moves, the acrobat must move upward by 15 m more to cover the initial distance between them.

Solve: We apply Equation 2.12 to each object separately:

$$\Delta y_{\text{A}} = \left(v_{\text{A},y}\right)_{\text{i}} \Delta t + \frac{1}{2} a_y \left(\Delta t\right)^2$$

$$\Delta y_{\text{B}} = \left(v_{\text{B},y}\right)_{\text{i}} \Delta t + \frac{1}{2} a_y \left(\Delta t\right)^2 = \frac{1}{2} a_y \left(\Delta t\right)^2$$

In the second equation we have use the fact that the ball is dropped, not thrown. Note that no subscript is required for the time or the acceleration, since we need the acrobat and ball to be in the same place at the same time, and since both are accelerating only due to gravity. Requiring $\Delta y_{\text{A}} = \Delta y_{\text{B}} + (9.0\text{ m})$, we find

$$\left(v_{\text{A},y}\right)_{\text{i}} \Delta t + \frac{1}{2} a_y \left(\Delta t\right)^2 = (9.0\text{ m}) + \frac{1}{2} a_y \left(\Delta t\right)^2$$

Subtracting $\frac{1}{2} a_y \left(\Delta t\right)^2$ from both sides yields

$$\left(v_{\text{A},y}\right)_{\text{i}} \Delta t = (9.0\text{ m}) \Rightarrow \Delta t = (9.0\text{ m}) / \left(v_{\text{A},y}\right)_{\text{i}} = (9.0\text{ m}) / (8.0\text{ m/s}) = 1.1\text{ s}.$$

Assess: Given the length scales of sever meters, a time of 1.1 s for the two objects to meet is reasonable.

P2.50. Strategize: If we ignore air resistance then the only force acting on both balls after they leave the hand (before they land) is gravity; they are therefore in free fall.
Prepare: Think about ball A's velocity. It decreases until it reaches the top of its trajectory and then increases in the downward direction as it descends. When it gets back to the level of the student's hand it will have the same speed downward that it had initially going upward; it is therefore now just like ball B (only later).
Solve: (a) Because both balls are in free fall they must have the same acceleration, both magnitude and direction, 9.8 m/s^2, down.
(b) Because ball B has the same downward speed when it gets back to the level of the student that ball A had, they will have the same speed when they hit the ground.
Assess: Draw a picture of ball B's trajectory and draw velocity vector arrows at various points of its path.
Air resistance would complicate this problem significantly.

P2.51. Strategize: Once the jumper leaves the ground, he or she is in freefall, in which the acceleration is constant. Thus, we can use the kinematic equations.
Prepare: Use the kinematic equation $(v_y)_{\text{f}}^2 = (v_y)_{\text{i}}^2 + 2a_y\Delta y$ where $(v_y)_{\text{f}}^2 = 0$ at the top of the leap.

We assume $a_y = -9.8\text{ m/s}^2$ and we are given $\Delta y = 1.1\text{ m}$.

Solve:

$$(v_y)_{\text{i}}^2 = -2a_y\Delta y \quad \Rightarrow \quad (v_y)_{\text{i}} = \sqrt{-2a_y\Delta y} = \sqrt{-2(-9.8\text{ m/s}^2)(1.1\text{ m})} = 4.6\text{ m/s}$$

Assess: This is an achievable take-off speed for good jumpers. The units also work out correctly and the two minus signs under the square root make the radicand positive.

P2.52. Strategize: Once the ball is in the air, it is in freefall, in which acceleration is constant. Thus we can use kinematic equations.
Prepare: Assume the trajectory is symmetric (i.e., the ball leaves the ground) so half of the total time is the upward portion and half downward. Put the origin at the ground. Assume no air resistance.
Solve:
(a) On the way down $(v_y)_{\text{i}} = 0\text{ m/s}$, $y_{\text{f}} = 0\text{ m}$, and $\Delta t = 2.6\text{ s}$. Solve for y_{i}.

$$0 = y_{\text{i}} + \frac{1}{2}a_y(\Delta t)^2 \quad \Rightarrow \quad y_{\text{i}} = -\frac{1}{2}a_y(\Delta t)^2 = -\frac{1}{2}(-9.8\text{ m/s}^2)(2.6\text{ s})^2 = 33.1\text{ m}$$

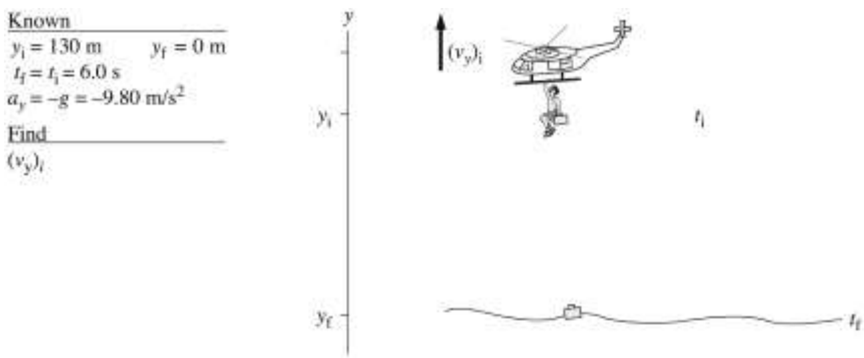
or 33 m to two significant figures.

(b) On the way up $(v_y)_\text{f} = 0$ m/s.

$$(v_y)_\text{i}^2 = -2a_y\Delta y \quad\Rightarrow\quad (v_y)_\text{i} = \sqrt{-2a_y\Delta y} = \sqrt{-2(-9.8\text{ m/s}^2)(33.1\text{ m})} = 25\text{ m/s}$$

Assess: When thinking about real football games, this speed seems reasonable.

P2.53. Strategize: Once the briefcase is dropped it is in freefall, during which the acceleration is constant. Thus we can use kinematic equations.
Prepare: Since the villain is hanging on to the ladder as the helicopter is ascending, he and the briefcase are moving with the same upward velocity as the helicopter. We can calculate the initial velocity of the briefcase, which is equal to the upward velocity of the helicopter. See the following figure.



Solve: We can use Equation 2.12 here. We know the time it takes the briefcase to fall, its acceleration, and the distance it falls. Solving for $(v_y)_\text{i}\Delta t$,

$$(v_y)_\text{i}\Delta t = (y_\text{f} - y_\text{i}) - \frac{1}{2}(a_y)\Delta t^2 = -130\text{ m} - \left[\frac{1}{2}(-9.80\text{ m/s}^2)(6.0\text{ s})^2\right] = 46\text{ m}$$

Dividing by Δt to solve for $(v_y)_\text{i}$,

$$(v_x)_\text{i} = \frac{46\text{ m}}{6.0\text{ s}} = 7.7\text{ m/s}$$

Assess: Note the placement of negative signs in the calculation. The initial velocity is positive, as expected for a helicopter ascending.

P2.54. Strategize: Assume the jumper is in free fall after leaving the ground, so that we can use the kinematic equations.
Prepare: We assume $a_y = -9.8\text{ m/s}^2$ and we are given $(y_\text{f} - y_\text{i}) = 1.1$ m. We can use Equation 2.12 to determine the unknown time.
Solve: Since the trajectory is symmetric we'll compute the time it takes to come down from 1.1 m to the floor and then double it.

$$(y_\text{f} - y_\text{i}) = \frac{1}{2}a_y(\Delta t)^2 \Rightarrow \Delta t = \sqrt{\frac{2(y_\text{f} - y_\text{i})}{a_y}} = \sqrt{\frac{2(-1.1\text{ m})}{-9.8\text{ m/s}^2}} = 0.47\text{ s}$$

The whole "hang time" will be double this, or 0.95 s.
Assess: This is about the time for a big leap. The units also work out correctly and the two minus signs under the square root make the radicand positive.

P2.55. Strategize: Since the stones are in freefall after they leave the climber's hands, acceleration will be constant. Thus we can use kinematic equations.

Prepare: There are several steps in this problem, so first draw a picture and, like the examples in the book, list the known quantities and what we need to find.

Call the pool of water the origin and call $t = 0$ s when the first stone is released. We will assume both stones are in free fall after they leave the climber's hand, so $a_y = -g$. Let a subscript 1 refer to the first stone and a 2 refer to the second.

Known	Find
$(y_1)_i = 50$ m	$(t_2)_f$ or t_f
$(y_2)_i = 50$ m	$(v_2)_i$
$(y_1)_f = 0.0$ m	$(v_1)_f$
$(y_2)_f = 0.0$ m	$(v_2)_f$
$(y_1)_i = -2.0$ m/s	
$(t_2)_f = (t_1)_f$; simply call this t_f	
$(t_2)_i = 1.0$ s	

Solve: (a) Using $(t_1)_i = 0$

$$(y_1)_f = (y_1)_i + (v_1)_i \Delta t + \frac{1}{2} a_y \Delta t^2$$

$$0.0 \text{ m} = 50 \text{ m} + (-2 \text{ m/s})t_f + \frac{1}{2}(-g)t_f^2$$

$$0.0 \text{ m} = 50 \text{ m} - (2 \text{ m/s})t_f - (4.9 \text{ m/s}^2)t_f^2$$

Solving this quadratic equation gives two values for t_f: 3.0 s and -3.4 s, the second of which (being negative) is outside the scope of this problem.

Both stones hit the water at the same time, and it is at $t = 3.0$ s, or 3.0 s after the first stone is released.

(b) For the second stone $\Delta t_2 = t_f - (t_2)_i = 3.0 \text{ s} - 1.0 \text{ s} = 2.0 \text{ s}$. We solve now for $(v_2)_i$.

$$(y_2)_f = (y_2)_i + (v_2)_i \Delta t + \frac{1}{2} a_y \Delta t^2$$

$$0.0 \text{ m} = 50 \text{ m} + (v_2)_i \Delta t_2 + \frac{1}{2}(-g)\Delta t_2^2$$

$$0.0 \text{ m} = 50 \text{ m} + (v_2)_i(2.0 \text{ s}) - (4.9 \text{ m/s}^2)(2.0 \text{ s})^2$$

$$(v_2)_i = \frac{-50 \text{ m} + (4.9 \text{ m/s}^2)(2.0 \text{ s})^2}{2.0 \text{ s}} = -15.2 \text{ m/s}$$

Thus, the second stone is thrown down at a speed of 15 m/s.

(c) Equation 2.11 allows us to compute the final speeds for each stone.

$$(v_y)_f = (v_y)_i + a_y \Delta t$$

For the first stone (which was in the air for 3.0 s):

$$(v_1)_f = -2.0 \text{ m/s} + (-9.8 \text{ m/s}^2)(3.0 \text{ s}) = -31 \text{ m/s}$$

The speed is the magnitude of this velocity, or 31 m/s.

For the second stone (which was in the air for 2.0 s):

$$(v_2)_f = -15.2 \text{ m/s} + (-9.8 \text{ m/s}^2)(2.0 \text{ s}) = -35 \text{ m/s}$$

The speed is the magnitude of this velocity, or 35 m/s.

Assess: The units check out in each of the previous equations. The answers seem reasonable. A stone dropped from rest takes 3.2 s to fall 50 m; this is comparable to the first stone, which was able to fall the 50 m in only 3.0 s because it started with an initial velocity of -2.0 m/s. So we are in the right ballpark. And the second stone would have to be thrown much faster to catch up (because the first stone is accelerating).

P2.56. Strategize: This is an estimation problem, so a range of answers may be acceptable. Note that the slope of the velocity vs. time graph is changing, meaning the acceleration is not constant. We cannot use kinematic equations in solving this problem.
Prepare: Given the velocity vs. time graph we need to compute slopes to determine accelerations and then estimate the area under the curve to determine distance traveled.
Solve:
(a) At the origin a tangent line looks like it goes through $(0\text{ s},\ 0\text{ m/s})$ and $(2\text{ s},\ 10\text{ m/s})$, so the slope is

$$a(0\text{ s}) = \frac{10\text{ m/s}}{2.0\text{ s}} = 5\text{ m/s}^2$$

(b) Compute slopes similarly for $t = 2.0$ s and $t = 4.0$ s.

$$a(2.0\text{ s}) = \frac{8.0\text{ m/s}}{4.0\text{ s}} = 2\text{ m/s}^2 \qquad a(4.0\text{ s}) = \frac{5.0\text{ m/s}}{6.0\text{ s}} = 0.8\text{ m/s}^2$$

(c) We estimate the area under the curve. It looks like the area under the curve but above 10 m/s is a bit larger than the area above the curve but below 10 m/s. If they were equal the area would be $(8\text{ s})(10\text{ m/s}) = 80\text{ m}$, so we estimate a little more than 80 m.
Assess: It is very difficult to get a good estimate of slopes and areas from such small graphs, but the answers are reasonable. We do see the acceleration decreasing as we expected.

P2.57. Strategize: This problem involves two phases, each of which is a constant velocity phase. But in between, the truck speeds up and has non-zero acceleration briefly. Thus, we can apply kinematic equations to either constant-velocity phase of the trip, but not to the trip as a whole.
Prepare: Assume the truck driver is traveling with constant velocity during each segment of his trip.
Solve: Since the driver usually takes 8 hours to travel 440 miles, his usual velocity is

$$v_{\text{usual }x} = \frac{\Delta x}{\Delta t_{\text{usual}}} = \frac{440\text{ mi}}{8\text{ h}} = 55\text{ mph}$$

However, during this trip he was driving slower for the first 120 miles. Usually he would be at the 120 mile point in

$$\Delta t_{\text{usual at 120 mi}} = \frac{\Delta x}{v_{\text{usual at 120 mi }x}} = \frac{120\text{ mi}}{55\text{ mph}} = 2.18\text{ h}$$

He is 15 minutes, or 0.25 hr late. So the time he’s taken to get 120 mi is 2.18 hr + 0.25 hr = 2.43 hr. He wants to complete the entire trip in the usual 8 hours, so he only has 8 hr – 2.43 hr = 5.57 hr left to complete 440 mi – 120 mi = 320 mi. So he needs to increase his velocity to

$$v_{\text{to catch up }x} = \frac{\Delta x}{\Delta t_{\text{ to catch up}}} = \frac{320\text{ mi}}{5.57\text{ h}} = 57\text{ mph}$$

where additional significant figures were kept in the intermediate calculations.
Assess: This result makes sense. He is only 15 minutes late.

P2.58. Strategize: This problems involves no accelerations, only constant-velocity motion.
Prepare: We can describe the position of either runner using $\Delta x = v_x \Delta t$. We will do this for each runner separately and use subscripts J and A for the respective runners. However, since the runners start at different times, we will need to be careful in noting what time we call $t = 0$. Let us choose the moment Jenny starts running as $t = 0$, such that $\Delta t_{\text{J}} = t$ and $\Delta t_{\text{A}} = t - (15\text{ s})$. In order for the Alyssa to catch up with Jenny, we require $\Delta x_{\text{J}} = \Delta x_{\text{A}}$.

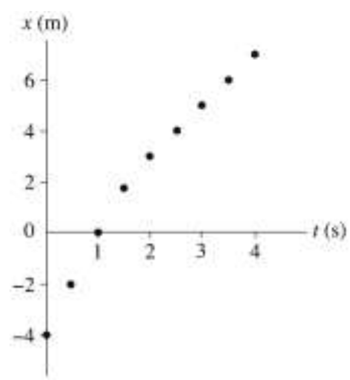
Solve: For Alyssa, we have $\Delta x_A = v_{A,x}\Delta t_A = v_{A,x}\left(t-(15\text{ s})\right)$ and for Jenny we have $\Delta x_J = v_{J,x}\Delta t_J = v_{J,x}t$. Requiring that $\Delta x_J = \Delta x_A$, we find $v_{A,x}\left(t-(15\text{ s})\right) = v_{J,x}t \Rightarrow t = \dfrac{(15\text{ s})v_{A,x}}{(v_{A,x}-v_{J,x})} = \dfrac{(15\text{ s})(4.0\text{ m/s})}{((4.0\text{ m/s})-(3.8\text{ m/s}))} = 300\text{ s}$ or 5.0 min.

Assess: Since the running speeds are so similar, it is plausible that it would take a few minutes for Alyssa to catch up with Jenny.

P2.59. Strategize: The timing between images in Figure P2.59 is constant. We expect to find a a period of constant velocity, followed by a decrease in speed, followed by another period of constant (lower) velocity.
Prepare: We assume that the track, except for the sticky section, is frictionless and aligned along the *x*-axis. Because the motion diagram of Figure P2.59 is made at two frames of film per second, the time interval between consecutive ball positions is 0.5 s.
Solve: (a)

Times (s)	Position
0	–4.0
0.5	–2.0
1.0	0
1.5	1.8
2.0	3.0
2.5	4.0
3.0	5.0
3.5	6.0
4.0	7.0

(b)



(c) $\Delta x = x$ (at $t = 1$ s) – x (at $t = 0$ s) = 0 m – (–4 m) = 4 m.
(d) $\Delta x = x$ (at $t = 4$ s) – x (at $t = 2$ s) = 7 m – 3 m = 4 m.
(e) From $t = 0$ s to $t = 1$ s, $v_s = \Delta x/\Delta t = 4$ m/s.
(f) From $t = 2$ s to $t = 4$ s, $v_x = \Delta x/\Delta t = 2$ m/s.
(g) The average acceleration is

$$a = \frac{\Delta v}{\Delta t} = \frac{2\text{ m/s} - 4\text{ m/s}}{2\text{ s} - 1\text{ s}} = -2\text{ m/s}^2$$

Assess: The sticky section has decreased the ball's speed from 4 m/s, to 2 m/s, which is a reasonable magnitude.

P2.60. Strategize: This problem involves motion at constant speeds.

Prepare: The position of either runner can be described by $\Delta x = v_x \Delta t.$ We will apply this to each runner separately and use subscripts H and K for the respective runners. In order for Hanna to pass Kara, the distance covered by Hanna and Kara must satisfy $\Delta x_{\text{H}} = \Delta x_{\text{K}} + (400 \text{ m}).$

Solve: We have $\Delta x_{\text{H}} = v_{\text{H},x}\Delta t$ and $\Delta x_{\text{K}} = v_{\text{K},x}\Delta t.$ Note that no subscript is required on the time. Requiring $\Delta x_{\text{H}} = \Delta x_{\text{K}} + (400 \text{ m}),$ we find

$$v_{\text{H},x}\Delta t = (400 \text{ m}) + v_{\text{K},x}\Delta t \Rightarrow \Delta t = \frac{(400 \text{ m})}{(v_{\text{H},x} - v_{\text{K},x})}.$$

The x components of the women's velocities can be calculated from the given distances and times for the total run:

$$v_{\text{H},x} = \frac{(12.5)(400 \text{ m})}{(15.3 \text{ min})}\left(\frac{1 \text{ min}}{60 \text{ s}}\right) = 5.45 \text{ m/s}$$

$$v_{\text{K},x} = \frac{(12.5)(400 \text{ m})}{(17.5 \text{ min})}\left(\frac{1 \text{ min}}{60 \text{ s}}\right) = 4.76 \text{ m/s}$$

Inserting these into the equation above, we find

$$\Delta t = \frac{(400 \text{ m})}{((5.45 \text{ m/s}) - (4.76 \text{ m/s}))} = 580 \text{ s}$$

Thus when Hanna passes Kara, Hanna has traveled $\Delta x_{\text{H}} = v_{\text{H},x}t = (5.45 \text{ m/s})(580 \text{ s}) = 3.16 \times 10^3 \text{ m},$ or 7.9 laps.

Assess: One could check the math by finding how many laps Kara had completed after 580 s. One finds $\Delta x_{\text{H}} = v_{\text{H},x}t = (4.76 \text{ m/s})(580 \text{ s}) = 2.76 \times 10^3 \text{ m}$ or 6.9 laps. This confirms that Hanna passes Kara at that time.

P2.61. Strategize: This is an estimation problem, so a range of answers may be acceptable.

Prepare: We will represent the jetliner's motion to be along the *x*-axis.

Solve:

(a) Using $a_x = \Delta v/\Delta t,$ we have,

$$a_x(t = 0 \text{ to } t = 10 \text{ s}) = \frac{23 \text{ m/s} - 0 \text{ m/s}}{10 \text{ s} - 0 \text{ s}} = 2.3 \text{ m/s}^2 \qquad a_x(t = 20 \text{ s to } t = 30 \text{ s}) = \frac{69 \text{ m/s} - 46 \text{ m/s}}{30 \text{ s} - 20 \text{s}} = 2.3 \text{ m/s}^2$$

For all time intervals a_x is 2.3 m/s^2. In *g*s this is (2.3 m/s^2)/(9.8 m/s^2) = 0.23*g*

(b) Because the jetliner's acceleration is constant, we can use kinematics as follows:

$$(v_x)_{\text{f}} = (v_x)_{\text{i}} + a_x(t_{\text{f}} - t_{\text{i}}) \Rightarrow 80 \text{ m/s} = 0 \text{ m/s} + (2.3 \text{ m/s}^2)(t_{\text{f}} - 0 \text{ s}) \Rightarrow t_{\text{f}} = 34.8 \text{ s}$$

or 35 s to two significant figures.

(c) Using the above values, we calculate the takeoff distance as follows:

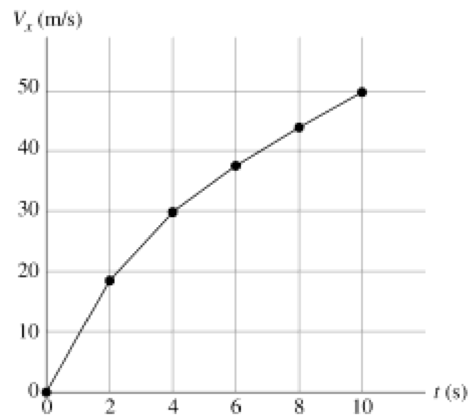
$$x_{\text{f}} = x_{\text{i}} + (v_x)_{\text{i}}(t_{\text{f}} - t_{\text{i}}) + \frac{1}{2}a_x(t_{\text{f}} - t_{\text{i}})^2 = 0 \text{ m} + (0 \text{ m/s})(34.8 \text{ s}) + \frac{1}{2}(2.3 \text{ m/s}^2)(34.8 \text{ s})^2 = 1390 \text{ m}$$

For safety, the runway should be 3 × 1390 m = 4.2 km.

P2.62. Strategize: In part (a), we convert units and plot the x component of the velocity vs. time. In part (b) we will use our plot from (a) to graphically estimate the distance covered by the car. Finally, for part (c), we can determine the instantaneous acceleration by finding the slope of the velocity curve very near the specified points.

Prepare: We will represent the automobile's motion along the *x*-axis. Also, as the hint says, acceleration is the slope of the velocity graph. The distance traveled is the area under the velocity vs. time curve, which we will estimate graphically.
Solve: (a) First convert mph to m/s.

t (s)	v_x (mph)	v_x (m/s)
0	0	0
2	41	18.3
4	66	29.5
6	83	37.1
8	97	43.4
10	110	49.2



The acceleration is not constant because the velocity-versus-time graph is not a straight line.
(b) This is an estimation problem, so many answers are acceptable. If the velocity vs time curve were a straight line, the area under the curve would be easy to compute: $\frac{1}{2}(v_x)_{\text{max}}\,\Delta t_{\text{total}} = \frac{1}{2}(49.2 \text{ m/s})(10 \text{ s}) = 250 \text{ m}$

Since the curve is not a straight line, but is bowed upward slightly, we expect the actual distance covered will be somewhat higher than this estimate. We could inflate our estimate by a few percent to match this expectation. 270 m is a very good estimate.
(c) Acceleration is the slope of the velocity graph. You can use a straightedge to estimate the slope of the graph at $t = 2$ s and at $t = 8$ s. Alternatively, you can estimate the slope using the two data points on either side of 2 s and 8 s.

$$a_x(\text{at } 2\text{ s}) \approx \frac{v_x(\text{at } 4\text{ s}) - v_x(\text{at } 0\text{ s})}{4\text{ s} - 0\text{ s}} = \frac{29.5 \text{ m/s} - 0.0 \text{ m/s}}{4 \text{ s}} = 7.4 \text{ m/s}^2$$
$$a_x(\text{at } 8\text{ s}) \approx \frac{v_x(\text{at } 10\text{ s}) - v_x(\text{at } 6\text{ s})}{10\text{ s} - 6\text{ s}} = \frac{49.2 \text{ m/s} - 37.1 \text{ m/s}}{4 \text{ s}} = 3.0 \text{ m/s}^2$$

Assess: The graph in (a) shows that the Porsche 944 Turbo's acceleration is not a constant, but decreases with increasing time.

P2.63. Strategize: This is an estimation problem. For all parts, we will read approximate values from the graph.
Prepare: The acceleration is given by $a_x = \frac{\Delta v_x}{\Delta t}$, which is the slope of the graph provided. The maximum acceleration is near the beginning of the time shown, where the slope is maximal. The distance traveled is the area under the curve of the graph. It would be difficult to calculate this exactly,but since the curve is roughly linear between the times 0 and 50 ms, we can approximate the area using $\frac{1}{2}\left((v_x)_{\text{end}} - (v_x)_{\text{start}}\right)\left(t_{\text{end}} - t_{\text{start}}\right)$.

Solve: **(a)** The slope is largest between $t=0$ and $t=50$ ms. In this interval, v_x changes from 0 to approximately 0.8 m/s. Thus

$$(a_x)_{\text{max}} = \frac{v_x(t=50\text{ ms}) - v_x(t=0)}{50\text{ ms} - 0} = \frac{(0.8\text{ m/s}) - (0\text{ m/s})}{(50\times10^{-3}\text{ s}) - 0} = 16\text{ m/s}^2$$

Dividing this by 9.8 m/s^2 yields $(a_x) = 1.6g$.

(b) We can estimate the acceleration at this time by using the velocities at the times just before and just after:

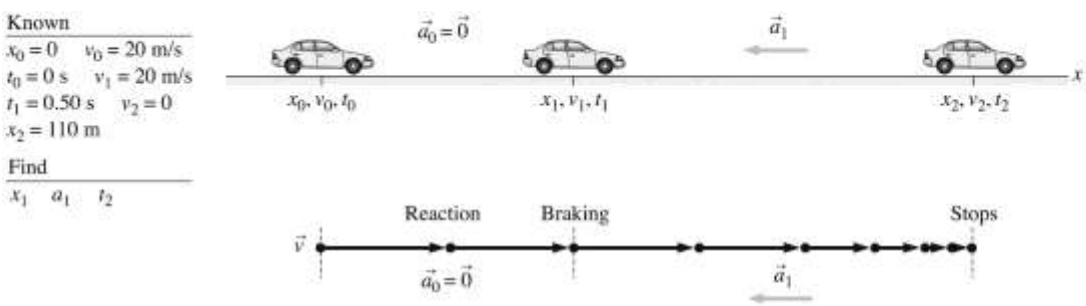
$$a_x(t=150\text{ ms}) = \frac{v_x(t=200\text{ ms}) - v_x(t=100\text{ ms})}{(200\text{ ms}) - (100\text{ ms})} = \frac{(1.8\text{ m/s}) - (1.3\text{ m/s})}{(100\times10^{-3}\text{ s}) - 0} = 5\text{ m/s}^2 \text{ or } 0.5g$$

(c) We estimate the area under the curve to be

$$\Delta x = \frac{1}{2}\left((v_x)_{\text{end}} - (v_x)_{\text{start}}\right)(t_{\text{end}} - t_{\text{start}}) = \frac{1}{2}(0.8\text{ m/s})(50\times10^{-3}\text{ s}) = 0.02\text{ m or 2 cm.}$$

Assess: Since the large initial acceleration is only applied over a short time, a displacement of 2 cm during the first 50 ms is reasonable.

P2.64. **Strategize:** We will assume constant acceleration, such that we can use the kinematic equations.
Prepare: Shown below is a visual overview of your car's motion that includes a pictorial representation, a motion diagram, and a list of values. We label the car's motion along the *x*-axis. This is a two-part problem. First, we will find the car's displacement during your reaction time when the car's deceleration is zero. This will give us the distance over which you must brake to bring the car to rest. Kinematic equations can then be used to find the required deceleration.



Solve: **(a)** During the reaction time,

$$x_1 = x_0 + v_0(t_1 - t_0) + 1/2\, a_0(t_1 - t_0)^2$$
$$= 0\text{ m} + (20\text{ m/s})(0.70\text{ s} - 0\text{ s}) + 0\text{ m} = 14\text{ m}$$

After reacting, $x_2 - x_1 = 110\text{ m} - 14\text{ m} = 96\text{ m}$, that is, you are 96 m away from the intersection.
(b) To stop successfully,

$$v_2^2 = v_1^2 + 2a_1(x_2 - x_1) \Rightarrow (0\text{ m/s})^2 = (20\text{ m/s})^2 + 2a_1(96\text{ m}) \Rightarrow a_1 = -2.1\text{ m/s}^2$$

(c) The time it takes to stop can be obtained as follows:

$$v_2 = v_1 + a_1(t_2 - t_1) \Rightarrow 0\text{ m/s} = 20\text{ m/s} + (-2.1\text{ m/s}^2)(t_2 - 0.70\text{ s}) \Rightarrow t_2 = 10\text{ s}$$

P2.65. **Strategize:** Remember that in estimation problems different people may make slightly different estimates. That is OK as long as they end up with reasonable answers that are the same order-of-magnitude. We will assume constant acceleration, such that we can use the kinematic equations.

Prepare: We can use Equation 2.12, and noting that the initial speed is zero, we have

$$x_f = \frac{1}{2}a_x(\Delta t)^2$$

Solve: (a) I guessed about 1.0 cm; this was verified with a ruler and mirror.
(b) We are given a closing time of 0.024 s, so we can compute the acceleration from rearranging the kinematic equations.

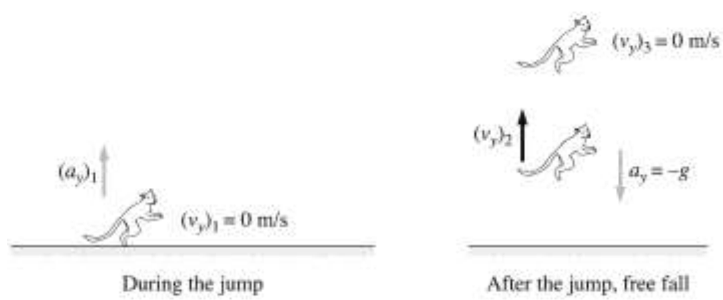
$$a_x = \frac{2x_f}{(\Delta t)^2} = \frac{2(1.0\ \text{cm})}{(0.024\ \text{s})^2}\left(\frac{1\ \text{m}}{100\ \text{cm}}\right) = 35\ \text{m/s}^2$$

(c) Since we know the Δt and the a and $v_i = 0.0\ \text{m/s}$, we can compute the final speed from Equation 2.11:

$$v_f = a\Delta t = (35\ \text{m/s}^2)(0.024\ \text{s}) = 0.84\ \text{m/s}$$

Assess: The uncertainty in our estimates might or might not barely justify two significant figures.
The final speed is reasonable; if we had arrived at an answer 10 times bigger or 10 times smaller we would probably go back and check our work. The lower lid gets smacked at this speed up to 15 times per minute!

P2.66. Strategize: Whenever the acceleration is approximately constant, we can use the kinematic equations.
Prepare: There are two separate segments of this motion, the jump and the free fall after the jump.
Solve: See the following figure. Before the jump, the velocity of the bush baby is 0 m/s.



We could solve for the acceleration of the bush baby during the jump using Equation 2.13 if we knew the final velocity the bush baby reached at the end of the jump, $(v_y)_2$.
We can find this final velocity from the second part of the motion. During this part of the motion the bush baby travels with the acceleration of gravity. The initial velocity it has obtained from the jump is $(v_y)_2$. When it reaches its maximum height its velocity is $(v_y)_3 = 0$ m/s. It travels 2.3 m during the upward free-fall portion of its motion. The initial velocity it had at the beginning of the free-fall motion can be calculated from

$$(v_y)_2 = \sqrt{-2(a_y)_2\Delta y_2} = \sqrt{-2(-9.80\ \text{m/s}^2)(2.3\ \text{m})} = 6.714\ \text{m/s}$$

This is the bush baby's final velocity at the end of the jump, just as it leaves the ground, legs straightened. Using this velocity and Equation 2.13 we can calculate the acceleration of the bush baby during the jump.

$$(a_y)_1 = \frac{(v_y)_2^2 - (v_y)_1^2}{2\Delta y_1} = \frac{(6.714\ \text{m/s})^2 - (0\ \text{m/s})_1^2}{2(0.16\ \text{m})} = 140\ \text{m/s}^2$$

In g's, the acceleration is $\dfrac{140\ \text{m/s}^2}{9.80\ \text{m/s}^2} = 14g$'s.

Assess: This is a very large acceleration, which is not unexpected considering the height of the jump. Note the acceleration during the jump is positive, as expected.

P2.67. Strategize: We assume constant acceleration so we can use the kinematic equations.
Prepare: Fleas are amazing jumpers; they can jump several times their body height—something we cannot do. Equation 2.13 relates the three variables we are concerned with in part (a): speed, distance (which we know), and acceleration (which we want).

$$(v_y)_f^2 = (v_y)_i^2 + 2a_y \Delta y$$

In part (b) we use Equation 2.12 because it relates the initial and final velocities and the acceleration (which we know) with the time interval (which we want).

$$(v_y)_f = (v_y)_i + a_y \Delta t$$

Part (c) is about the phase of the jump *after* the flea reaches takeoff speed and leaves the ground. So now it is $(v_y)_i$, that is 1.0 m/s instead of $(v_y)_f$. And the acceleration is not the same as in part (a)—it is now $-g$ (with the positive direction up) since we are ignoring air resistance. We do not know the time it takes the flea to reach maximum height, so we employ Equation 2.13 again because we know everything in that equation except Δy.
Solve: (a) Use $(v_y)_i = 0.0$ m/s and rearrange Equation 2.13.

$$a_y = \frac{(v_y)_f^2}{2\Delta y} = \frac{(1.0\text{ m/s})^2}{2(0.50\text{ mm})}\left(\frac{1000\text{ mm}}{1\text{ m}}\right) = 1000\text{ m/s}^2$$

(b) Having learned the acceleration from part **(**a**)** we can now rearrange Equation 2.11 to find the time it takes to reach takeoff speed. Again use $(v_y)_i = 0.0$ m/s.

$$\Delta t = \frac{(v_y)_f}{a_y} = \frac{1.0\text{ m/s}}{1000\text{ m/s}^2} = .0010\text{ s}$$

(c) This time $(v_y)_f = 0.0$ m/s as the flea reaches the top of its trajectory. Rearrange Equation 2.13 to get

$$\Delta y = \frac{-(v_y)_i^2}{2a_y} = \frac{-(1.0\text{ m/s})^2}{2(-9.8\text{ m/s}^2)} = 0.051\text{ m} = 5.1\text{ cm}$$

Assess: Just over 5 cm is pretty good considering the size of a flea. It is about 10–20 times the size of a typical flea. Check carefully to see that each answer ends up in the appropriate units.
The height of the flea at the top will round to 5.2 cm above the ground if you include the 0.050 cm during the initial acceleration phase before the feet actually leave the ground.

P2.68. Strategize: If we assume the acceleration is constant as the beetle speeds up, and is then (a different) constant after the beetle is in the air, then we can use kinematic equations during each of those two phases, separately.
Prepare: Use the kinematic equations with $(v_y)_i = 0$ m/s in the acceleration phase.

Solve:
(a) It leaves the ground with the final speed of the jumping phase.

$$(v_y)_f^2 = 2a_y\Delta y = 2(400)(9.8\text{ m/s}^2)(0.0060\text{ m}) \quad \Rightarrow \quad (v_y)_f = 6.86\text{ m/s}$$

or 6.9 m/s to two significant figures.
(b)

$$\Delta t = \frac{\Delta v_y}{a_y} = \frac{6.86\text{ m/s}}{(400)(9.8\text{ m/s}^2)} = 1.7496\text{ ms} \approx 1.7\text{ ms}$$

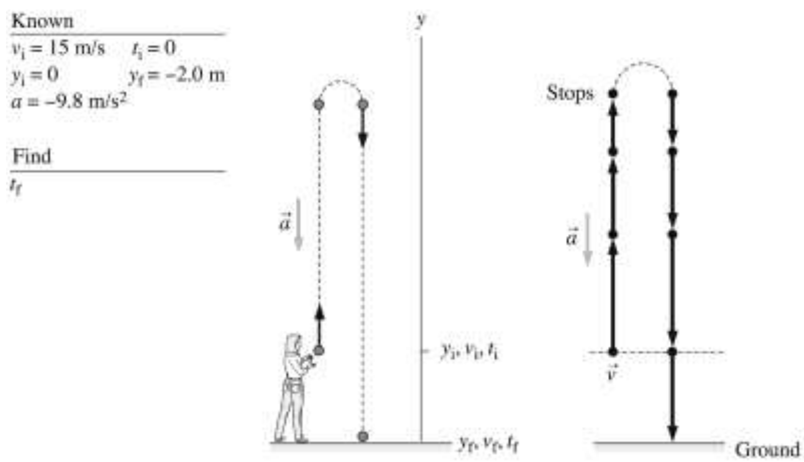
(c) Now the initial speed for the free-fall phase is the final speed of the jumping phase and $(v_y)_f = 0$.

$$(v_y)_i^2 = -2a_y\Delta y \quad \Rightarrow \quad \Delta y = \frac{(v_y)_i^2}{-2a_y} = \frac{(6.86 \text{ m/s})^2}{-2(-9.8 \text{ m/s}^2)} = 2.4 \text{ m}$$

Assess: This is an amazing height for a beetle to jump, but given the large acceleration, this sounds right.

P2.69. Strategize: As soon as the ball leaves the student's hand, it is falling freely and thus kinematic equations hold.

Prepare: A visual overview of the ball's motion that includes a pictorial representation, a motion diagram, and a list of values is shown below. We label the ball's motion along the *y*-axis. The ball's acceleration is equal to the acceleration due to gravity that always acts vertically downward toward the center of the earth. The initial position of the ball is at the origin where $y_i = 0$, but the final position is below the origin at $y_f = -2.0$ m. Recall sign conventions, which tell us that v_i is positive and a is negative.



Solve: With all the known information, it is clear that we must use

$$y_f = y_i + v_i\Delta t + \frac{1}{2}a\Delta t^2$$

Substituting the known values

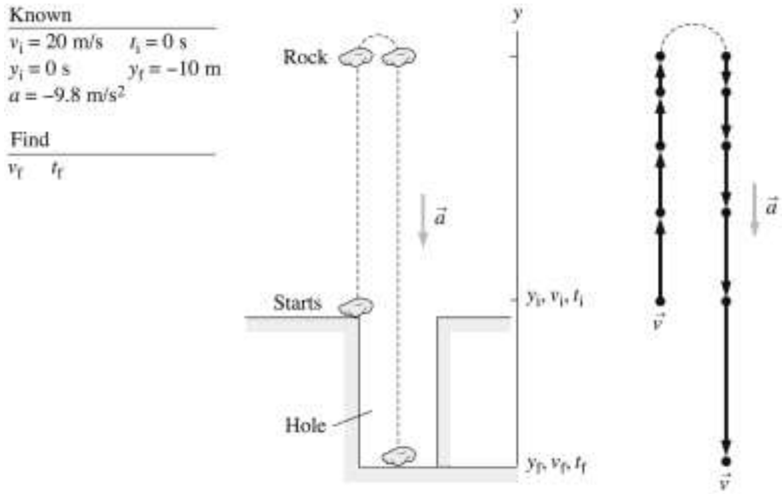
$$-2 \text{ m} = 0 \text{ m} + (15 \text{ m/s})t_f + (1/2)(-9.8 \text{ m/s}^2)t_f^2$$

The solution of this quadratic equation gives $t_f = 3.2$ s. The other root of this equation yields a negative value for t_f, which is not physical for this problem.

Assess: A time of 3.2 s is reasonable.

P2.70. Strategize: As soon as the rock is tossed up, it falls freely and thus kinematic equations hold.

Prepare: A visual overview of the rock's motion that includes a pictorial representation, a motion diagram, and a list of values is shown below. We represent the rock's motion along the *y*-axis. The rock's acceleration is equal to the acceleration due to gravity that always acts vertically downward toward the center of the earth. The initial position of the rock is at the origin where $y_i = 0$, but the final position is below the origin at $y_f = -10$ m. Recall sign conventions which tell us that v_i is positive and a is negative.



Solve: (a) Substituting the known values into $y_f = y_i + v_i \Delta t + \frac{1}{2} a \Delta t^2$, we get

$$-10\text{ m} = 0\text{ m} + 20\text{ (m/s)}t_f + \frac{1}{2}(-9.8\text{ m/s}^2)t_f^2$$

One of the roots of this equation is negative and is not physically relevant. The other root is $t_f = 4.53$ s which is the answer to part (b). Using $v_f = v_i + a\Delta t$, we obtain

$$v_f = 20\text{(m/s)} + (-9.8\text{ m/s}^2)(4.53\text{ s}) = -24\text{ m/s}$$

(b) The time is 4.5 s.
Assess: A time of 4.5 s is a reasonable value. The rock's velocity as it hits the bottom of the hole has a negative sign because of its downward direction. The magnitude of 24 m/s compared to 20 m/s when the rock was tossed up is consistent with the fact that the rock travels an additional distance of 10 m into the hole.

P2.71. Strategize: We treat the diver's motion as one-dimensional (purely vertical). Since the diver falls under the influence of gravity, acceleration is constant and we can use kinematic equations. Let us choose our axes such that $+y$ points vertically upward.

Prepare: We know the initial velocity of the diver, the acceleration due to gravity, and the height above the water. The first part of the question can be solved by applying Equation 2.12: $y_f = y_i + (v_y)_i \Delta t + \frac{1}{2} a_y (\Delta t)^2$, and solving for the time. Once the time is known, Equation 2.11 can be used to determine the final speed: $(v_y)_f = (v_y)_i + a_y \Delta t$.

Solve: (a) From Equation 2.12, we have a quadratic equation in time. Thus the solutions for the unknown time are given by

$$\Delta t = \left(-(v_y)_i \pm \sqrt{(v_y)_i^2 - 4\left(\frac{1}{2}a_y\right)(-\Delta y)}\right)\frac{1}{a_y}$$

$$\Delta t = \left(-(6.3\text{ m/s}) \pm \sqrt{(6.3\text{ m/s})^2 - 4\left(\frac{1}{2}(-9.8\text{ m/s}^2)\right)(-(-3.0\text{ m}))}\right)\frac{1}{(-9.8\text{ m/s}^2)}$$

$$\Delta t = -0.37\text{ s or } 1.7\text{ s}$$

Because we want to know a duration of time after which the diver will reach the water, we want a positive time, so our answer is 1.7 s.
(b) Using the answer from part (a) (prior to rounding), Equation 2.11 yields

$$(v_y)_f = (v_y)_i + a_y \Delta t = (6.3\text{ m/s}) + (-9.8\text{ m/s}^2)(1.66\text{ s}) = -9.9\text{ m/s}.$$

We are asked for the speed, not the velocity or any component of the velocity. So we report 9.9 m/s.

Assess: Our answer to the first part fits our intuition that it takes around a second to go from a diving board to the water. The answer to the second part is reasonable for two reasons. Firstly, the component we calculated had the correct sign (since the diver should be moving downward). Secondly, the final speed is greater than the initial speed. This is reasonable since the diver would reach his initial speed as he fell down past the diving board, and would continue to speed up as he approached the water.

P2.72. **Strategize:** Since constant acceleration is involved, we can use kinematic equations.

Prepare: We are given initial and final speeds, and a displacement, and we are asked for acceleration. Equation 2.13 can be used to answer this problem. All values must first be converted to SI units. Let us call the initial direction of motion the $+x$ direction.

Solve: We start by expressing all given quantities in SI units:

$$(75\text{ mph})\left(\frac{1610\text{ m}}{1\text{ mi}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right)=33.5\text{ m/s}$$

$$(55\text{ mph})\left(\frac{1610\text{ m}}{1\text{ mi}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right)=24.6\text{ m/s}$$

$$(0.5\text{ mi})\left(\frac{1610\text{ m}}{1\text{ mi}}\right)=805\text{ m}$$

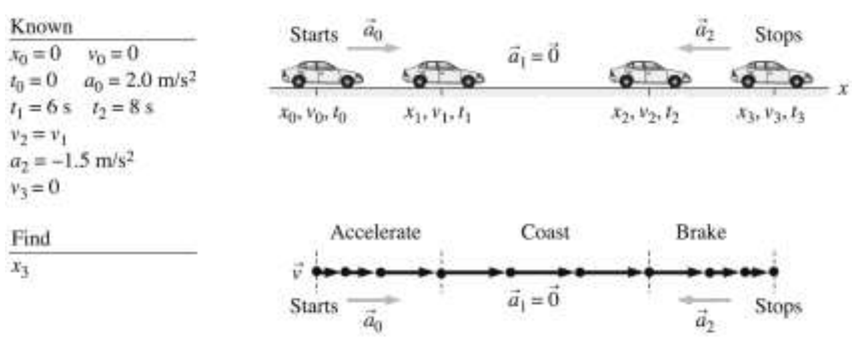
Employing Equation 2.13, we find

$$(v_x)_\text{f}^2=(v_x)_\text{i}^2+2a_x\Delta x\Rightarrow a_x=\frac{(v_x)_\text{f}^2-(v_x)_\text{i}^2}{2\Delta x}=\frac{(24.6\text{ m/s})^2-(33.5\text{ m/s})^2}{2(805\text{ m})}=-0.32\text{ m/s}^2$$

Assess: Since the change in speed can occur over such a long distance, we expect a relatively small answer, and since the vehicle is slowing in the x direction, we expected the answer to be negative as well. This answer is very reasonable.

P2.73. **Strategize:** Clearly the acceleration changes in this problem. But during each phase of the motion (speed up, constant velocity, slowing down), let us assume that the acceleration is constant over each interval individually. That way we can apply the kinematic equations to each interval separately.

Prepare: A visual overview of car's motion that includes a pictorial representation, a motion diagram, and a list of values is shown below. We label the car's motion along the *x*-axis. This is a three-part problem. First the car accelerates, then it moves with a constant speed, and then it decelerates. The total displacement between the stop signs is equal to the sum of the three displacements, that is, $x_3 - x_0 = (x_3 - x_2) + (x_2 - x_1) + (x_1 - x_0)$.



Solve: First, the car accelerates:

$$v_1 = v_0 + a_0(t_1 - t_0) = 0\text{ m/s} + (2.0\text{ m/s}^2)(6\text{ s} - 0\text{ s}) = 12\text{ m/s}$$

$$x_1 = x_0 + v_0(t_1 - t_0) + \frac{1}{2}a_0(t_1 - t_0)^2 = 0\text{ m} + \frac{1}{2}(2.0\text{ m/s}^2)(6\text{ s} - 0\text{ s})^2 = 36\text{ m}$$

Second, the car moves at v_1:

$$x_2 - x_1 = v_1(t_2 - t_1) + \frac{1}{2}a_1(t_2 - t_1)^2 = (12\text{ m/s})(8\text{ s} - 6\text{ s}) + 0\text{ m} = 24\text{ m}$$

Third, the car decelerates:

$$v_3 = v_2 + a_2(t_3 - t_2) \Rightarrow 0 \text{ m/s} = 12 \text{ m/s} + (-1.5 \text{ m/s}^2)(t_3 - t_2) \Rightarrow (t_3 - t_2) = 8 \text{ s}$$

$$x_3 = x_2 + v_2(t_3 - t_2) + \frac{1}{2}a_2(t_3 - t_2)^2 \Rightarrow x_3 - x_2 = (12 \text{ m/s})(8 \text{ s}) + \frac{1}{2}(-1.5 \text{ m/s}^2)(8 \text{ s})^2 = 48 \text{ m}$$

Thus, the total distance between stop signs is

$$x_3 - x_0 = (x_3 - x_2) + (x_2 - x_1) + (x_1 - x_0) = 48 \text{ m} + 24 \text{ m} + 36 \text{ m} = 108 \text{ m}$$

or 110 m to two significant figures.

Assess: A distance of approximately 360 ft in a time of around 16 s with an acceleration/deceleration is reasonable.

P2.74. Strategize: The problem describes a phase of constant acceleration, meaning we can use kinematic equations.

Prepare: Since we are given the initial speed (rest), the final speed and the acceleration of the tongue, we can determine the time required using Equation 2.11. We can determine the distance using Equation 2.13.

Solve: (a) Inserting values into Equation 2.11, we have:

$$(v_x)_\text{f} = (v_x)_\text{i} + a_x \Delta t \Rightarrow \Delta t = \frac{(v_x)_\text{f} - (v_x)_\text{i}}{a_x} = \frac{(5.0 \text{ m/s}) - (0 \text{ m/s})}{(2500 \text{ m/s}^2)} = 2.0 \times 10^{-3} \text{ s}$$

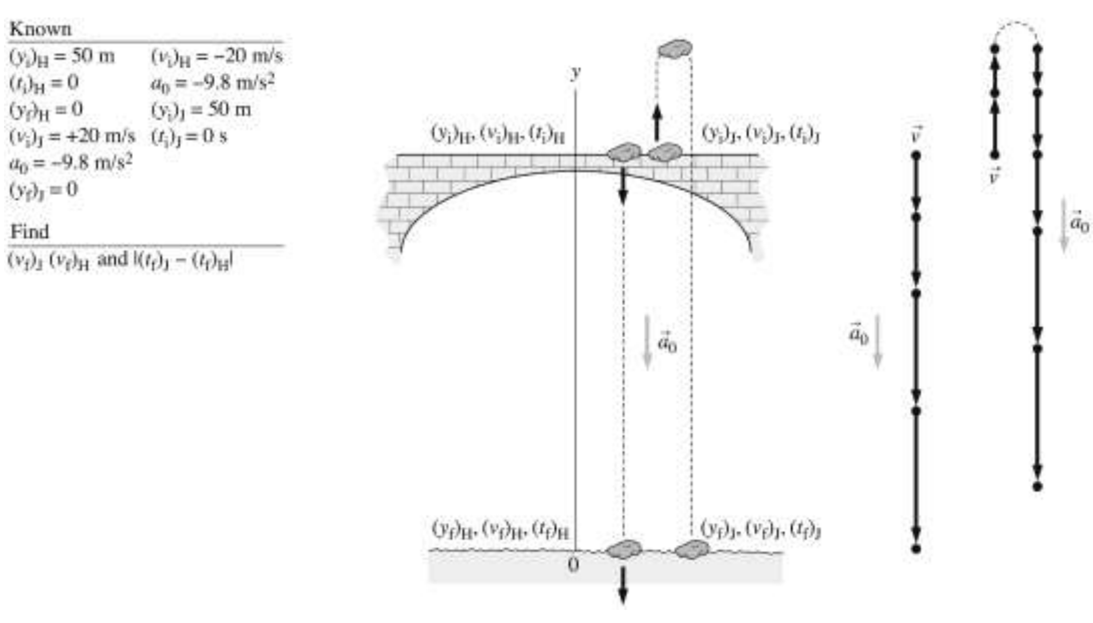
(b) Inserting values into Equation 2.13, we have:

$$(v_x)_\text{f}^2 = (v_x)_\text{i}^2 + 2a_x \Delta x \Rightarrow \Delta x = \frac{(v_x)_\text{f}^2 - (v_x)_\text{i}^2}{2a_x} = \frac{(5.0 \text{ m/s})^2 - (0 \text{ m/s})^2}{2(2500 \text{ m/s}^2)} = 5.0 \times 10^{-3} \text{ m}$$

Assess: The period of constant acceleration only brings the chameleon’s tongue 5.0 mm out of its mouth.

P2.75. Strategize: As soon as the rocks are thrown, they fall freely and thus kinematics equations are applicable.

Prepare: A visual overview of the motion of the two rocks, one thrown down by Heather and the other thrown up at the same time by Jerry, that includes a pictorial representation, a motion diagram, and a list of values is shown below. We represent the motion of the rocks along the *y*-axis with origin at the surface of the water. The initial position for both cases is $y_\text{i} = 50$ m and similarly the final position for both cases is at $y_\text{f} = 0$. Recall sign conventions, which tell us that $(v_\text{i})_\text{J}$ is positive and $(v_\text{i})_\text{H}$ is negative.



Solve: **(a)** For Heather,

$$(y_\text{f})_\text{H} = (y_\text{i})_\text{H} + (v_\text{i})_\text{H}[(t_\text{f})_\text{H} - (t_\text{i})_\text{H}] + \frac{1}{2}a_0[(t_\text{f})_\text{H} - (t_\text{i})_\text{H})]^2$$

$$\Rightarrow\ 0\text{ m} = (50\text{ m}) + (-20\text{ m/s})[(t_\text{f})_\text{H} - 0\text{ s}] + \frac{1}{2}(-9.8\text{ m/s}^2)[(t_\text{f})_\text{H} - 0\text{ s}]^2$$

$$\Rightarrow\ 4.9\text{ m/s}^2\ (t_\text{f})^2_\text{H} + 20\text{ m/s}\ (t_\text{f})_\text{H} - 50\text{ m} = 0$$

The two mathematical solutions of this equation are −5.83 s and +1.75 s. The first value is not physically acceptable since it represents a rock hitting the water before it was thrown, therefore, $(t_\text{f})_\text{H} = 1.75$ s.
For Jerry,

$$(y_\text{f})_\text{J} = (y_\text{i})_\text{J} + (v_\text{i})_\text{J}[(t_\text{f})_\text{J} - (t_\text{i})_\text{J}] + \frac{1}{2}a_0[(t_\text{f})_\text{J} - (t_\text{i})_\text{J})]^2$$

$$\Rightarrow\ 0\text{ m} = (50\text{ m}) + (+20\text{ m/s})[(t_\text{f})_\text{J} - 0\text{ s}] + \frac{1}{2}(-9.8\text{ m/s}^2)[(t_\text{f})_\text{J} - 0\text{ s}]^2$$

Solving this quadratic equation will yield $(t_\text{f})_\text{J}$ = −1.75 s and +5.83 s. Again only the positive root is physically meaningful. The elapsed time between the two splashes is $(t_\text{f})_\text{J} - (t_\text{f})_\text{H}$ = 5.83 s – 1.75 s = 4.1 s.
(b) Knowing the times, it is easy to find the impact velocities:

$$(v_\text{f})_\text{H} = (v_\text{i})_\text{H} + a_0[(t_\text{f})_\text{H} - (t_\text{i})_\text{H}] = (-20\text{ m/s}) + (-9.8\text{ m/s})(1.75\text{ s} - 0\text{ s}) = -37\text{ m/s}$$
$$(v_\text{f})_\text{J} = (v_\text{i})_\text{J} + a_0[(t_\text{f})_\text{J} - (t_\text{i})_\text{J}] = (+20\text{ m/s}) + (-9.8\text{ m/s}^2)(5.83\text{ s} - 0\text{ s}) = -37\text{ m/s}$$

The two rocks hit the water with equal speeds.
Assess: The two rocks hit the water with equal speeds because Jerry's rock has the same downward speed as Heather's rock when it reaches Heather's starting position during its downward motion.

P2.76. **Strategize:** When speeding up, we will assume that the acceleration of any creature (gazelle or human) is constant. Of course, once we are told that the creature reaches its top speed, the acceleration must drop to zero. During a period of constant acceleration, we can apply the kinematic equations.
Prepare: Use the kinematic equations with $(v_x)_\text{i} = 0$ m/s in the acceleration phase.
Solve:
(a) The gazelle gains speed at a steady rate for the first 6.5 s.

$$(v_x)_\text{f} = (v_x)_\text{f} + a_x\Delta t = 0\text{ m/s} + (4.2\text{ m/s}^2)(6.5\text{ s}) = 27.3\text{ m/s} \approx 27\text{ m/s}$$

(b) Use a different kinematic equation to find the time during the acceleration phase.

$$\Delta t = \sqrt{\frac{2\Delta x}{a_x}} = \sqrt{\frac{2(30\text{ m})}{4.2\text{ m/s}^2}} = 3.8\text{ s}$$

So, indeed, the fast human wins by 0.2 s.
(c) We'll do this in two parts. First we'll find out how far the gazelle goes during the 6.5 s acceleration phase.

$$\Delta x = \frac{1}{2}a_x(\Delta t)^2 = \frac{1}{2}(4.2\text{ m/s}^2)(6.5\text{ s})^2 = 88.725\text{ m}$$

We subtract this distance from the 200 m total to find out how long it takes the gazelle to do the constant speed phase at 27.3 m/s. 200 m – 88.725 m = 111.275 m.

$$\Delta t = \frac{\Delta x}{v_x} = \frac{111.275\text{ m}}{27.3\text{ m/s}} = 4.1\text{ s}$$

The total time for the gazelle is then 6.5 s + 4.1 s = 10.6 s, which is much less than the human.
Assess: We might be surprised that humans can beat gazelles in short races, but we are not surprised that the gazelle wins the 200 m race. The numbers are in the right ballpark.

P2.77. Strategize: When speeding up, we will assume that the acceleration of any creature (horse or human) is constant. Of course, once we are told that the creature reaches its top speed, the acceleration must drop to zero. During a period of constant acceleration, we can apply the kinematic equations.

Prepare: Use the kinematic equations with $(v_x)_\mathrm{i} = 0$ m/s in the acceleration phase.

Solve: The man gains speed at a steady rate for the first 1.8 s to reach a top speed of

$$(v_x)_\mathrm{f} = (v_x)_\mathrm{i} + a_x \Delta t = 0 \text{ m/s} + (6.0 \text{ m/s}^2)(1.8 \text{ s}) = 10.8 \text{ m/s}$$

During this time he will go a distance of

$$\Delta x = \frac{1}{2} a_x (\Delta t)^2 = \frac{1}{2}(6.0 \text{ m/s}^2)(1.8 \text{ s})^2 = 9.72 \text{ m}$$

The man then covers the remaining 100 m – 9.72 m = 90.28 m at constant velocity in a time of

$$\Delta t = \frac{\Delta x}{v_x} = \frac{90.28 \text{ m}}{10.8 \text{ m/s}} = 8.4 \text{ s}$$

The total time for the man is then 1.8 s + 8.4 s = 10.2 s for the 100 m.

We now re-do all the calculations for the horse going 200 m. The horse gains speed at a steady rate for the first 4.8 s to reach a top speed of

$$(v_x)_\mathrm{f} = (v_x)_\mathrm{i} + a_x \Delta t = 0 \text{ m/s} + (5.0 \text{ m/s}^2)(4.8 \text{ s}) = 24 \text{ m/s}$$

During this time the horse will go a distance of

$$\Delta x = \frac{1}{2} a_x (\Delta t)^2 = \frac{1}{2}(5.0 \text{ m/s}^2)(4.8 \text{ s})^2 = 57.6 \text{ m}$$

The horse then covers the remaining 200 m – 57.6 m = 142.4 m at constant velocity in a time of

$$\Delta t = \frac{\Delta x}{v_x} = \frac{142.2 \text{ m}}{24 \text{ m/s}} = 5.9 \text{ s}$$

The total time for the horse is then 4.8 s + 5.9 s = 10.7 s for the 200 m.

The man wins the race (10.2 s < 10.7 s), but he only went half the distance the horse did.

Assess: We know that 10.2 s is about right for a human sprinter going 100 m. The numbers for the horse also seem reasonable.

P2.78. Strategize: Assume the vaulter is in free fall before he hits the pad, during which acceleration is constant. Then we can use the kinematic equations to describe the fall. We will also assume that the acceleration is constant (but different) during the compression of the mat.

Prepare: He falls a distance of 4.2 m – 0.8 m = 3.4 m before hitting the pad.

Solve: We will find the impact speed assuming $(v_x)_\mathrm{i} = 0$ m/s

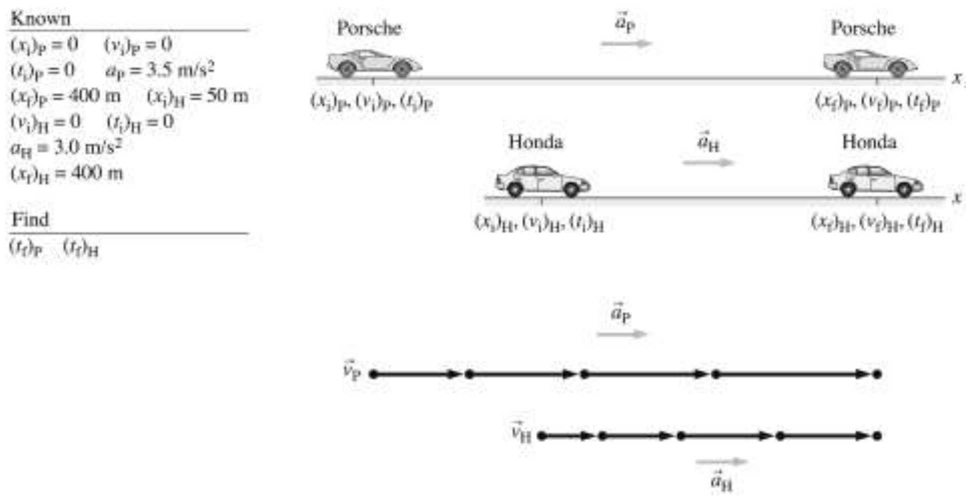
$$(v_y)_\mathrm{f}^2 = (v_y)_\mathrm{i}^2 + 2a_y \Delta y \Rightarrow (v_y)_\mathrm{f} = \sqrt{2(9.8 \text{ m/s}^2)(3.4 \text{ m})} = 8.16 \text{ m/s}$$

We use the same equation for the pad-compression phase but now the 8.16 m/s is the initial speed and the final speed is zero. Solve for a_x.

$$(v_y)_\mathrm{f}^2 = (v_y)_\mathrm{i}^2 + 2a_y \Delta y \Rightarrow a_y = \frac{-(v_y)_\mathrm{i}^2}{2\Delta y} = \frac{-(8.16 \text{ m/s})^2}{2(-0.50 \text{ m})} = 67 \text{ m/s}^2$$

Assess: This is a large acceleration, but it is not dangerous for such short periods of time. It took a lot longer for the vaulter to gain 8.16 m/s of speed at an acceleration of g than it did to lose 8.16 m/s of speed at a much larger acceleration.

P2.79. Strategize: acceleration kinematic equations are applicable because both cars have constant accelerations.
Prepare: A visual overview of the two cars that includes a pictorial representation, a motion diagram, and a list of values is shown below. We label the motion of the two cars along the x-axis. Constant We can easily calculate the times $(t_f)_H$ and $(t_f)_P$ from the given information.



Solve: The Porsche's time to finish the race is determined from the position equation

$$(x_f)_P = (x_i)_P + (v_i)_P((t_f)_P - (t_i)_P) + \frac{1}{2}a_P((t_f)_P - (t_i)_P)^2$$

$$\Rightarrow\ 400\text{ m} = 0\text{ m} + 0\text{ m} + \frac{1}{2}(3.5\text{ m/s}^2)((t_f)_P - 0\text{ s})^2 \Rightarrow\ (t_f)_P = 15\text{ s}$$

The Honda's time to finish the race is obtained from Honda's position equation as

$$(x_f)_H = (x_i)_H + (v_i)_H((t_f)_H - (t_i)_H) + \frac{1}{2}a_H((t_f)_H - (t_i)_H)^2$$

$$400\text{ m} = 100\text{ m} + 0\text{ m} + \frac{1}{2}(3.0\text{ m/s}^2)((t_f)_H - 0\text{ s})^2 \Rightarrow\ (t_f)_H = 14\text{ s}$$

The Honda wins by 1.0 s.
Assess: It seems reasonable that the Honda would win given that it only had to go 300 m. If the Honda's head start had only been 50 m rather than 100 m the race would have been a tie.

P2.80. Strategize: We will assume constant acceleration, such that we can use kinematic equations.
Prepare: A visual overview of the car's motion that includes a pictorial representation, a motion diagram, and a list of values is shown below. We label the car's motion along the x-axis. This is a two-part problem. First, we need to use the information given to determine the acceleration during braking. We will then use this acceleration to find the stopping distance for a different initial velocity.
Solve: (a) First, the car at 30 m/s coasts at constant speed before braking:

$$x_1 = x_0 + v_0(t_1 - t_0) = v_0 t_1 = (30\text{ m/s})(0.5\text{ s}) = 15\text{ m}$$

Then, the car brakes to a halt. Because we don't know the time interval during braking, we will use

$$v_2^2 = 0 = v_1^2 + 2a_1(x_2 - x_1)$$

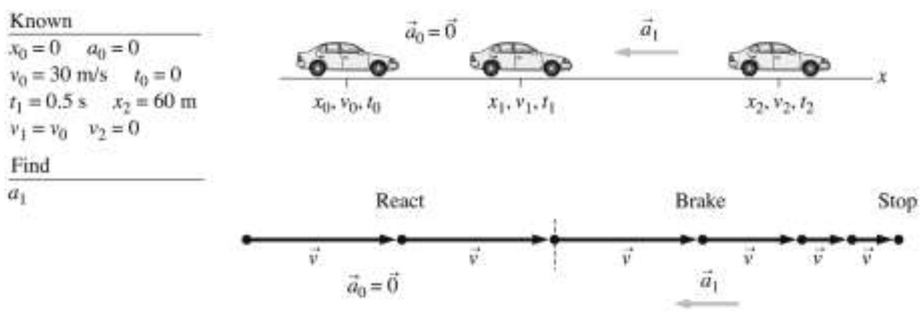
$$\Rightarrow\ a_1 = -\frac{v_1^2}{2(x_2 - x_1)} = -\frac{(30\text{ m/s})^2}{2(60\text{ m} - 15\text{ m})} = -10\text{ m/s}^2$$

We use $v_1 = v_0 = 30$ m/s. Note the minus sign, because $\vec{a}_1$ points to the left.

The car coasts at a constant speed for 0.5 s, traveling 15 m. The graph will be a straight line with a slope of 30 m/s. For $t \geq 0.5$ the graph will be a parabola until the car stops at t_2. We can find t_2 from

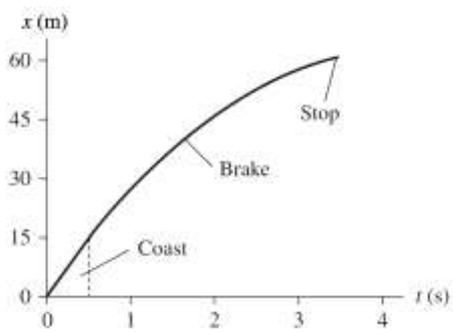
$$v_2 = 0 = v_1 + a_1(t_2 - t_1) \Rightarrow t_2 = t_1 - \frac{v_1}{a_1} = 3.5\,\text{s}$$

The parabola will reach zero slope (v = 0 m/s) at t = 3.5 s. This is enough information to draw the graph shown in the figure.



(b) We can repeat these steps now with v_0 = 40 m/s. The coasting distance before braking is

$$x_1 = v_0 t_1 = (40\text{ m/s})(0.5\text{ s}) = 20\text{ m}$$



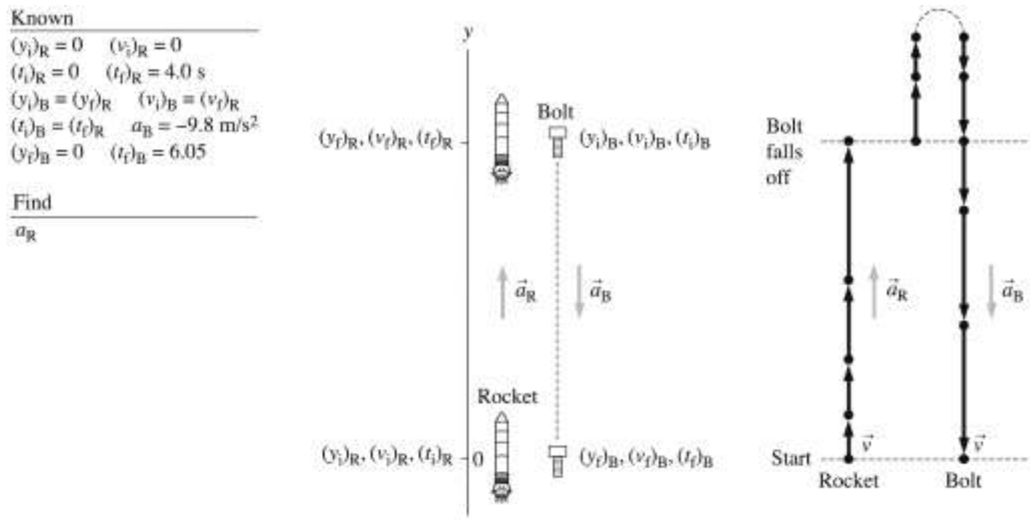
So the stopping distance is

$$v_2^2 = 0 = v_1^2 + 2a_1(x_2 - x_1)$$

$$\Rightarrow x_2 = x_1 - \frac{v_1^2}{2a_1} = 20\text{ m} - \frac{(40\text{ m/s})^2}{2(-10\text{ m/s}^2)} = 100\text{ m}$$

P2.81. Strategize: There are two periods of constant acceleration, but the two accelerations are different. We assume constant acceleration of the rocket (and the bolt with it) and then constant acceleration due to gravity during freefall. We can apply kinematic equations to either period individually, but not over both with a single equation.

Prepare: A visual overview of the motion of the rocket and the bolt that includes a pictorial representation, a motion diagram, and a list of values is shown below. We represent the rocket's motion along the y-axis. The initial velocity of the bolt as it falls off the side of the rocket is the same as that of the rocket, that is, $(v_i)_B = (v_f)_R$ and it is positive since the rocket is moving upward. The bolt continues to move upward with a deceleration equal to g = 9.8 m/s^2 before it comes to rest and begins its downward journey.



Solve: To find a_R we look first at the motion of the rocket:

$$(y_f)_R = (y_i)_R + (v_i)_R((t_f)_R - (t_i)_R) + \frac{1}{2}a_R((t_f)_R - (t_i)_R)^2$$
$$= 0 \text{ m} + 0 \text{ m/s} + \frac{1}{2}a_R(4.0 \text{ s} - 0 \text{ s})^2 = 8a_R$$

So we must determine the magnitude of y_{R1} or y_{B0}. Let us now look at the bolt's motion:

$$(y_f)_B = (y_i)_B + (v_i)_B((t_f)_B - (t_i)_B) + \frac{1}{2}a_B((t_f)_B - (t_i)_B)^2$$
$$0 = (y_f)_R + (v_f)_R(6.0 \text{ s} - 0 \text{ s}) + \frac{1}{2}(-9.8 \text{ m/s}^2)(6.0 \text{ s} - 0 \text{ s})^2$$
$$\Rightarrow (y_f)_R = 176.4 \text{ m} - (6.0 \text{ s})(v_f)_R$$

Since $(v_f)_R = (v_i)_R + a_R((t_f)_R - (t_i)_R) = 0 \text{ m/s} + 4a_R = 4a_R$ the above equation for $(y_f)_R$ yields $(y_f)_R = 176.4 - 6.0\,(4a_R)$. We know from the first part of the solution that $(y_f)_R = 8a_R$. Therefore, $8a_R = 176.4 - 24.0a_R$ and hence $a_R = 5.5 \text{ m/s}^2$.

Assess: This seems like a reasonable acceleration for a rocket.

P2.82. Strategize: Acceleration in freefall due to gravity is a constant in either case. On Earth $a_y = -9.8 \text{m/s}^2$ (constant), and on the moon $a_y = -1.63 \text{m/s}^2$ (constant). So we can use kinematic equations.

Prepare: We can calculate the initial velocity obtained by the astronaut on the earth and then use that to calculate the maximum height the astronaut can jump on the moon.

Solve: The astronaut can jump a maximum 0.50 m on the earth. The maximum initial velocity his leg muscles can give him can be calculated with Equation 2.13. His velocity at the peak of his jump is zero.

$$(v_y)_i = \sqrt{-2(a_y)\Delta y} = \sqrt{-2(-9.80 \text{ m/s}^2)(0.50 \text{ m})} = 3.1 \text{ m/s}$$

We can also use Equation 2.13 to find the maximum height the astronaut can jump on the moon. The acceleration due to the moon's gravity is $\frac{9.80 \text{ m/s}^2}{6} = 1.63 \text{ m/s}^2$. On the moon, given the initial velocity above, the astronaut can jump

$$\Delta y_{moon} = \frac{-(v_y)_i^2}{2(a_y)_{moon}} = \frac{-(3.1 \text{ m/s})^2}{2(-1.63 \text{ m/s}^2)} = 3.0 \text{ m}$$

Assess: The answer, choice B, makes sense. The astronaut can jump much higher on the moon.

P2.83. **Strategize:** Azin freefall due to gravity is a constant in either case. On Earth $a_y = -9.8\text{m/s}^2$ (constant), and on the moon $a_y = -1.63\text{m/s}^2$ (constant). So we can use kinematic equations.

Prepare: We assume that the astronaut's safe landing speed on the moon should be the same as the safe landing speed on the earth.

Solve: The brute force method is to compute the landing speed on the earth with Equation 2.13, and plug that back into the Equation 2.13 for the moon and see what the Δy could be there. This works, but is unnecessarily complicated and gives information (the landing speed) we don't really need to know.

To be more elegant, set up Equation 2.13 for the earth and moon, with both initial velocities zero, but then set the final velocities (squared) equal to each other.

$$(v_{\text{earth}})_{\text{f}}^2 = 2(a_{\text{earth}})\Delta y_{\text{earth}} \quad (v_{\text{moon}})_{\text{f}}^2 = 2(a_{\text{moon}})\Delta y_{\text{moon}}$$
$$2(a_{\text{earth}})\Delta y_{\text{earth}} = 2(a_{\text{moon}})\Delta y_{\text{moon}}$$

Dividing both sides by $2(a_{\text{moon}})\Delta y_{\text{earth}}$ gives

$$\frac{a_{\text{earth}}}{a_{\text{moon}}} = \frac{\Delta y_{\text{moon}}}{\Delta y_{\text{earth}}}$$

This result could also be accomplished by dividing the first two equations; the left side of the resulting equation would be 1, and then one arrives at our same result.

Since the acceleration on the earth is six times greater than on the moon, then one can safely jump from a height six times greater on the moon and still have the same landing speed.

So the answer is B.

Assess: Notice that in the elegant method we employed we did not need to find the landing speed (but for curiosity's sake it is 4.4 m/s, which seems reasonable).

P2.84. **Strategize:** Acceleration in freefall due to gravity is a constant in either case. On Earth $a_y = -9.8\text{m/s}^2$ (constant), and on the moon $a_y = -1.63\text{m/s}^2$ (constant). So we can use kinematic equations.

Prepare: We can calculate the initial velocity with which the astronaut throws the ball on the earth and then use that to calculate the time the ball is in motion after it is thrown and comes back down on the moon.

Solve: The initial velocity with which the ball is thrown on the earth can be calculated from Equation 2.12. Since the ball starts near the ground and lands near the ground, $x_{\text{f}} = x_{\text{i}}$. Solving the equation for $(v_y)_{\text{i}}$,

$$(v_y)_{\text{i}} = -\frac{1}{2}a_y\Delta t = -\frac{1}{2}(-9.80\text{ m/s}^2)(3.0\text{ s}) = 15\text{ m/s}$$

The acceleration due to the moon's gravity is $\dfrac{9.80\text{ m/s}^2}{6} = 1.63\text{ m/s}^2$. We can find the time it takes to return to the lunar surface using the same equation as above, this time solving for Δt. If thrown upward with this initial velocity on the moon,

$$\Delta t = \frac{-2(v_y)_{\text{i}}}{a_y} = \frac{-2(15\text{ m/s})}{-1.63\text{ m/s}^2} = 18\text{ s}$$

The correct choice is B.

Assess: This makes sense. The ball is in motion for a much longer time on the moon.