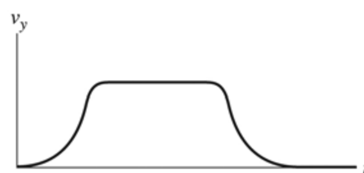
2

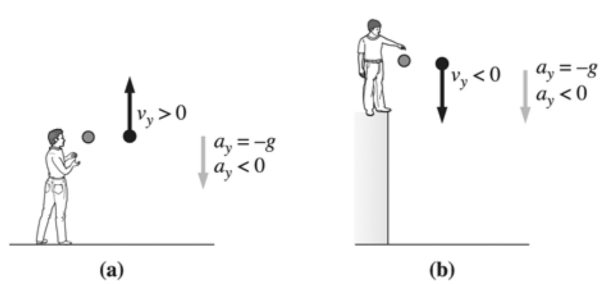
MOTION IN ONE DIMENSION

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.



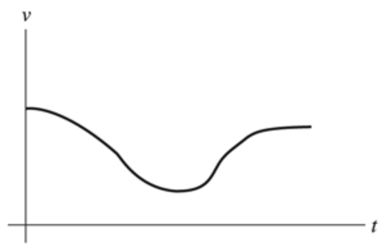
Assess: After drawing velocity-versus-time graphs (as well as others), stop and think if it matches the physical situation, especially by checking end points, maximum values, places where the slope is zero, etc. This one passes those tests.

Q2.2. Reason: (a) The sign conventions for velocity are in Figure 2.7. The sign conventions for acceleration are in Figure 2.26. 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.

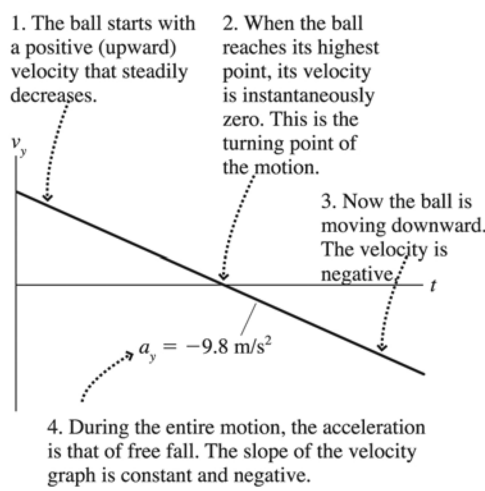


Assess: After drawing velocity-versus-time graphs (as well as others), stop and think if it matches the physical situation, especially by checking end points, maximum values, places where the slope is zero, etc. This one passes those tests.

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.

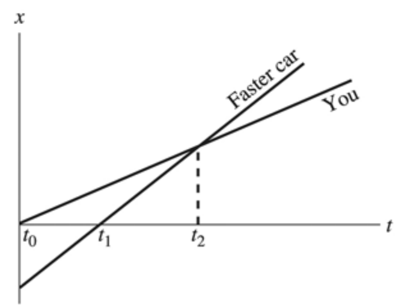
At the instant the rock leaves the hand it has a large positive (up) velocity, so the value on the graph at $t = 0$ needs to be a large positive number. The velocity decreases as the rock rises, but the velocity arrow would still point up. So the graph is still above the t axis, but decreasing. At the 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: Yes. The acceleration vector will point south when the car is slowing down while traveling north.
Assess: The acceleration vector will always point in the direction opposite the velocity vector in straight line motion if the object is slowing down. Feeling good about this concept requires letting go of the common every day (mis)usage where velocity and acceleration are sometimes treated like synonyms. Physics definitions of these terms are more precise and when discussing physics we need to use them precisely.

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.

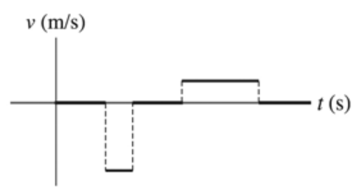
Q2.8. Reason: We will neglect air resistance, and thus assume that the ball is in free fall.
(a) $-g$ After leaving your hand the ball is traveling up but slowing, therefore the acceleration is down (*i.e.*, negative).
(b) $-g$ At the very top the velocity is zero, but it had previously been directed 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: (a) Once the rock leaves the thrower's hand, it is in free fall. While in free fall, the acceleration of the rock is exactly the acceleration due to gravity, which has a magnitude g and is downward. The fact that the rock was thrown and not simply dropped means that the rock has an initial velocity when it leaves the thrower's hand. This does not affect the acceleration of gravity, which does not depend on how the rock was thrown.
(b) Just before the rock hits the water, it is still in free fall. Its acceleration remains the acceleration of gravity. Its velocity has increased due to gravity, but acceleration due to gravity is independent of velocity.
Assess: No matter what the velocity of an object is, the acceleration due to gravity always has magnitude g and is always straight downward.

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.

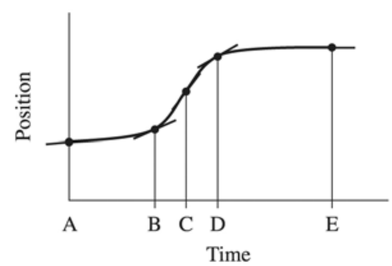
Q2.12. Reason: **(a)** A's speed is greater at $t = 1\text{ s}$. The slope of the tangent to B's curve at $t = 1\text{ s}$ is smaller than the slope of A's line.
(b) A and B have the same speed just before $t = 3\text{ s}$. At that time, the slope of the tangent to the curve representing B's motion is 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 $a_x = \dfrac{10 \text{ m/s}}{5.0 \text{ s}} = 2.0 \text{ m/s}^2$

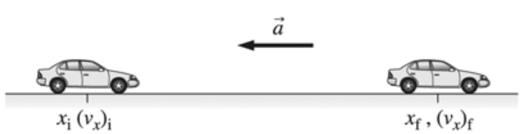
B $a_x = \dfrac{5.0 \text{ m/s}}{2.0 \text{ s}} = 2.5 \text{ m/s}^2$

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.

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

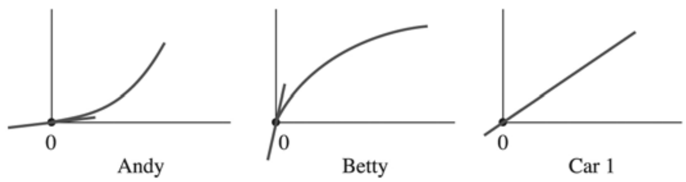
Solving for Δx,

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

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.

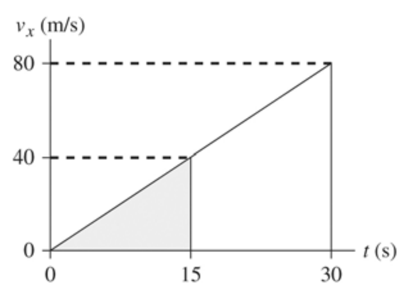
$$a = \frac{\Delta v}{\Delta t} = \frac{80 \text{ m/s}}{30 \text{ s}} = 2.667 \text{ m/s}^2$$

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: This can be solved with simple ratios. Since $\vec{a} = \dfrac{\Delta \vec{v}}{\Delta t}$ and the a stays the same, it would take twice as long to change $\vec{v}$ twice as much.
The answer is B.
Assess: This result can be checked by actually computing the acceleration and plugging it back into the equation for the second case, but ratios are slicker and quicker.

Q2.26. Reason: This can be solved with simple ratios. Since $\vec{a} = \dfrac{\Delta \vec{v}}{\Delta t}$ if $\vec{a}$ is doubled then the car can change velocity by twice as much in the same amount of time.
The answer is A.
Assess: This result can be checked by actually computing the acceleration, doubling it, and plugging it back into the equation for the second case, but ratios are slicker and quicker.

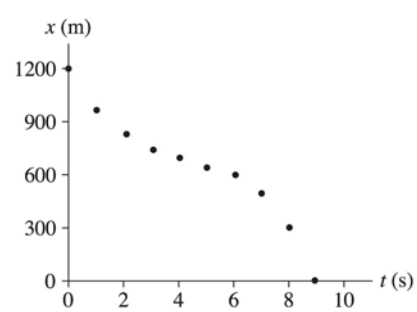
Problems

P2.1. 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. Prepare: Let us review our sign conventions. 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:

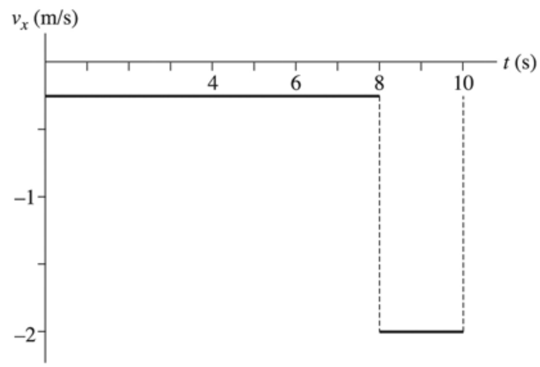
Diagram	Position	Velocity
(a)	Negative	Positive
(b)	Negative	Negative
(c)	Positive	Negative

P2.3. Prepare: The slope of the position graph is the velocity graph. 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)

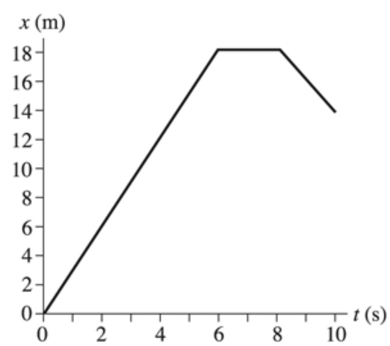


Assess: We expect the sneaking up phase to be longer than the spring phase, so this looks like a realistic situation.

P2.4. Prepare: To get a position from a velocity graph we count the area under the curve.

Solve:

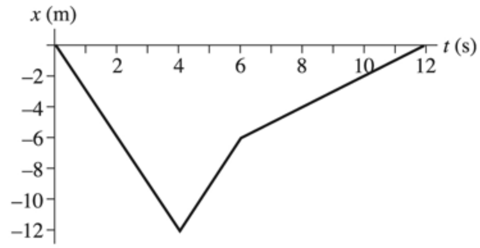
(a)



(b) We need to count the area under the velocity graph (area below the x-axis is subtracted). There are 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. 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. Prepare: Note that the slope of the position-versus-time graph at every point gives the velocity at that point. Referring to Figure P2.9, 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.

P2.7. 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.

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

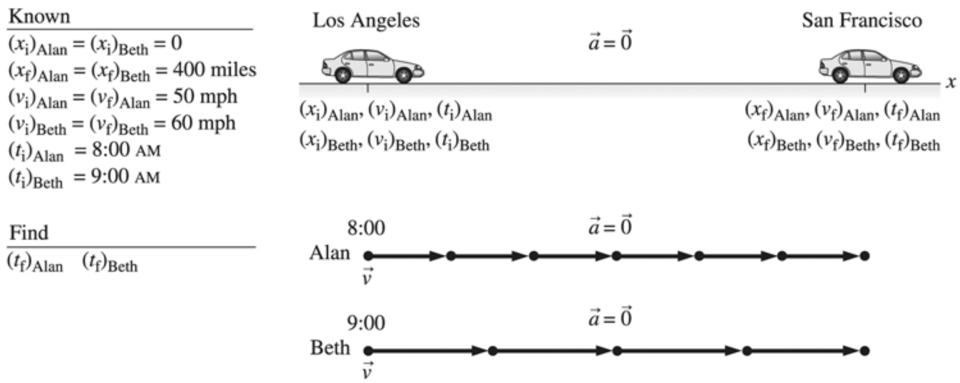
Assess: Just under a half second is reasonable for a major league pitch.

P2.8. 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.

P2.9. 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

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

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

(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.

P2.10. 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.

P2.11. Prepare: Since each runner is running at a steady pace, they both are traveling with a constant speed. Each 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 $(0.417\text{ h})\left(\dfrac{60\text{ min}}{1\text{ h}}\right) = 25.0\text{ min}$

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

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

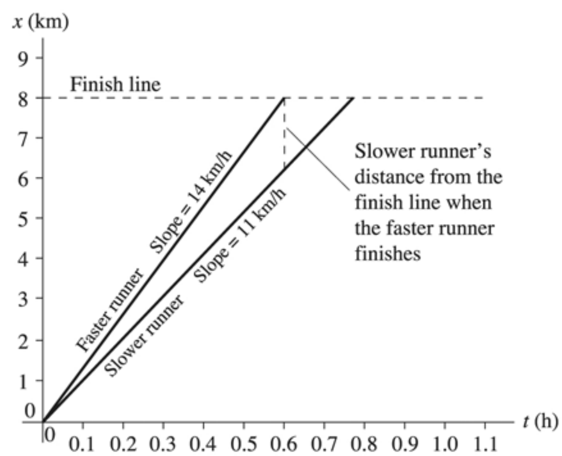
The time the second runner waits is 25.0 min – 20.7 min = 4.3 min

Assess: For uniform motion, velocity is given by Equation 2.1.

P2.12. 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 $\text{distance} = \text{speed} \times \text{time}$ 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 $d = (11.0\text{ km/h}) \times (0.571\text{ h}) = 6.29\text{ km}$.

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.

P2.13. Prepare: Assume v_x is constant so the ratio $\dfrac{\Delta x}{\Delta t}$ is also constant.

Solve:

(a)

$$\frac{30\text{ m}}{3.0\text{ s}} = \frac{\Delta x}{1.5\text{ s}} \quad \Rightarrow \quad \Delta x = 1.5\text{ s}\left(\frac{30\text{ m}}{3.0\text{ s}}\right) = 15\text{ m}$$

(b)

$$\frac{30\text{ m}}{3.0\text{ s}} = \frac{\Delta x}{9.0\text{s}} \quad \Rightarrow \quad \Delta x = 9.0\text{ s}\left(\frac{30\text{ m}}{3.0\text{ s}}\right) = 90\text{ m}$$

Assess: Setting up the ratio allows us to easily solve for the distance traveled in any given time.

P2.14. Prepare: Assume v_x is constant so the ratio $\frac{\Delta x}{\Delta t}$ is also constant.

Solve:

(a)

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

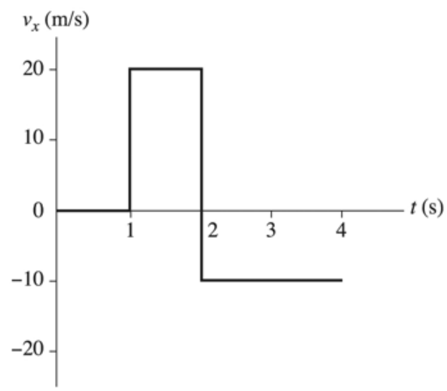
(b)

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

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

P2.15. 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.

P2.16. Prepare: The distance traveled is the area under the v_y graph.

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.

P2.17. Prepare: Since 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.

P2.18. 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)

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

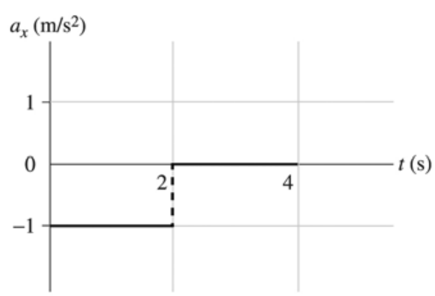
(b)

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

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

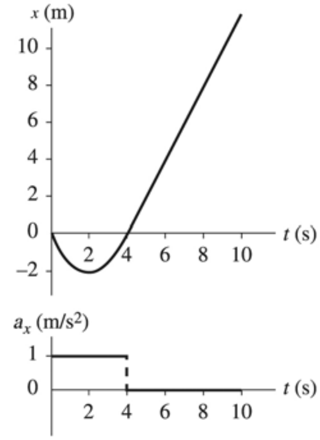
P2.19. Prepare: The graph in Figure P2.19 shows distinct slopes in the time intervals: 0 – 2 s and 2 s – 4 s. We can thus obtain the acceleration values from this graph using $a_x = \Delta v_x/\Delta t$. A linear decrease in velocity from $t = 0$ s to $t = 2$ s implies a constant negative acceleration. On the other hand, a constant velocity between $t = 2$ s and $t = 4$ s means zero acceleration.

Solve:



P2.20. Prepare: Displacement is equal to the area under the velocity graph between t_i and t_f, and acceleration is the slope of the velocity-versus-time graph.

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.

P2.21. Prepare: Acceleration is the rate of change of velocity. The sign conventions for position are in Figure 2.1. Conventions for velocity are in Figure 2.7. Conventions for acceleration are in Figure 2.26.
Solve: (a) Since the displacements are toward the right and the velocity vectors point toward the right, the velocity is always positive. Since the velocity vectors are increasing in length and are pointing toward the right, the acceleration is positive. The position is always negative, but it is only differences in position that are important in calculating velocity.
(b) Since the displacements and the velocity vectors are always downward, the velocity is always negative. Since the velocity vectors are increasing in length and are downward, the acceleration is negative. The position is always negative, but it is only differences in position that are important in calculating velocity.
(c) Since the displacements are downward, and the velocity vectors are always downward, the velocity is always negative. Since the velocity vectors are increasing in length and are downward, the acceleration is negative. The position is always positive, but it is only differences in position that are important in calculating velocity.
Assess: The origin for coordinates can be placed anywhere.

P2.22. Prepare: To figure the acceleration we compute the slope of the velocity graph by looking at the rise and the run for each straight line segment.
Solve: Speeding up:

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

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.

P2.23. Prepare: From a velocity-versus-time graph we find the acceleration by computing the slope. 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.

P2.24. 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.

P2.25. 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.

P2.26. 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 $(v_x)_\text{i} = 0.0\text{ m/s}$ 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.

P2.27. 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 $v_i = 0$, final velocity $v_f = 26.8$ m/s, and $\Delta t = 10$ s, we can find the acceleration using

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

(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:

$$x_f - x_i = v_i\Delta t + \frac{1}{2}a(\Delta t)^2 = \frac{1}{2}a(\Delta t)^2 = 134\text{ m} = 440\text{ feet}$$

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

P2.28. 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 $(v_y)_i = 0.0$ m/s and rearrange Equation 2.13.

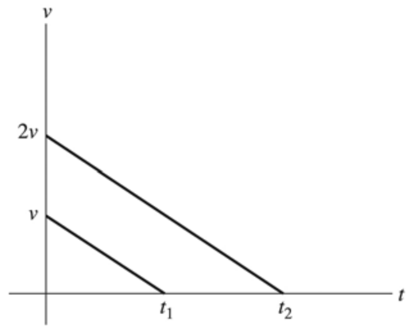
$$a_y = \frac{(v_y)_f^2}{2\Delta y} = \frac{(1.0\text{ m/s})^2}{2(0.50\text{ mm})}\left(\frac{1000\text{ mm}}{1\text{ m}}\right) = 1000\text{ m/s}^2$$

(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 $(v_y)_i = 0.0$ 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.

P2.29. Reason: Assume that the acceleration during braking is constant.
There are a number of ways to approach this question. First, you probably recall from a driver's education course that stopping distance is not directly proportional to velocity; this already tips us off that the answer probably is not 2*d*.
Solve: Let's look at a velocity-versus-time graph of the situation(s). Call time $t = 0$ just as the brakes are applied; this is the last instant the speed is *v*. The graph will then decrease linearly and become zero at some later time t_1. Now add a second line to the graph starting at $t = 0$ and 2*v*. It must also linearly decrease to zero—and it must have the same slope because we were told the acceleration is the same in both cases. This second line will hit the *t*-axis at a time $t_2 = 2t_1$. Now the crux of the matter: the displacement is the area under the velocity-versus-time graph. Carefully examine the two triangles and see that the larger one has 4 times the area of the smaller one; one way is to realize it has a base twice as large and a height twice as large, another is to mentally cut out the smaller triangle and flip and rotate it to convince yourself that four copies of it would cover the larger triangle. Thus, the stopping distance for the 2*v* case is 4*d*.



Yet a third way to examine this question is with algebra. Equation 2.13 relates velocities and displacements at a constant acceleration. (We don't want an equation with t in it since t is neither part of the supplied information nor what we're after.)

$$(v_x)_\mathrm{f}^2 = (v_x)_\mathrm{i}^2 + 2a_x\Delta x$$

Note that the stopping distance is the Δx in the equation, and that $v_\mathrm{f} = 0$.

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

Given that a is constant and the same in both cases, we see that there is a square relationship between the stopping distance and the initial velocity, so doubling the velocity will quadruple the stopping distance.

Assess: It demonstrates clear and versatile thinking to approach a question in multiple ways, and it gives an important check on our work.

The graphical approach in this case is probably the more elegant and insightful; there is a danger that the algebraic approach can lead to blindly casting about for an equation and then plugging and chugging. This latter mentality is to be strenuously avoided. Equations should only be used with correct conceptual understanding.

Also note in the last equation above that the left side cannot be negative, but the right side isn't either since a is negative for a situation where the car is slowing down. So the signs work out. The units work out as well since both sides will be in $\mathrm{m^2/s^2}$.

P2.30. Prepare: We'll do this in parts, first computing the acceleration after the congestion.

Solve:

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

Now use the same acceleration to find the new velocity.

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

Assess: The answer is a reasonable 58 mph.

P2.31. Prepare: Because the skier slows steadily, her deceleration is a constant during the glide and we can use the kinematic equations of motion under constant 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

$$v_\mathrm{f}^2 = v_\mathrm{i}^2 + 2a(x_\mathrm{f} - x_\mathrm{i})$$

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

The magnitude of this acceleration is 2.8 $\mathrm{m/s^2}$.

Assess: A deceleration of 2.8 $\mathrm{m/s^2}$ or 6.3 mph/s is reasonable.

P2.32. Prepare: The kinematic equation that relates velocity, acceleration, and distance is $(v_x)_f^2 = (v_x)_i^2 + 2a_x\Delta x$. Solve for Δx.

$$\Delta x = \frac{(v_x)_f^2 - (v_x)_i^2}{2a_x}$$

Note that $(v_x)_i^2 = 0$ for both planes.

Solve: The accelerations are same, so they cancel.

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

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

P2.33. Prepare: Because the car slows steadily, the deceleration is a constant and we can use the kinematic equations of motion under constant acceleration.

Solve: Since we know the car's initial and final speeds and the width of the patch over which she decelerates, we will use

$$v_f^2 = v_i^2 + 2a(x_f - x_i)$$

$$\Rightarrow a = \frac{v_f^2 - v_i^2}{2(x_f - x_i)} = \frac{(0 \text{ m/s})^2 - (90 \text{ m/s})^2}{2(110 \text{ m})} = -37 \text{ m/s}^2$$

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.

P2.34. 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 m/s^2.

(b)

$$x(\text{at } t = 3.0 \text{ s}) = x(\text{at } t = 0 \text{ s}) + \text{area between } t = 0 \text{ s and } t = 3 \text{ s}$$

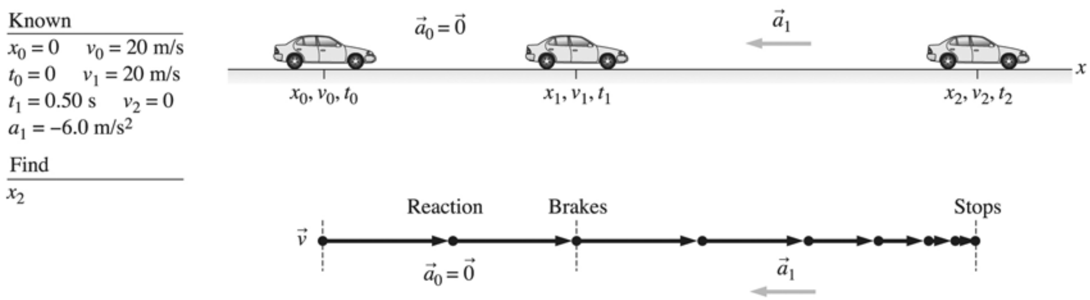
$$= 0.0 \text{ m} + 4 \text{ m/s} \times 2 \text{ s} + 2 \text{ m/s} \times 1 \text{ s} + (1/2) \times 2 \text{ m/s} \times 1 \text{ s} = 11.0 \text{ m}$$

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.

P2.35. 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

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

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!

P2.36. 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 $(v_x)_\text{i} = 0$ and $x_\text{i} = 0$,

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

We also compute the speed it attains.

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

Now the distance traveled at a constant speed of 5.0 m/s.

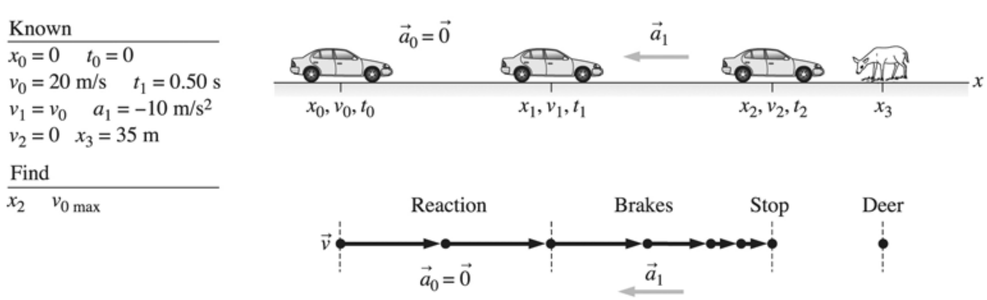
$$\Delta x = v_x \Delta t = (5.0 \text{ m/s})(30 \text{ ms}) = 0.15 \text{ m} = 15 \text{ cm}$$

Now add the two distances to get the total.

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

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

P2.37. 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

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

The distance between you and the deer is $(x_3 - x_2)$ or (35 m – 30 m) = 5 m.

(b) Let us find $v_{0\,\text{max}}$ such that $v_2 = 0$ m/s at $x_2 = x_3 = 35$ m. Using the following equation,

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

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

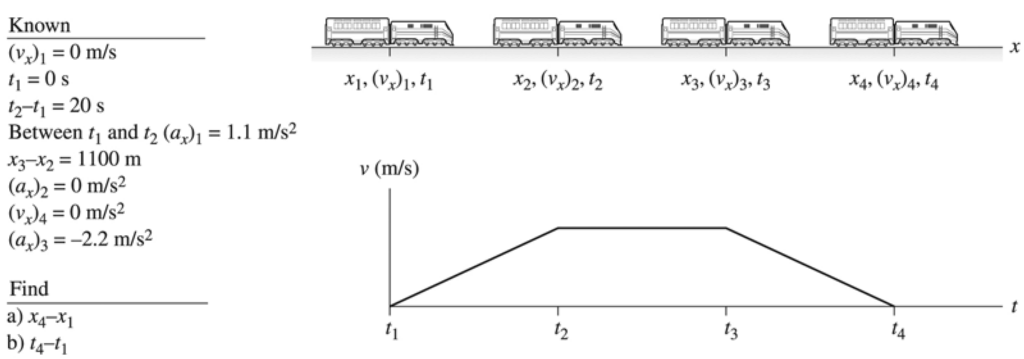
$$-v_{0\,\text{max}}^2 = (-20\ \text{m/s}^2)[35\ \text{m} - (0.50\ \text{s})\,v_{0\,\text{max}}] \Rightarrow v_{0\,\text{max}}^2 + (10\ \text{m/s})v_{0\,\text{max}} - 700\ \text{m}^2/\text{s}^2 = 0$$

The solution of this quadratic equation yields $v_{0\,\text{max}} = 22$ 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.

P2.38. Prepare: There are three parts to this motion. The acceleration is constant during each part. We are given the acceleration and time for the first and last segments and are asked to find a distance. Equations 2.8, 2.11, 2.12, and 2.13 apply during these segments. During the middle constant velocity segment we can use Equation 2.5.

Solve: Refer to the diagram below.



(a) From x_1 to x_2 the train has a constant acceleration of $(a_x)_1 = +1.1$ m/s^2. Placing the origin at the starting position of the train, $x_1 = 0$ m. Since the train starts from rest, $(v_x)_1 = 0$ m/s. We can calculate the distance the train goes during this phase of the motion using Equation 2.12.

$$x_2 = x_1 + (v_x)_1(t_2 - t_1) + \frac{1}{2}(a_x)_1(t_2 - t_1)^2 = \frac{1}{2}(1.1\ \text{m/s}^2)(20\ \text{s})^2 = 220\ \text{m}$$

From x_2 to x_3 the train is traveling with constant velocity. We are given that $x_3 - x_2 = 1100$ m, so $x_3 = x_2 + 1100$ m = 220 m + 1100 m = 1320 m.

From x_3 to x_4 the train has a constant negative acceleration of $(a_x)_3 = -2.2$ m/s^2. The train stops at the station so $(v_x)_4 = 0$ m/s. We will need to find either the time the train takes to stop or its initial velocity just before beginning to stop in order to continue. We can find the velocity of the train just before it begins to stop by noticing that it is equal to the velocity of the train during the middle segment of the trip, $(v_x)_3$, which is also equal to the velocity of the train at the end of the first segment of the trip: $(v_x)_3 = (v_x)_2$. We can find $(v_x)_2$ using Equation 2.11 during the first segment of the trip.

$$(v_x)_2 = (v_x)_1 + (a_x)_1(t_2 - t_1) = (1.1\ \text{m/s}^2)(20\ \text{s}) = 22\ \text{m/s}$$

We now have enough information to calculate the distance the train takes to stop using Equation 2.13:

$$(v_x)_4^2 = (v_x)_3^2 + 2(a_x)_3(x_4 - x_3)$$

Solving for $(x_4 - x_3)$,

$$(x_4 - x_3) = \frac{(v_x)_4^2 - (v_x)_3^2}{2(a_x)_3} = \frac{(0\text{ m/s})^2 - (22\text{ m/s})^2}{2(-2.2\text{ m/s})} = 110\text{ m}$$

Finally, we can calculate $x_4 = x_3 + 110\text{ m} = 1320\text{ m} + 100\text{ m} = 1430\text{ m}.$

The total distance the train travels is 1400 m to two significant figures.

(b) We are given the time the train takes during the first part of the trip, $t_2 - t_1 = 15\text{ s}.$ During the constant velocity segment, we know that the train travels $x_3 - x_2 = 1100\text{ m}.$ We calculated its velocity during this segment in part **(a)** as $(v_x)_2 = 21\text{ m/s}.$ Using Equation 2.5, we can calculate the time.

$$t_3 - t_2 = \frac{x_3 - x_2}{(v_x)_2} = \frac{1100\text{ m}}{22\text{ m/s}} = 50\text{ s}$$

To calculate the time the train takes to stop, we can use Equation 2.8.

$$t_4 - t_3 = \frac{(v_x)_4 - (v_x)_3}{(a_x)_3} = \frac{(0\text{ m/s}) - (22\text{ m/s})}{(-2.2\text{ m/s})} = 10\text{ s}$$

So the total time the train takes to go between stations is $t_4 - t_1 = 20\text{ s} + 50\text{ s} + 10\text{ s} = 80\text{ s}.$

Assess: Note that a good visual overview with a velocity-versus-time graph was very useful in organizing this complicated problem. We had to calculate a velocity in an early segment to use as an initial velocity in a later segment. This is often the case in problems involving different motions such as this one.

P2.39. Prepare: Use kinematic equations for constant acceleration. 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.

P2.40. Prepare: Use kinematic equations for constant acceleration. Call the point where the motorcycle started the origin.

Solve:

(a)

$$(v_x)_\text{f}^2 = (v_x)_\text{i}^2 + 2a_x\Delta x \Rightarrow a_x = \frac{(v_x)_\text{f}^2 - (v_x)_\text{i}^2}{2(\Delta x)} = \frac{(240\text{ km/h})^2}{2(95\text{ m})}\left(\frac{1000\text{ m}}{1\text{ km}}\right)^2\left(\frac{1\text{ h}}{3600\text{ s}}\right)^2 = 23.4\text{ m/s}^2$$

This should be reported as 23 m/s^2.

(b)

$$a = \frac{\Delta v}{\Delta t} \Rightarrow \Delta t = \frac{\Delta v}{a} = \frac{240\text{ km/h}}{23.4\text{ m/s}^2}\left(\frac{1000\text{ m}}{1\text{ km}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right) = 2.9\text{ s}$$

Assess: Navy pilots are used to such large accelerations.

P2.41. Prepare: We will use the equation for constant acceleration to find out how far the sprinter travels during the acceleration phase. 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

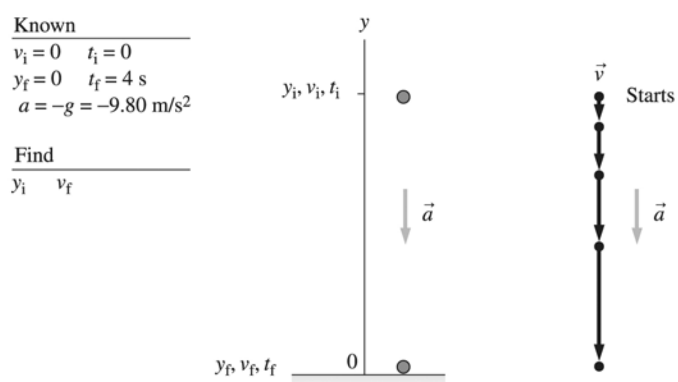
$$\Delta t = \frac{\Delta x}{v_x} = \frac{88.0 \text{ m}}{11.2 \text{ m/s}} = 7.86 \text{ s}$$

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 2.23 for Carl Lewis.

P2.42. Prepare: A visual overview of a ball bearing's motion that includes a pictorial representation, a motion diagram, and a list of values is shown below. We label the bearing's motion along the *y*-axis. The bearing is under free fall, so kinematic equations hold.



Solve: (a) The shot is in free fall, so we can use free fall kinematics with $a = -g$. The height must be such that the shot takes 4 s to fall, so we choose $t_f = 4$ s. From the given information it is easy to see that we need to use

$$y_f = y_i + v_i(t_f - t_i) - \frac{1}{2}g(t_f - t_i)^2 \Rightarrow y_i = \frac{1}{2}gt_f^2 = \frac{1}{2}(9.8 \text{ m/s}^2)(4 \text{ s})^2 = 78 \text{ m}$$

(b) The impact velocity is $v_f = v_i - g(t_f - t_i) = -gt_1 = -39$ m/s.

Assess: Note the minus sign. The question asked for *velocity*, not speed, and the *y*-component of $\vec{v}$ is negative because the vector points downward.

P2.43. Prepare: The bill must drop its own length. Assume it is in free fall.

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.

P2.44. 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, $y_0 = 0.0$ 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:

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

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.

P2.45. Prepare: Use kinematic equations for constant acceleration. Assume the gannet is in free fall during the dive.
Solve:

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

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

P2.46. Prepare: 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.
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.

P2.47. Prepare: Assume the jumper is in free fall after leaving the ground, so use the kinematic equation $(v_y)_f^2 = (v_y)_i^2 + 2a_y\Delta y$ where $(v_y)_f^2 = 0$ at the top of the leap.
We assume $a_y = -9.8\text{ m/s}^2$ and we are given $\Delta y = 1.1$ m.
Solve:

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

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.

P2.48. 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 $(v_y)_i = 0$ m/s, $y_f = 0$ m, and $\Delta t = 2.6$ s. Solve for y_i.

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

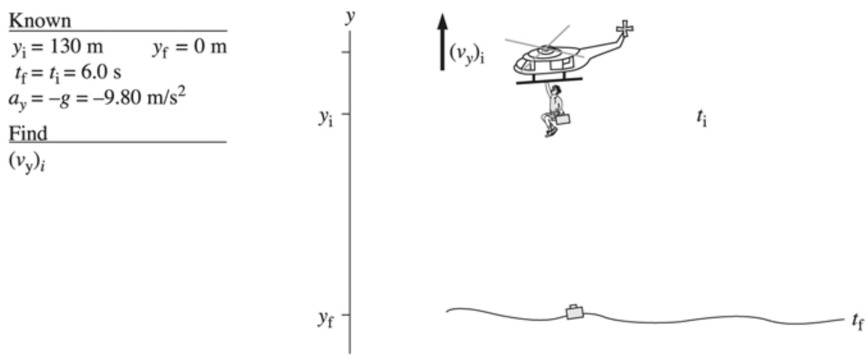
or 33 m to two significant figures.

(b) On the way up $(v_y)_f = 0$ m/s.

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

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

P2.49. 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 $(v_y)_i\Delta t$,

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

Dividing by Δt to solve for $(v_y)_i$,

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

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

P2.50. Prepare: Assume the jumper is in free fall after leaving the ground, so use the kinematic equations.
We assume $a_y = -9.8$ m/s^2 and we are given $(y_f - y_i) = 1.1$ m.

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.

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

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.

P2.51. 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 $\Delta t_2 = t_f - (t_2)_i = 3.0 \text{ s} - 1.0 \text{ s} = 2.0$ 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).

P2.52. **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 s, 0 m/s) and (2 s, 10 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.

P2.53. 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 $2.18\text{ hr} + 0.25\text{ hr} = 2.43\text{ hr}$. 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.

P2.54. Prepare: This is a unit conversion problem. Use Equation 2.8 to find the acceleration in km/h/s and then convert units.

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

Solve: (a)

$$a_x = \frac{\Delta v_x}{\Delta t} = \frac{150\text{ km/h}}{0.50\text{ s}}\left(\frac{1000\text{ m}}{1\text{ km}}\right)\left(\frac{1\text{ h}}{60\text{ min}}\right)\left(\frac{1\text{ min}}{60\text{ s}}\right) = 83\text{ m/s}^2$$

(b) Use Equation 2.16

$$\text{acceleration (in units of } g) = \frac{\text{acceleration (in units of m/s}^2)}{9.80\text{ m/s}^2} = \frac{83\text{ m/s}^2}{9.80\text{ m/s}^2} = 8.5g$$

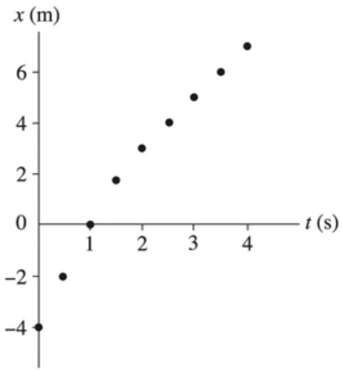
Assess: This is quite remarkable; g is not an insignificant acceleration, but this is 8.5 times as much. Also remarkable is the exit velocity; 150 km/h is faster than you drive on the highway.

P2.55. 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 P2.51 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, $v_s = \Delta x/\Delta t = 4 \text{ m/s}$.

(f) From $t = 2$ s to $t = 4$ s, $v_x = \Delta x/\Delta t = 2 \text{ m/s}$.

(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.

P2.56. Prepare: We must carefully apply the equations of constant velocity to see why the answers to parts a and b are different.

Solve:

(a) This will be in two parts with each half having $\Delta x = 50 \text{ mi}$.

$$\Delta t = \frac{\Delta x_1}{(v_x)_1} + \frac{\Delta x_2}{(v_x)_2} = \frac{50 \text{ mi}}{40 \text{ mi/h}} + \frac{50 \text{ mi}}{60 \text{ mi/h}} = 2.1 \text{ h}$$

(b) Let's see how far she goes in each half of the time.

$$\Delta t_1 = \frac{\Delta x_1}{40 \text{ mi/h}} \qquad \Delta t_2 = \frac{\Delta x_2}{60 \text{ mi/h}}$$

But we know $\Delta t_1 = \Delta t_2$ so

$$7\frac{\Delta x_1}{40 \text{ mi/h}} = \frac{\Delta x_2}{60 \text{ mi/h}}$$

We also know $\Delta x_1 + \Delta x_2 = 100 \text{ mi}$.

$$\frac{\Delta x_1}{40 \text{ mi/h}} = \frac{100 \text{ mi} - \Delta x_1}{60 \text{ mi/h}} \quad \Rightarrow \quad \Delta x_1 = 40 \text{ mi}$$

This means $\Delta x_2 = 100 \text{ mi} - 40 \text{ mi} = 60 \text{ mi}$. Now for the total.

$$\Delta t_{tot} = \Delta t_1 + \Delta t_2 = \frac{40 \text{ mi}}{40 \text{ mi/h}} + \frac{60 \text{ mi}}{60 \text{ mi/h}} = 2.0 \text{ h}$$

Assess: The answers are not greatly different because 40 mph and 60 mph aren't greatly different.

P2.57. 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 gs this is (2.3 m/s^2)/(9.8 m/s^2) = 0.23g

(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:

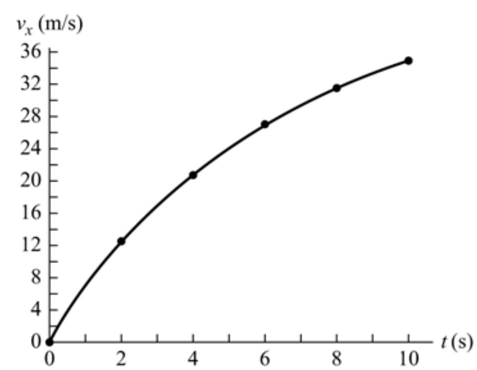
$$x_\text{f} = x_\text{i} + (v_x)_\text{i}(t_\text{f} - t_\text{i}) + \frac{1}{2}a_x(t_\text{f} - t_\text{i})^2 = 0 \text{ m} + (0 \text{ m/s})(34.8 \text{ s}) + \frac{1}{2}(2.3 \text{ m/s}^2)(34.8 \text{ s})^2 = 1390 \text{ m}$$

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

P2.58. 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.

Solve: (a) First convert mph to m/s.

t (s)	v_x (mph)	v_x (m/s)
0	0	0
2	28	12.5
4	46	20.6
6	60	26.8
8	70	31.3
10	78	34.9



The acceleration is not constant because the velocity-versus-time graph is not a straight line.

(b) 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.

$$a_x(\text{at 2 s}) \approx \frac{v_x(\text{at 4 s}) - v_x(\text{at 0 s})}{4 \text{ s} - 0 \text{ s}} = \frac{20.6 \text{ m/s} - 0.0 \text{ m/s}}{4 \text{ s}} = 5.1 \text{ m/s}^2$$

$$a_x(\text{at 8 s}) \approx \frac{v_x(\text{at 10 s}) - v_x(\text{at 6 s})}{10 \text{ s} - 6 \text{ s}} = \frac{34.9 \text{ m/s} - 26.8 \text{ m/s}}{4 \text{ s}} = 2.0 \text{ m/s}^2$$

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

P2.59. Prepare: After appropriate unit conversions, we'll see how far the spacecraft goes during the acceleration phase and what speed it achieves and then how long it would take to go the remaining distance at that speed.

$$0.50 \text{ y} = 1.578 \times 10^7 \text{ s}$$

Solve: Because $(v_x)_\text{i} = 0$ m/s and $x_\text{i} = 0$ m

$$x_\text{f} = \frac{1}{2}a_x(\Delta t)^2 = \frac{1}{2}(9.8 \text{ m/s}^2)(1.578 \times 10^7 \text{ s})^2 = 1.220 \times 10^{15} \text{ m}$$

which is not a very large fraction of the whole distance. The spacecraft must still go 4.1×10^{16} m -1.220×10^{15} m $=3.98\times10^{16}$ m at the achieved speed.

The speed is

$$\Delta v_x = a_x\Delta t = (9.8\text{ m/s}^2)(1.578\times10^7\text{ s}) = 1.55\times10^8\text{ m/s}$$

which is half the speed of light. The time taken to go the remaining distance at that speed is

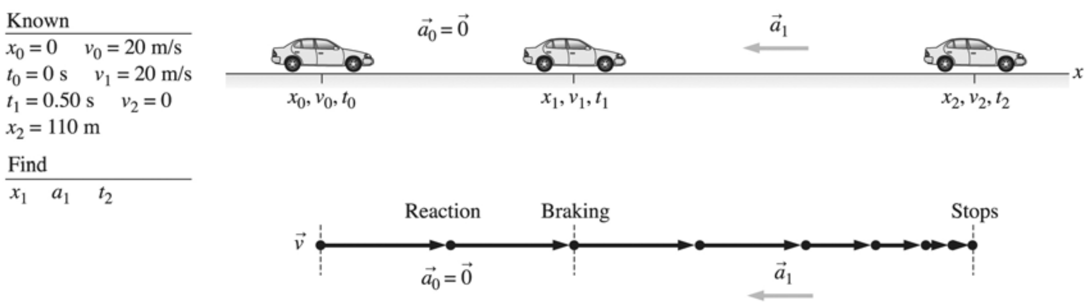
$$\Delta t = \frac{\Delta x}{v_x} = \frac{3.98\times10^{16}\text{ m}}{1.55\times10^8\text{ m/s}} = 2.57\times10^8\text{ s} = 8.15\text{ y}$$

Now the total time needed is the sum of the time for the acceleration phase and the time for the constant velocity phase.

$$\Delta t = 0.50\text{ y} + 8.15\text{ y} = 8.7\text{ y}$$

Assess: It is now easy to see why travel to other stars will be so difficult. We even made some overly generous assumptions and ignored relativistic effects.

P2.60. 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. For constant deceleration of your car, kinematic equations hold. 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, $x_2 - x_1 = 110$ m – 14 m = 96 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:

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

P2.61. Prepare: 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.

By assuming the acceleration to be constant we can use

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

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.

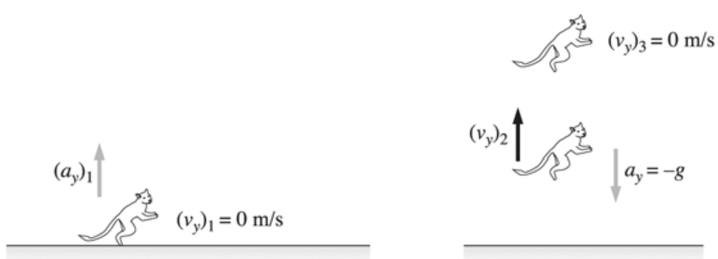
$$a_x = \frac{2x_f}{(\Delta t)^2} = \frac{2(1.0\text{ cm})}{(0.024\text{ s})^2}\left(\frac{1\text{ m}}{100\text{ cm}}\right) = 35\text{ m/s}^2$$

(c) Since we know the Δt and the a and $v_i = 0.0$ 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!

P2.62. Prepare: Since the acceleration during the jump is approximately constant, we can use the kinematic equations. 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.

P2.63. 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).

$$(v_y)_\text{f}^2 = (v_y)_\text{i}^2 + 2a_y\Delta y$$

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).

$$(v_y)_\text{f} = (v_y)_\text{i} + a_y\Delta t$$

Part **(c)** is about the phase of the jump *after* the flea reaches takeoff speed and leaves the ground. So now it is $(v_y)_\text{i}$, that is 1.0 m/s instead of $(v_y)_\text{f}$. 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 $(v_y)_\text{i} = 0.0\text{ m/s}$ and rearrange Equation 2.13.

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

(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 $(v_y)_\text{i} = 0.0\text{ m/s}$.

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

(c) This time $(v_y)_\text{f} = 0.0\text{ m/s}$ as the flea reaches the top of its trajectory. Rearrange Equation 2.13 to get

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

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.

P2.64. **Prepare:** Use the kinematic equations with $(v_y)_\text{i} = 0$ m/s in the acceleration phase.

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

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

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

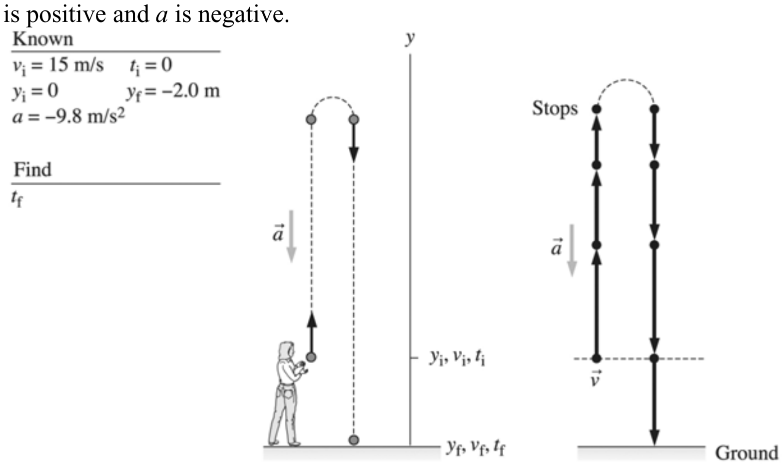
$$\Delta t = \frac{\Delta v_y}{a_y} = \frac{6.86\text{ m/s}}{(400)(9.8\text{ m/s}^2)} = 1.7496\text{ ms} \approx 1.7\text{ ms}$$

(c) Now the initial speed for the free-fall phase is the final speed of the jumping phase and $(v_y)_\text{f} = 0$.

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

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

P2.65. **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. As soon as the ball leaves the student's hand, it is falling freely and thus kinematic equations hold. 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 $y_\text{i} = 0$, but the final position is below the origin at $y_\text{f} = -2.0$ 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

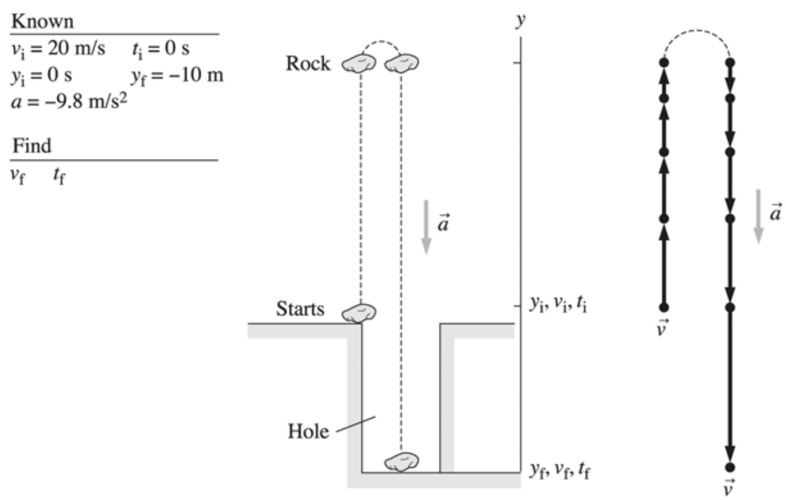
$$y_f = y_i + v_i \Delta t + \frac{1}{2} a \Delta t^2$$

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.

P2.66. 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. As soon as the rock is tossed up, it falls freely and thus kinematic equations hold. 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

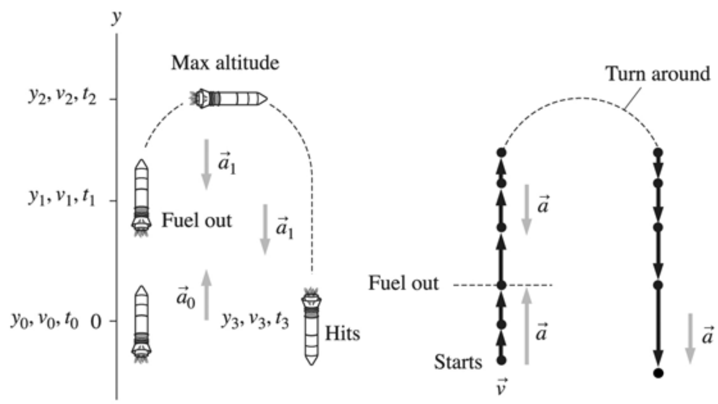
$$v_f = 20(\text{m/s}) + (-9.8 \text{ m/s}^2)(4.53 \text{ s}) = -24 \text{ m/s}$$

(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.

P2.67. Prepare: A visual overview of the rocket's motion 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 rocket accelerates upward for 30 s, but as soon as the rocket runs out of fuel, it falls freely. The kinematic equations hold separately before as well as after the rocket runs out of fuel because accelerations for both situations are constant, 30.0 m/s^2 for the former and 9.8 m/s^2 for the latter. Also, note that $a_0 = +30.0$ m/s^2 is vertically upward, but $a_1 = a_2 = -9.8$ m/s^2 acts vertically downward. This is a three-part problem. For the first accelerating phase, the initial position of the rocket is at the origin where $y_0 = 0$, but the position when fuel runs out is at y_1. Recall sign conventions, which tell us that v_0 is positive. From the given information, we can find v_1. For the second part of the problem, v_1 is positive as the rocket is moving upward, v_2 is zero as it reaches the maximum altitude, and a_1 is negative. This helps us find y_2. The third part involves finding t_2 and t_3, which can be obtained using kinematics.

Known
$y_0 = 0 \quad v_0 = 0$
$t_0 = 0 \quad a_0 = 30\ \text{m/s}^2$
$t_1 = 30\ \text{s}$
$a_1 = -9.8\ \text{m/s}^2$
$v_2 = 0 \quad y_3 = 0$
$a_2 = -9.8\ \text{m/s}^2$

Find
$y_2 \quad t_3$



Solve: (a) There are three parts to the motion. Both the second and third parts of the motion are free fall, with $a = -g$. The maximum altitude is y_2. In the acceleration phase

$$y_1 = y_0 + v_0(t_1 - t_0) + \frac{1}{2}a(t_1 - t_0)^2 = \frac{1}{2}at_1^2 = \frac{1}{2}(30\ \text{m/s}^2)(30\ \text{s})^2 = 13{,}500\ \text{m}$$

$$v_1 = v_0 + a(t_1 - t_0) = at_1 = (30\ \text{m/s}^2)(30\ \text{s}) = 900\ \text{m/s}$$

In the coasting phase,

$$v_2^2 = 0 = v_1^2 - 2g(y_2 - y_1) \Rightarrow y_2 = y_1 + \frac{v_1^2}{2g} = 13{,}500\ \text{m} + \frac{(900\ \text{m/s})^2}{2(9.8\ \text{m/s}^2)} = 54{,}800\ \text{m} = 54.8\ \text{km}$$

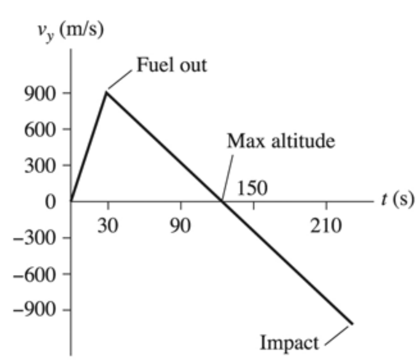
The maximum altitude is 54.8 km (≈33 miles).
(b) The rocket is in the air until time t_3. We already know $t_1 = 30$ s. We can find t_2 as follows:

$$v_2 = 0\ \text{m/s} = v_1 - g(t_2 - t_1) \Rightarrow t_2 = t_1 + \frac{v_1}{g} = 122\ \text{s}$$

Then t_3 is found by considering the time needed to fall 54,800 m:

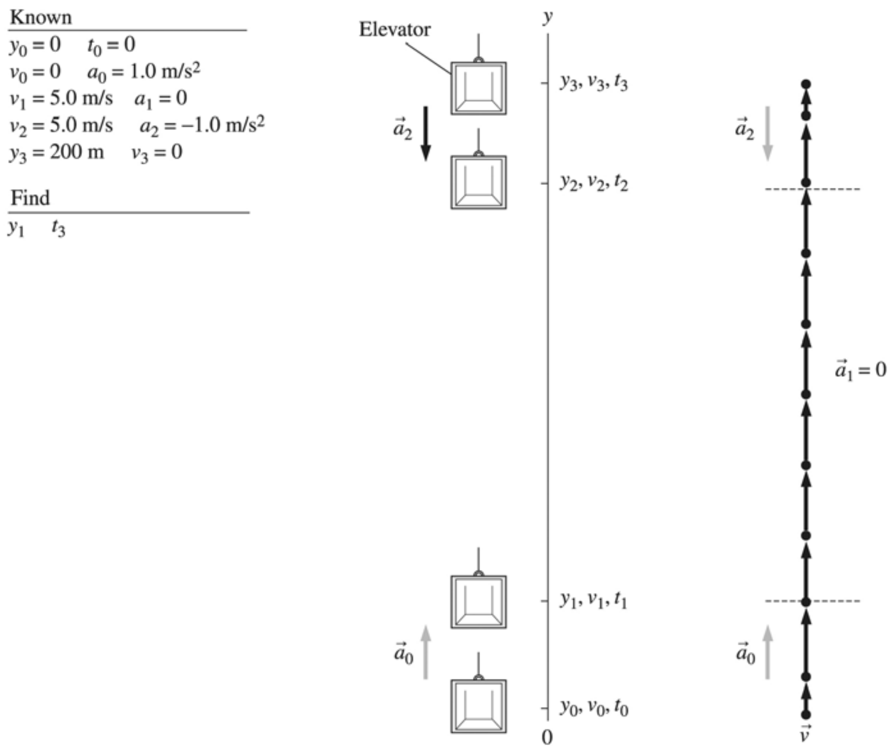
$$y_3 = 0\ \text{m} = y_2 + v_2(t_3 - t_2) - \frac{1}{2}g(t_3 - t_2)^2 = y_2 - \frac{1}{2}g(t_3 - t_2)^2 \Rightarrow t_3 = t_2 + \sqrt{\frac{2y_2}{g}} = 230\ \text{s}$$

(c) The velocity increases linearly, with a slope of 30 (m/s)/s, for 30 s to a maximum speed of 900 m/s. It then begins to decrease linearly with a slope of –9.8 (m/s)/s. The velocity passes through zero (the turning point at y_2) at $t_2 = 122$ s. The impact velocity at $t_3 = 230$ s is calculated to be $v_3 = v_2 - g(t_3 - t_2) = -1000$ m/s.



Assess: In reality, friction due to air resistance would prevent the rocket from reaching such high speeds as it falls, and the acceleration upward would not be constant because the mass changes as the fuel is burned, but that is a more complicated problem.

P2.68. Prepare: A visual overview of the elevator's motion that includes a pictorial representation, a motion diagram, and a list of values is shown below. We represent the elevator's motion along the y-axis. The elevator's net displacement is $y_3 - y_0 = 200$ m. However, the displacement $y_1 - y_0$ occurs during the accelerating period, $y_3 - y_2$ occurs during the decelerating period, and $y_2 - y_1$ occurs at a speed of 5.0 m/s with no acceleration. It is clear that we must apply kinematics equations separately to each of these three periods. For the accelerating period, $y_0 = 0$, $v_0 = 0$, $v_1 = 5.0$ m/s, and $a_0 = 1.0$ m/s^2, so y_1 and t_1 can be easily determined. For the decelerating period, $v_3 = 0$, $v_2 = 5.0$ m/s, and $a_2 = -1.0$ m/s^2, so $y_3 - y_2$ and $t_3 - t_2$ can also be determined. From the thus obtained information, we can obtain $y_2 - y_1$ and use kinematics once again to find $t_2 - t_1$ and hence the total time to make the complete trip.



Solve: **(a)** To calculate the distance to accelerate up:

$$v_1^2 = v_0^2 + 2a_0(y_0 - y_0) \Rightarrow (5\text{ m/s})^2 = (0\text{ m/s})^2 + 2(1\text{ m/s}^2)(y_1 - 0\text{ m}) \Rightarrow y_1 = 12.5\text{ m} = 13\text{ m}$$

(b) To calculate the time to accelerate up:

$$v_1 = v_0 + a_0(t_1 - t_0) \Rightarrow 5\text{ m/s} = 0\text{ m/s} + (1\text{ m/s}^2)(t_1 - 0\text{ s}) \Rightarrow t_1 = 5\text{ s}$$

To calculate the distance to decelerate at the top:

$$v_3^2 = v_2^2 + 2a_2(y_3 - y_2) \Rightarrow (0\text{ m/s})^2 = (5\text{ m/s})^2 + 2(-1\text{ m/s}^2)(y_3 - y_2) \Rightarrow y_3 - y_2 = 12.5\text{ m}$$

To calculate the time to decelerate at the top:

$$v_3 = v_2 + a_2(t_3 - t_2) \Rightarrow 0\text{ m/s} = 5\text{ m/s} + (-1\text{ m/s}^2)(t_3 - t_2) \Rightarrow t_3 - t_2 = 5\text{ s}$$

The distance moved up at 5 m/s is

$$y_2 - y_1 = (y_3 - y_0) - (y_3 - y_2) - (y_1 - y_0) = 200\text{ m} - 12.5\text{ m} - 12.5\text{ m} = 175\text{ m}$$

The time to move up 175 m is given by

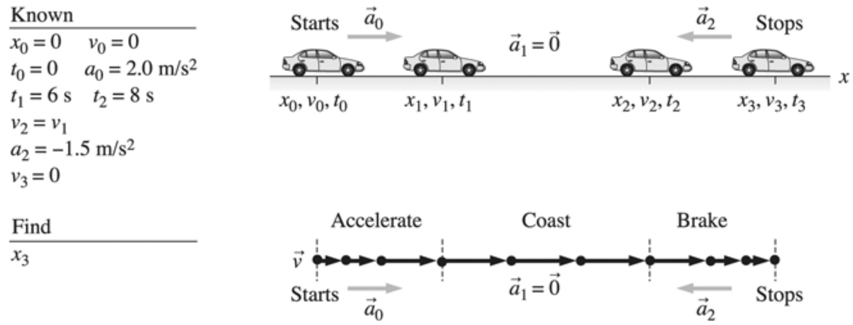
$$y_2 - y_1 = v_1(t_2 - t_1) + \frac{1}{2}a_1(t_2 - t_1)^2 \Rightarrow 175\text{ m} = (5\text{ m/s})(t_2 - t_1) \Rightarrow (t_2 - t_1) = 35\text{ s}$$

To total time to move to the top is

$$(t_1 - t_0) + (t_2 - t_1) + (t_3 - t_2) = 5\text{ s} + 35\text{ s} + 5\text{ s} = 45\text{ s}$$

Assess: To cover a distance of 200 m at 5 m/s (ignoring acceleration and deceleration times) will require a time of 40 s. This is comparable to the time of 45 s for the entire trip as obtained above.

P2.69. 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:

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

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

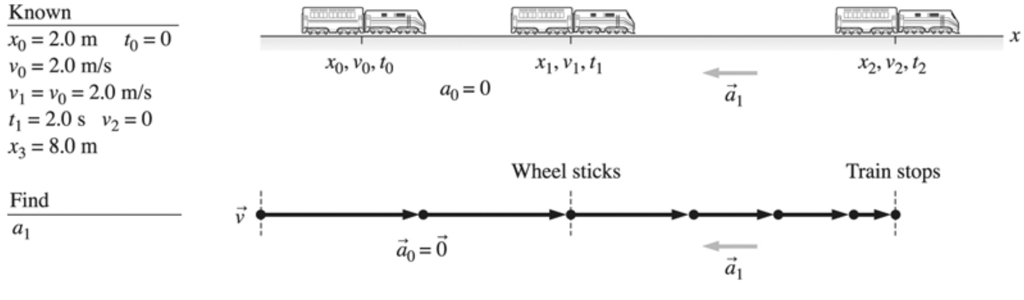
Thus, the total distance between stop signs is

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

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.

P2.70. Prepare: A visual overview of the toy train's motion that includes a pictorial representation, a motion diagram, and a list of values is shown below. We label the train's motion along the *x*-axis. We first focus our attention on the decelerating period and determine from the given information that a_1 can be determined provided we know $x_2 - x_1$. While x_2 is given as 6.0 m + 2.0 m = 8.0 m, kinematics in the coasting period helps us find x_1.



Solve: Using kinematics,

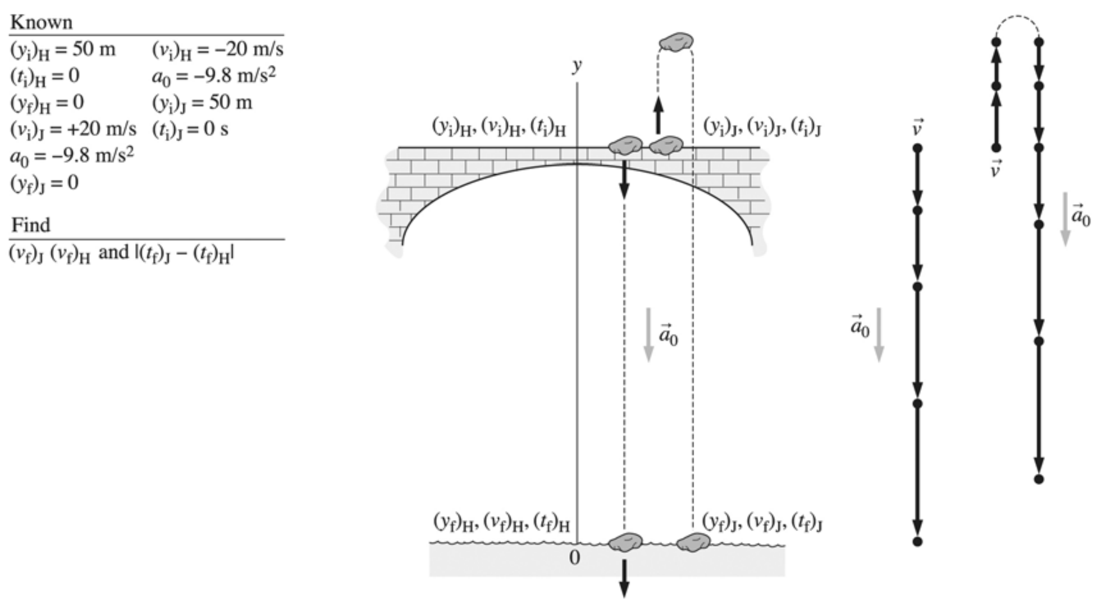
$$x_1 = x_0 + v_0(t_1 - t_0) + \frac{1}{2}a_0(t_1 - t_0)^2 = 2\text{ m} + (2.0\text{ m/s})(2.0\text{ s} - 0\text{ s}) + 0\text{ m} = 6.0\text{ m}$$

The acceleration can now be obtained as follows:

$$v_2^2 = v_1^2 + 2a_1(x_2 - x_1) \Rightarrow 0\text{ m}^2/\text{s}^2 = (2.0\text{ m/s})^2 + 2a_1(8.0\text{ m} - 6.0\text{ m}) \Rightarrow a_1 = -1.0\text{ m/s}^2$$

Assess: A deceleration of 1 m/s^2 in bringing the toy car to a halt, which was moving at a speed of only 2.0 m/s, over a distance of 2.0 m is reasonable.

P2.71. 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. As soon as the rocks are thrown, they fall freely and thus kinematics equations are applicable. The initial position for both cases is y_i = 50 m and similarly the final position for both cases is at $y_f = 0$. Recall sign conventions, which tell us that $(v_i)_J$ is positive and $(v_i)_H$ is negative.



Solve: (a) For Heather,

$$(y_f)_H = (y_i)_H + (v_i)_H[(t_f)_H - (t_i)_H] + \frac{1}{2}a_0[(t_f)_H - (t_i)_H)]^2$$

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

$$\Rightarrow 4.9\text{ m/s}^2\ (t_f)_H^2 + 20\text{ m/s}\ (t_f)_H - 50\text{ m} = 0$$

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, $(t_f)_H$ = 1.75 s.
For Jerry,

$$(y_f)_J = (y_i)_J + (v_i)_J[(t_f)_J - (t_i)_J] + \frac{1}{2}a_0[(t_f)_J - (t_i)_J)]^2$$

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

Solving this quadratic equation will yield $(t_f)_J$ = −1.75 s and +5.83 s. Again only the positive root is physically meaningful. The elapsed time between the two splashes is $(t_f)_J - (t_f)_H$ = 5.83 s – 1.75 s = 4.1 s.

(b) Knowing the times, it is easy to find the impact velocities:

$$(v_f)_H = (v_i)_H + a_0[(t_f)_H - (t_i)_H] = (-20 \text{ m/s}) + (-9.8 \text{ m/s})(1.75 \text{ s} - 0 \text{ s}) = -37 \text{ m/s}$$

$$(v_f)_J = (v_i)_J + a_0[(t_f)_J - (t_i)_J] = (+20 \text{ m/s}) + (-9.8 \text{ m/s}^2)(5.83 \text{ s} - 0 \text{ s}) = -37 \text{ m/s}$$

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.

P2.72. Prepare: Use the kinematic equations with $(v_x)_i = 0$ m/s in the acceleration phase.

Solve:
(a) The gazelle gains speed at a steady rate for the first 6.5 s.

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

(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.

P2.73. Prepare: Use the kinematic equations with $(v_x)_i = 0$ 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

$$(v_x)_f = (v_x)_i + a_x\Delta t = 0 \text{ m/s} + (6.0 \text{ m/s}^2)(1.8 \text{ s}) = 10.8 \text{ m/s}$$

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

$$(v_x)_f = (v_x)_i + a_x\Delta t = 0 \text{ m/s} + (5.0 \text{ m/s}^2)(4.8 \text{ s}) = 24 \text{ m/s}$$

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.

P2.74. Prepare: Assume the vaulter is in free fall before he hits the pad. 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 $(v_x)_\text{i} = 0$ m/s

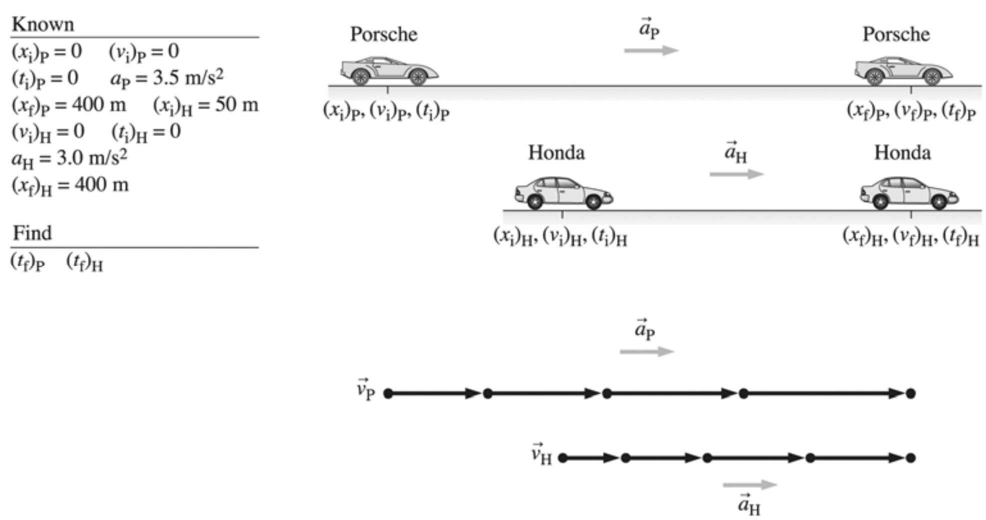
$$(v_y)_\text{f}^2 = (v_y)_\text{i}^2 + 2a_y\Delta y \Rightarrow (v_y)_\text{f} = \sqrt{2(9.8 \text{ m/s}^2)(3.4 \text{ m})} = 8.16 \text{ m/s}$$

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.

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

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.

P2.75. 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 acceleration kinematic equations are applicable because both cars have constant accelerations. We can easily calculate the times $(t_\text{f})_\text{H}$ and $(t_\text{f})_\text{P}$ from the given information.



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

$$(x_\text{f})_\text{P} = (x_\text{i})_\text{P} + (v_\text{i})_\text{P}((t_\text{f})_\text{P} - (t_\text{i})_\text{P}) + \frac{1}{2}a_\text{P}((t_\text{f})_\text{P} - (t_\text{i})_\text{P})^2$$

$$\Rightarrow 400 \text{ m} = 0 \text{ m} + 0 \text{ m} + \frac{1}{2}(3.5 \text{ m/s}^2)((t_\text{f})_\text{P} - 0 \text{ s})^2 \Rightarrow (t_\text{f})_\text{P} = 15 \text{ s}$$

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

$$(x_\text{f})_\text{H} = (x_\text{i})_\text{H} + (v_\text{i})_\text{H}((t_\text{f})_\text{H} - (t_\text{i})_\text{H}) + \frac{1}{2}a_\text{H}((t_\text{f})_\text{H} - (t_\text{i})_\text{H})^2$$

$$400 \text{ m} = 100 \text{ m} + 0 \text{ m} + \frac{1}{2}(3.0 \text{ m/s}^2)((t_\text{f})_\text{H} - 0 \text{ s})^2 \Rightarrow (t_\text{f})_\text{H} = 14 \text{ s}$$

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.

P2.76. 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

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

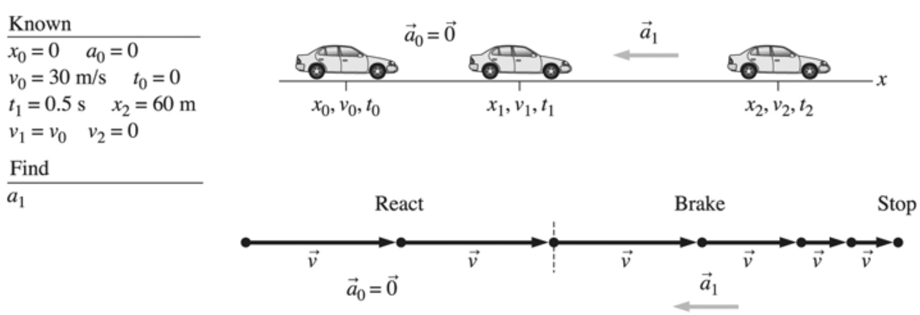
$$\Rightarrow a_1 = -\frac{v_1^2}{2(x_2 - x_1)} = -\frac{(30\text{ m/s})^2}{2(60\text{ m} - 15\text{ m})} = -10\text{ m/s}^2$$

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

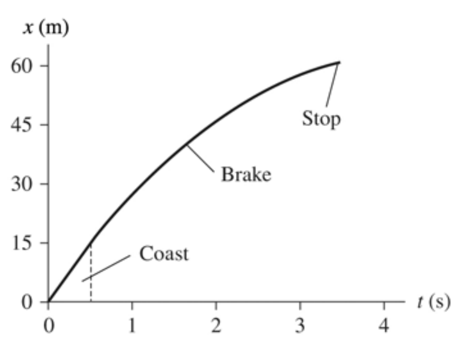
$$v_2 = 0 = v_1 + a_1(t_2 - t_1) \Rightarrow t_2 = t_1 - \frac{v_1}{a_1} = 3.5\text{ s}$$

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

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

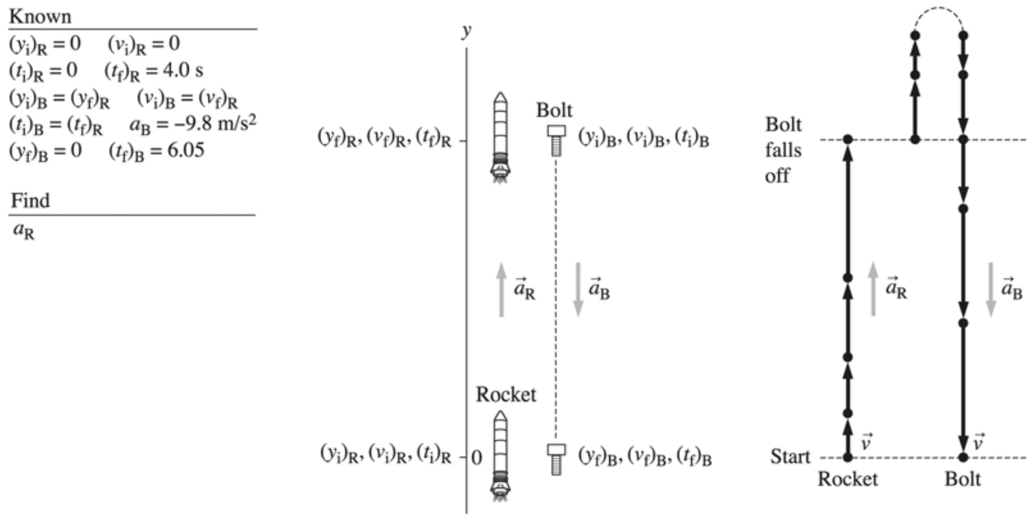


So the stopping distance is

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

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

P2.77. 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 $a_R = 5.5$ m/s^2.

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

P2.78. 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.

P2.79. Prepare: In free fall we use equations for constant acceleration. 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).

P2.80. 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.