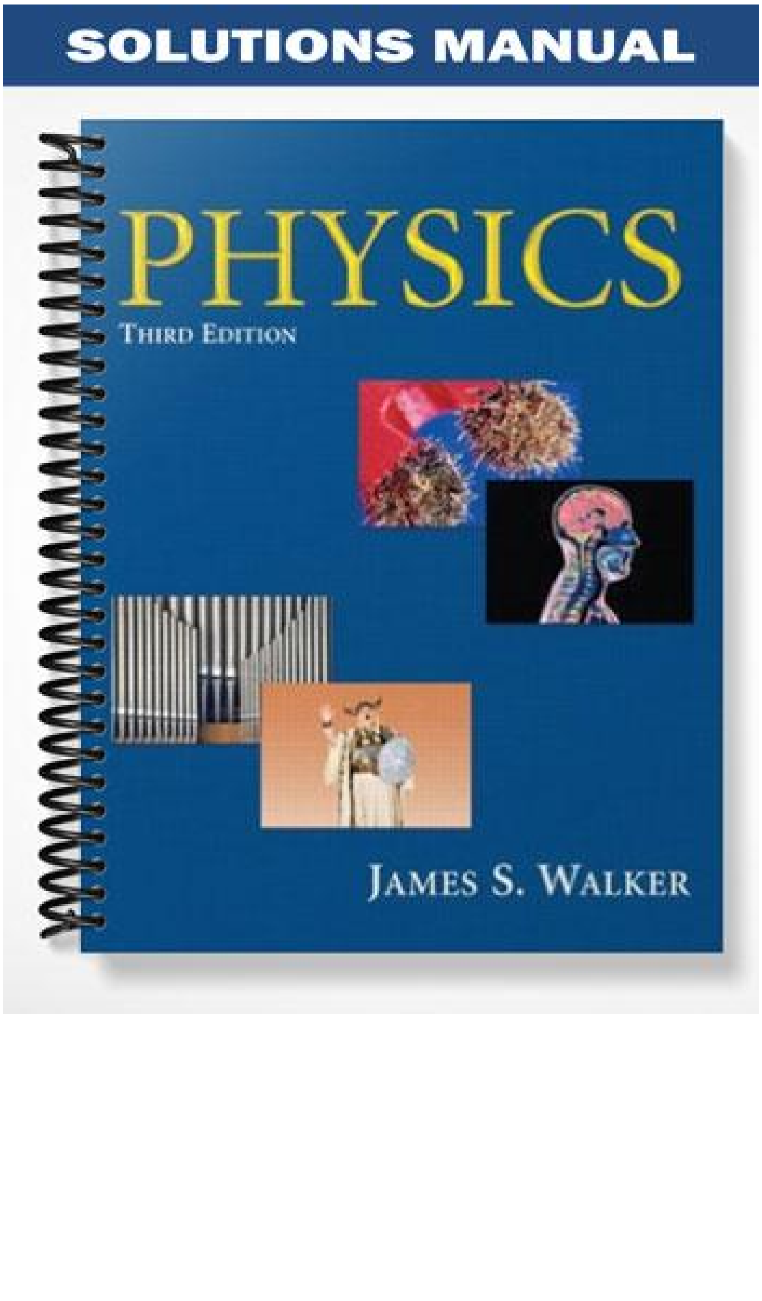

SOLUTIONS MANUAL
PHYSICS
THIRD EDITION
JAMES S. WALKER

Chapter 2: One-Dimensional Kinematics

Answers to Even-Numbered Conceptual Questions

2. An odometer measures the distance traveled by a car. You can tell this by the fact that an odometer has a nonzero reading after a round trip.

4. No. After one complete orbit the astronaut's displacement is zero. The distance traveled, however, is roughly 25,000 miles.

6. A speedometer measures speed, not velocity. For example, if you drive with constant speed in a circular path, your speedometer maintains the same reading, even though your velocity is constantly changing.

8. Yes. For example, your friends might have backed out of a parking place at some point in the trip, giving a negative velocity for a short time.

10. No. If you throw a ball upward, for example, you might choose the release point to be $y = 0$. This doesn't change the fact that the initial upward speed is nonzero.

12. **(a)** Yes. The object might simply be at rest. **(b)** Yes. An example would be a ball thrown straight upward; at the top of its trajectory its velocity is zero, but it has a nonzero acceleration downward.

14. Yes. A ball thrown straight upward and caught when it returns to its release point has zero average velocity, but it has been accelerating the entire time.

16. When she returns to her original position, her speed is the same as it was initially; that is, 4.5 m/s.

18. **(a)** No. Displacement is the *change* in position, and therefore it is independent of the location chosen for the origin. **(b)** Yes. In order to know whether an object's displacement is positive or negative, we need to know which direction has been chosen to be positive.

Answers to Even-Numbered Conceptual Exercises

2. It takes longer to drive 10 km at 15 m/s that it does at 25 m/s. Therefore, the average speed for the entire trip is closer to 15 m/s than to 25 m/s, since more time is spent at the lower speed. It follows that the answer is (c); the average speed is less than 20 m/s.

4. The acceleration produced by bow A is less than the acceleration produced by bow B. This follows because bow B accelerates the arrow to the same speed as bow A, but in a shorter distance.

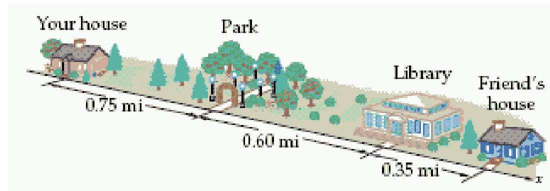
6. The hammer's increase in speed as it drops past window 1 is greater than its increase in speed as it drops past window 2. This is because the increase in speed is directly proportional to time, from $v - v_0 = at$, and more time is required for the hammer to drop past window 1.

8. (ii) The balls have the same speed just before they land because they both have the same downward speed when they are at the level of the roof. Ball B simply starts off with the speed v_0 downward. Ball A travels upward initially, but when it returns to the level of the roof it is moving downward with the speed v_0, just like ball B.

10. **(a)** Plot 3 corresponds to ball A because it shows a speed that starts at zero and increases linearly with time. **(b)** Plot 2 corresponds to ball B. In this case, the speed starts at v_0 and increases linearly with time. In addition, the slope of the linear increase is the same for plot 2 as for plot 3, as required since both balls experience the same free fall acceleration.

Solutions to Problems

1. **Picture the Problem**: You walk in both the positive and negative directions along a straight line.



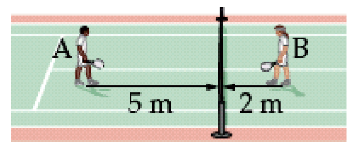
Strategy: The distance is the total length of travel, and the displacement is the net change in position.

Solution: (a) Add the lengths: $(0.75+0.60 \text{ mi})+(0.60 \text{ mi})=\boxed{1.95 \text{ mi}}$

(b) Subtract x_i from x_f to find the displacement. $\Delta x = x_f - x_i = 0.75-0.00 \text{ mi} = \boxed{0.75 \text{ mi}}$

Insight: The distance traveled is always positive, but the displacement can be negative.

2. **Picture the Problem**: Player A walks in the positive direction and player B walks in the negative direction.



Strategy: In each case the distance is the total length of travel, and the displacement is the net change in position.

Solution: (a) Note the distance traveled by player A: $\boxed{5 \text{ m}}$

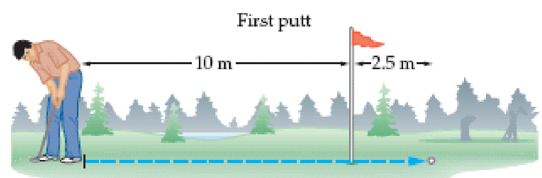
The displacement of player A is positive: $\Delta x = x_f - x_i = 5 \text{ m} - 0 \text{ m} = \boxed{5 \text{ m}}$

(b) Note the distance traveled by player B: $\boxed{2 \text{ m}}$

The displacement of player B is negative. Let the origin be at the initial position of player A. $\Delta x = x_f - x_i = 5 \text{ m} - 7 \text{ m} = \boxed{-2 \text{ m}}$

Insight: The distance traveled is always positive, but the displacement can be negative.

3. **Picture the Problem**: The ball is putted in the positive direction and then the negative direction.



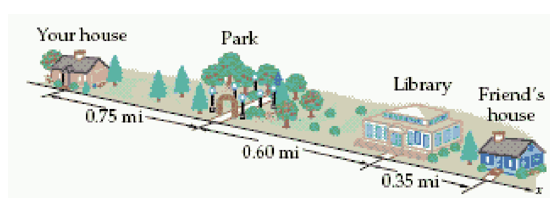
Strategy: The distance is the total length of travel, and the displacement is the net change in position.

Solution: (a) Add the lengths: $(10+2.5 \text{ m})+2.5 \text{ m} = \boxed{15 \text{ m}}$

(b) Subtract x_i from x_f to find the displacement. $\Delta x = x_f - x_i = 10-0 \text{ m} = \boxed{10 \text{ m}}$

Insight: The distance traveled is always positive, but the displacement can be negative.

4. **Picture the Problem**: You walk in both the positive and negative directions along a straight line.



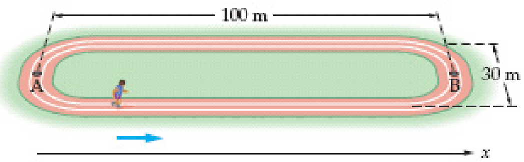
Strategy: The distance is the total length of travel, and the displacement is the net change in position.

Solution: (a) Add the lengths: $(0.60+0.35 \text{ mi})+(0.75+0.60+0.35 \text{ mi})=\boxed{2.65 \text{ mi}}$

(b) Subtract x_i from x_f to find the displacement. $\Delta x = x_f - x_i = 0.75-0.00 \text{ mi} = \boxed{0.75 \text{ mi}}$

Insight: The distance traveled is always positive, but the displacement can be negative.

5. **Picture the Problem**: The runner moves along the oval track.



Strategy: The distance is the total length of travel, and the displacement is the net change in position.

Solution: 1. (a) Add the lengths: $(15\text{ m})+(100\text{ m})+(15\text{ m})=\boxed{130\text{ m}}$

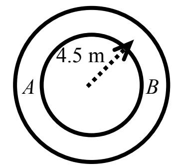
2. Subtract x_i from x_f to find the displacement. $\Delta x = x_f - x_i = 100-0\text{ m} = \boxed{100\text{ m}}$

3. (b) Add the lengths $15+100+30+100+15\text{ m}=\boxed{260\text{ m}}$

4. Subtract x_i from x_f to find the displacement. $\Delta x = x_f - x_i = 0-0\text{ m} = \boxed{0\text{ m}}$

Insight: The distance traveled is always positive, but the displacement can be negative. The displacement is always zero for a complete circuit, as in this case.

6. **Picture the Problem**: The pony walks around the circular track.



Strategy: The distance is the total length of travel, and the displacement is the net change in position.

Solution: (a) 1. The distance traveled is half the circumference: $d=\frac{1}{2}(2\pi r)=\pi r=\pi(4.5\text{ m})=\boxed{14\text{ m}}$

2. The displacement is the distance from *A* to *B*: $\Delta x = x_f - x_i = 2r = 2(4.5\text{ m}) = \boxed{9.0\text{ m}}$

3. (b) The distance traveled will [increase] when the child completes one circuit, because the pony will have taken more steps.

4. (c) The displacement will [decrease] when the child completes one circuit, because the displacement is maximum when the child has gone halfway around, and is zero when the child returns to the starting position.

5. (d) The distance traveled equals the circumference: $d=2\pi r=2\pi(4.5\text{ m})=\boxed{28\text{ m}}$

6. The displacement is zero because the child has returned to her starting position.

Insight: The distance traveled is always positive, but the displacement can be negative. The displacement is always zero for a complete circuit, as in this case.

7. **Picture the Problem**: The runner sprints in the forward direction.

Strategy: The average speed is the distance divided by elapsed time.

Solution: Divide the distance by the time: $s=\dfrac{\text{distance}}{\text{time}}=\dfrac{200.0\text{ m}}{19.75\text{ s}}=\boxed{10.13\text{ m/s}}\times\dfrac{1\text{ mi}}{1609\text{ m}}\times\dfrac{3600\text{ s}}{1\text{ h}}=\boxed{22.66\text{ mi/h}}$

Insight: The displacement would be complicated in this case because the 200-m dash usually takes place on a curved track. Fortunately, the average speed depends upon distance traveled, not displacement.

8. **Picture the Problem**: The swimmer swims in the forward direction.

Strategy: The average speed is the distance divided by elapsed time.

Solution: Divide the distance by the time: $s=\dfrac{\text{distance}}{\text{time}}=\dfrac{100.0\text{ m}}{54.64\text{ s}}=\boxed{1.830\text{ m/s}}\times\dfrac{1\text{ mi}}{1609\text{ m}}\times\dfrac{3600\text{ s}}{1\text{ h}}=\boxed{4.095\text{ mi/h}}$

Insight: The displacement would be zero in this case because the swimmer swims either two lengths of a 50-m pool or four lengths of a 25-m pool, returning to the starting point each time. However, the average speed depends upon distance traveled, not displacement.

9. **Picture the Problem**: The kangaroo hops in the forward direction.

Strategy: The distance is the average speed multiplied by the time elapsed. The time elapsed is the distance divided by the average speed.

Solution: 1. (a) Multiply the average speed by the time elapsed: $d = st = \left(65\ \frac{\text{km}}{\text{h}}\right)\left(3.2\ \text{min} \times \frac{1\ \text{h}}{60\ \text{min}}\right) = \boxed{3.5\ \text{km}}$

2. (b) Divide the distance by the average speed: $t = \frac{d}{s} = \frac{0.25\ \text{km}}{65\ \text{km/h}} \times \frac{60\ \text{min}}{1\ \text{h}} = \boxed{14\ \text{s}}$

Insight: The instantaneous speed might vary from 65 km/h, but the time elapsed and the distance traveled depend only upon the average speed during the interval in question.

10. **Picture the Problem**: The rubber ducks drift along the ocean surface.

Strategy: The average speed is the distance divided by elapsed time.

Solution: 1. (a) Divide the distance by the time: $s = \frac{d}{t} = \frac{1600\ \text{mi}}{10\ \text{mo}} \times \frac{1609\ \text{m}}{1\ \text{mi}} \times \frac{1\ \text{mo}}{30.5\ \text{d}} \times \frac{1\ \text{d}}{8.64 \times 10^4 \text{s}} = \boxed{0.098\ \text{m/s}}$

2. (b) Divide the distance by the time: $s = \frac{d}{t} = \frac{1600\ \text{mi}}{10\ \text{mo}} \times \frac{1\ \text{mo}}{30.5\ \text{d}} \times \frac{1\ \text{d}}{24\ \text{h}} = \boxed{0.22\ \text{mi/h}}$

Insight: The instantaneous speed might vary from 0.098 m/s, but we can calculate only average speed from the total distance traveled and time elapsed.

11. **Picture the Problem**: The radio waves propagate in a straight line.

Strategy: The time elapsed is the distance divided by the average speed. The distance to the Moon is 2.39×10^5 mi. We must double this distance because the signal travels there and back again.

Solution: Divide the distance by the average speed: $t = \frac{2d}{s} = \frac{2\left(2.39 \times 10^5\ \text{mi}\right)}{1.86 \times 10^5\ \text{mi/s}} = \boxed{2.57\ \text{s}}$

Insight: The time is slightly shorter than this because the given distance is from the center of the Earth to the center of the Moon, but presumably any radio communications would occur between the surfaces of the Earth and Moon. When the radii of the two spheres is taken into account, the time decreases to 2.52 s.

12. **Picture the Problem**: The sound waves propagate in a straight line from the thunderbolt to your ears.

Strategy: The distance is the average speed multiplied by the time elapsed. We will neglect the time it takes for the light wave to arrive at your eyes because it is vastly smaller than the time it takes the sound wave to travel.

Solution: Multiply the average speed by the time elapsed: $d = st = (340\ \text{m/s})(3.5\ \text{s}) = 1200\ \text{m} = \boxed{1.2\ \text{km}}$

Insight: The speed of sound, 340 m/s, works out to approximately one mile every five seconds, a useful rule of thumb for estimating the distance to an approaching thunderstorm!

13. **Picture the Problem**: The nerve impulses propagate at a fixed speed.

Strategy: The time elapsed is the distance divided by the average speed. The distance from your finger to your brain is on the order of one meter.

Solution: Divide the distance by the average speed: $t = \frac{d}{s} = \frac{1\ \text{m}}{1 \times 10^2\ \text{m/s}} = \boxed{0.010\ \text{s}}$

Insight: This nerve impulse travel time is not the limiting factor for human reaction time, which is about 0.2 s.

14. **Picture the Problem**: Your hair grows at a fixed speed.

Strategy: The growth rate is the length gained divided by the time elapsed. Hair grows at a rate of about half an inch a month, or about 1 cm or 0.01 m per month.

Solution: Divide the length gained by the elapsed time: $s = \frac{d}{t} = \frac{0.010\text{ m}}{1\text{ mo}} \times \frac{1\text{ mi}}{1609\text{ m}} \times \frac{1\text{ mo}}{30.5\text{ d}} \times \frac{1\text{ d}}{24\text{ h}} = \boxed{8.5\times10^{-9}\text{ mi/h}}$

Insight: Try converting this growth rate to a more appropriate unit such as μm/h. (Answer: 14 μm/h.) Choosing an appropriate unit can help you communicate a number more effectively.

15. **Picture the Problem**: The finch travels a short distance on the back of the tortoise and a longer distance through the air, with both displacements along the same direction.

Strategy: First find the total distance traveled by the finch and then determine the average speed by dividing by the total time elapsed.

Solution: 1. Determine the total distance traveled:

$$d = s_1\Delta t_1 + s_2\Delta t_2$$
$$d = \left[(0.060\text{ m/s})(1.2\text{ min}) + (12\text{ m/s})(1.2\text{ min})\right]\times 60\text{ s/min}$$
$$d = 870\text{ m} = 0.87\text{ km}$$

2. Divide the distance by the time elapsed:

$$s = \frac{d}{\Delta t} = \frac{870\text{ m}}{2.4\text{ min}\times 60\text{ s/min}} = \boxed{6.0\text{ m/s}}$$

Insight: Most of the distance traveled by the finch occurred by air. In fact, if we neglect the 4.3 m the finch traveled while on the tortoise's back, we still get an average speed of 6.0 m/s over the 2.4 min time interval! The bird might as well have been at rest.

16. **Picture the Problem**: You travel 8.0 km on foot and then an additional 16 km by car, with both displacements along the same direction.

Strategy: First find the total time elapsed by dividing the distance traveled by the average and divide by the total time elapsed to find the average speed. Set that average speed to the given value and solve for the car's speed.

Solution: 1. Use the definition of average speed to determine the total time elapsed.

$$\Delta t = \frac{d}{s_{av}} = \frac{8.0+16\text{ km}}{22\text{ km/h}} = 1.1\text{ h}$$

2. Find the time elapsed while in the car:

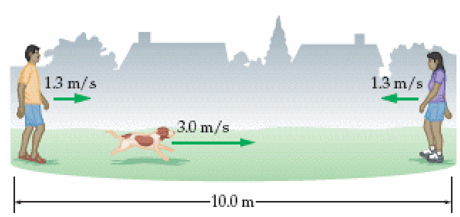
$$\Delta t_2 = \Delta t - \Delta t_1 = 1.1\text{ h} - 0.84\text{ h} = 0.3\text{ h}$$

3. Find the speed of the car:

$$s_2 = \frac{d_2}{\Delta t_2} = \frac{16\text{ km}}{0.3\text{ h}} = \boxed{50\text{ km/h}}$$

Insight: This problem illustrates the limitations that significant figures occasionally impose. If you keep an extra figure in the total elapsed time (1.09 h) you'll end up with the time elapsed for the car trip as 0.25 h, not 0.3, and the speed of the car is 64 km/h. But the rules of subtraction indicate we only know the total time to within a tenth of an hour, so we can only know the time spent in the car to within a tenth of an hour, or to within one significant digit.

17. **Picture the Problem**: The dog continuously runs back and forth as the owners close the distance between each other.



Strategy: First find the time that will elapse before the owners meet each other. Then determine the distance the dog will cover if it continues running at constant speed over that time interval.

Solution: 1. Find the time it takes each owner to walk 5.00 m before meeting each other:

$$\Delta t = \frac{d}{s_{av}} = \frac{5.00\text{ m}}{1.3\text{ m/s}} = 3.8\text{ s}$$

2. Find the distance the dog runs:

$$d = s\Delta t = (3.0\text{ m/s})(3.8\text{ s}) = \boxed{11\text{ m}}$$

Insight: The dog will actually run a shorter distance than this, because it is impossible for it to maintain the same 3.0 m/s as it turns around to run to the other owner. It must first slow down to zero speed and then accelerate again.

18. **Picture the Problem**: You travel in a straight line at two different speeds during the specified time interval.

Strategy: Determine the average speed by first calculating the total distance traveled and then dividing it by the total time elapsed.

Solution: 1. (a) Because the time intervals are the same, you spend equal times at 20 m/s and 30 m/s, and your average speed will be $\boxed{\text{equal to 25.0 m/s}}$.

2. (b) Divide the total distance by the time elapsed:

$$s_{av} = \frac{s_1\Delta t_1 + s_2\Delta t_2}{\Delta t_1 + \Delta t_2} = \frac{(20.0\text{ m/s})(10.0\text{ min}\times 60\text{ s}) + (30.0\text{ m/s})(600\text{ s})}{600 + 600\text{ s}}$$

$$s_{av} = \boxed{25.0\text{ m/s}}$$

Insight: The average speed is a weighted average according to how much *time* you spend traveling at each speed.

19. **Picture the Problem**: You travel in a straight line at two different speeds during the specified time interval.

Strategy: Determine the distance traveled during each leg of the trip in order to plot the graph.

Solution: 1. (a) Calculate the distance traveled in the first leg:

$$d_1 = s_1\Delta t_1 = (12\text{ m/s})(1.5\text{ min }\times 60\text{ s/min}) = \underline{\underline{1080\text{ m}}}$$

2. Calculate the distance traveled in the second leg:

$$d_2 = s_2\Delta t_2 = (0\text{ m/s})(3.5\text{ min}) = \underline{\underline{0\text{ m}}}$$

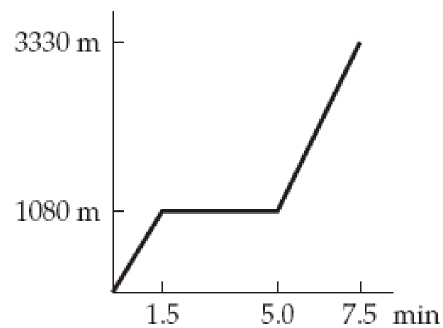
3. Calculate the distance traveled in the third leg:

$$d_3 = s_3\Delta t_3 = (15\text{ m/s})(2.5\text{ min }\times 60\text{ s/min}) = \underline{\underline{2250\text{ m}}}$$

4. Calculate the total distance traveled:

$$d = d_1 + d_2 + d_3 = \underline{\underline{3330\text{ m}}}$$

5. Draw the graph:



6. (b) Divide the total distance by the time elapsed:

$$s_{av} = \frac{d_1 + d_2 + d_3}{\Delta t_1 + \Delta t_2 + \Delta t_3} = \frac{3330\text{ m}}{7.5\text{ min }\times 60\text{ s/min}} = \boxed{7.4\text{ m/s}}$$

Insight: The average speed is a weighted average according to how much *time* you spend traveling at each speed. Here you spend the most amount of time at rest, so the average speed is less than either 12 m/s or 15 m/s.

20. **Picture the Problem**: You travel in a straight line at two different speeds during the specified time interval.

Strategy: Determine the average speed by first calculating the total distance traveled and then dividing it by the total time elapsed.

Solution: 1. (a) The distance intervals are the same but the time intervals are different. You will spend more time at the lower speed than at the higher speed. Since the average speed is a time weighted average, it will be $\boxed{\text{less than 25.0 m/s}}$.

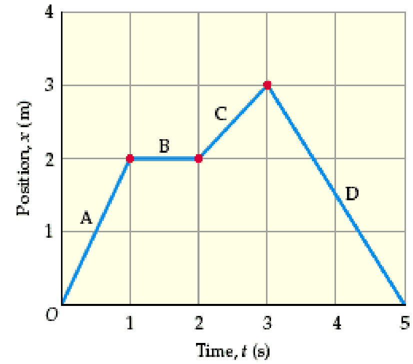
2. (b) Divide the total distance by the time elapsed:

$$s_{av} = \frac{d_1 + d_2}{\Delta t_1 + \Delta t_2} = \frac{d_1 + d_2}{\dfrac{d_1}{s_1} + \dfrac{d_2}{s_2}} = \frac{20.0\text{ mi}}{\left(\dfrac{10.0\text{ mi}}{20.0\text{ m/s}} + \dfrac{10.0\text{ mi}}{30.0\text{ m/s}}\right)}$$

$$s_{av} = \boxed{24.0\text{ m/s}}$$

Insight: Notice that in this case it is not necessary to convert miles to meters in both the numerator and denominator because the units cancel out and leave m/s in the numerator.

21. **Picture the Problem**: Following the motion specified in the position-versus-time graph, the father walks forward, stops, walks forward again, and then walks backward.



Strategy: Determine the direction of the velocity from the slope of the graph. Then determine the magnitude of the velocity by calculating the slope of the graph at each specified point.

Solution: 1. (a) The slope at A is positive so the velocity is $\boxed{\text{positive}}$. **(b)** The velocity at B is $\boxed{\text{zero}}$. **(c)** The velocity at C is $\boxed{\text{positive}}$. **(d)** The velocity at D is $\boxed{\text{negative}}$.

2. (e) Find the slope of the graph at A: $v_{av} = \dfrac{\Delta x}{\Delta t} = \dfrac{2.0\text{ m}}{1.0\text{ s}} = \boxed{2.0\text{ m/s}}$

3. (f) Find the slope of the graph at B: $v_{av} = \dfrac{\Delta x}{\Delta t} = \dfrac{0.0\text{ m}}{1.0\text{ s}} = \boxed{0.0\text{ m/s}}$

4. (g) Find the slope of the graph at C: $v_{av} = \dfrac{\Delta x}{\Delta t} = \dfrac{1.0\text{ m}}{1.0\text{ s}} = \boxed{1.0\text{ m/s}}$

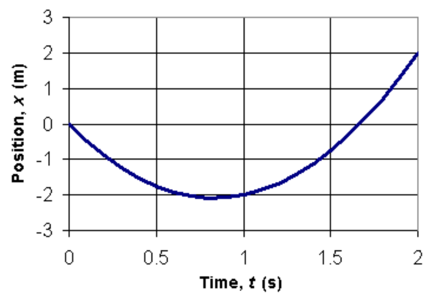
5. (h) Find the slope of the graph at D: $v_{av} = \dfrac{\Delta x}{\Delta t} = \dfrac{-3.0\text{ m}}{2.0\text{ s}} = \boxed{-1.5\text{ m/s}}$

Insight: The signs of each answer in (e) through (h) match those predicted in parts (a) through (d). With practice you can form both a qualitative and quantitative "movie" of the motion in your head simply by examining the position-versus-time graph.

22. **Picture the Problem**: The given position function indicates the particle begins traveling in the negative direction but is accelerating in the positive direction.

Strategy: Create the x-versus-t plot using a spreadsheet, or calculate individual values by hand and sketch the curve using graph paper. Use the known x and t information to determine the average speed and velocity.

Solution: 1. (a) Use a spreadsheet or similar program to create the plot:



2. (b) Find the average velocity from $t = 0$ to $t = 1.0$ s:

$$v_{av} = \frac{\Delta x}{\Delta t} = \frac{\left[(-5\text{ m/s})(1.0\text{ s}) + (3\text{ m/s}^2)(1.0\text{ s})^2\right] - [0.0\text{ m}]}{1.0\text{ s}}$$
$$= \boxed{-2.0\text{ m/s}}$$

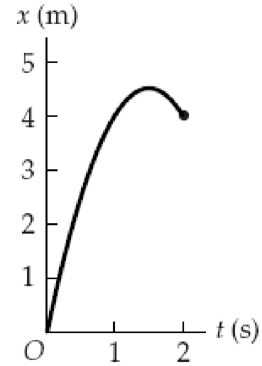
3. (c) The average speed is the magnitude of the average velocity: $s_{av} = |v_{av}| = \boxed{2.0\text{ m/s}}$

Insight: Note that the average velocity over the first second of time is equal to the slope of a straight line drawn from the origin to the curve at $t = 1.0$ s. At that time the position is −2.0 m.

23. **Picture the Problem**: The given position function indicates the particle begins traveling in the positive direction but is accelerating in the negative direction.

Strategy: Create the x-versus-t plot using a spreadsheet, or calculate individual values by hand and sketch the curve using graph paper. Use the known x and t information to determine the average speed and velocity.

Solution: 1. (a) Use a spreadsheet to create the plot shown at right:



2. (b) Find the average velocity from $t = 0$ to $t = 1.0$ s:

$$v_{av} = \frac{\Delta x}{\Delta t} = \frac{\left[(6\text{ m/s})(1.0\text{ s}) + (-2\text{ m/s}^2)(1.0\text{ s})^2\right] - [0.0\text{ m}]}{1.0\text{ s}}$$

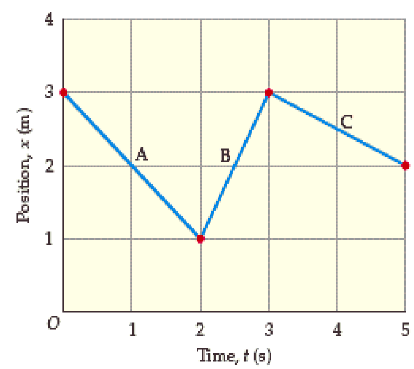
$$v_{av} = \boxed{4.0\text{ m/s}}$$

3. (c) The average speed is the magnitude of the average velocity:

$$s_{av} = |v_{av}| = \boxed{4.0\text{ m/s}}$$

Insight: Note that the average velocity over the first second of time is equal to the slope of a straight line drawn from the origin to the curve at $t = 1.0$ s. At that time the position is 4.0 m.

24. **Picture the Problem**: Following the motion specified in the position-versus-time graph, the tennis player moves left, then right, then left again, if we take left to be in the negative direction.



Strategy: Determine the direction of the velocity from the slope of the graph. The speed will be greatest for the segment of the curve that has the largest slope magnitude.

Solution: 1. (a) The magnitude of the slope at B is larger than A or C so we conclude $\boxed{\text{the speed is greatest at B}}$.

2. (b) Find the slope of the graph at A:

$$s_{av} = \frac{|\Delta x|}{\Delta t} = \frac{|-2.0\text{ m}|}{2.0\text{ s}} = \boxed{1.0\text{ m/s}}$$

3. (c) Find the slope of the graph at B:

$$s_{av} = \frac{|\Delta x|}{\Delta t} = \frac{|2.0\text{ m}|}{1.0\text{ s}} = \boxed{2.0\text{ m/s}}$$

4. (d) Find the slope of the graph at C:

$$s_{av} = \frac{|\Delta x|}{\Delta t} = \frac{|-1.0\text{ m}|}{2.0\text{ s}} = \boxed{0.50\text{ m/s}}$$

Insight: The speed during segment B is larger than the speed during segments A and C, as predicted. Speeds are always positive because they do not involve direction, but velocities can be negative to indicate their direction.

25. **Picture the Problem**: You travel in the forward direction along the roads leading to the wedding ceremony, but your average speed is different during the first and second portions of the trip.

Strategy: First find the distance traveled during the first 15 minutes in order to calculate the distance yet to travel. Then determine the speed you need during the second 15 minutes of travel.

Solution: 1. Use the definition of average speed to determine the distance traveled:

$$d_1 = s_1 \Delta t_1 = \left(5.0\ \frac{\text{mi}}{\text{h}}\right)\left(15.0\ \text{min} \times \frac{1\ \text{h}}{60\ \text{min}}\right) = \underline{\underline{1.25\ \text{mi}}}$$

2. Find the remaining distance to travel:

$$d_2 = d_{\text{total}} - d_1 = 10.0 - 1.25\ \text{mi} = \underline{\underline{8.8\ \text{mi}}}$$

3. Find the required speed for the second part of the trip:

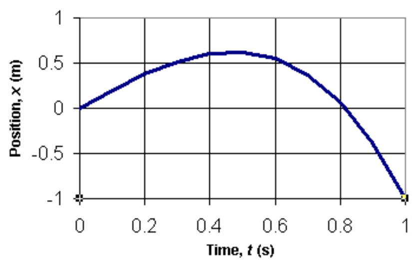
$$s_2 = \frac{d_2}{\Delta t_2} = \frac{8.8\ \text{mi}}{0.250\ \text{h}} = \boxed{35\ \text{mi/h}}$$

Insight: The car needs an average speed of 10 mi/0.5 h = 20 mi/h for the entire trip. However, in order to make it on time it must go seven times faster in the second half (time-wise) of the trip than it did in the first half of the trip.

26. **Picture the Problem**: The given position function indicates the particle begins traveling in the positive direction but is accelerating in the negative direction.

Strategy: Create the x-versus-t plot using a spreadsheet, or calculate individual values by hand and sketch the curve using graph paper. Use the known x and t information to determine the average speed and velocity.

Solution: 1. (a) Use a spreadsheet to create the plot:



2. (b) Find the average velocity from $t = 0.35$ to $t = 0.45$ s:

$$v_{\text{av}} = \frac{\Delta x}{\Delta t} = \frac{\left[(2\ \text{m/s})(0.45\ \text{s}) - (3\ \text{m/s}^3)(0.45\ \text{s})^3\right] - \left[(2\ \text{m/s})(0.35\ \text{s}) - (3\ \text{m/s}^3)(0.35\ \text{s})^3\right]}{0.10\ \text{s}}$$

$$= \boxed{0.55\ \text{m/s}}$$

3. (c) Find the average velocity from $t = 0.39$ to $t = 0.41$ s:

$$v_{\text{av}} = \frac{\Delta x}{\Delta t} = \frac{\left[(2\ \text{m/s})(0.41\ \text{s}) - (3\ \text{m/s}^3)(0.41\ \text{s})^3\right] - \left[(2\ \text{m/s})(0.39\ \text{s}) - (3\ \text{m/s}^3)(0.39\ \text{s})^3\right]}{0.41 - 0.39\ \text{s}}$$

$$= \boxed{0.56\ \text{m/s}}$$

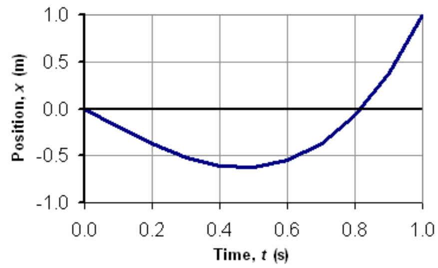
4. (d) The instantaneous speed at $t = 0.40$ s will be $\boxed{\text{closer to 0.56 m/s}}$. As the time interval becomes smaller the average velocity is approaching 0.56 m/s, so we conclude the average speed over an infinitesimally small time interval will be very close to that value.

Insight: Note that the instantaneous velocity at 0.40 s is equal to the slope of a straight line drawn tangent to the curve at that point. Since it is difficult to accurately draw a tangent line, we usually resort to mathematical methods like those illustrated above to determine the instantaneous velocity.

27. **Picture the Problem**: The given position function indicates the particle begins traveling in the negative direction but is accelerating in the positive direction.

Strategy: Create the x-versus-t plot using a spreadsheet, or calculate individual values by hand and sketch the curve using graph paper. Use the known x and t information to determine the average speed and velocity.

Solution: 1. (a) Use a spreadsheet to create the plot:



2. (b) Find the average velocity from $t = 0.150$ to $t = 0.250$ s:

$$v_{\text{av}} = \frac{\Delta x}{\Delta t} = \frac{\left(\left[(-2\text{ m/s})(0.250\text{ s})+(3\text{ m/s}^3)(0.250\text{ s})^3\right]-\left[(-2\text{ m/s})(0.150\text{ s})+(3\text{ m/s}^3)(0.150\text{ s})^3\right]\right)}{0.250-0.150\text{ s}} = \boxed{-1.63\text{ m/s}}$$

3. (c) Find the average velocity from $t = 0.190$ to $t = 0.210$ s:

$$v_{\text{av}} = \frac{\Delta x}{\Delta t} = \frac{\left(\left[(-2\text{ m/s})(0.210\text{ s})+(3\text{ m/s}^3)(0.210\text{ s})^3\right]-\left[(-2\text{ m/s})(0.190\text{ s})+(3\text{ m/s}^3)(0.190\text{ s})^3\right]\right)}{0.210-0.190\text{ s}} = \boxed{-1.64\text{ m/s}}$$

4. (d) The instantaneous speed at $t = 0.200$ s will be closer to −1.64 m/s. As the time interval becomes smaller the average velocity is approaching −1.64 m/s, so we conclude the average speed over an infinitesimally small time interval will be very close to that value.

Insight: Note that the instantaneous velocity at 0.200 s is equal to the slope of a straight line drawn tangent to the curve at that point. Since it is difficult to accurately draw a tangent line, we usually resort to mathematical methods like those illustrated above to determine the instantaneous velocity.

28. **Picture the Problem**: The airplane accelerates uniformly along a straight runway.

Strategy: The average acceleration is the change of the velocity divided by the elapsed time.

Solution: Divide the change in velocity by the time:

$$a_{\text{av}} = \frac{\Delta v}{\Delta t} = \frac{173-0\text{ mi/h}}{35.2\text{ s}} \times \frac{0.447\text{ m/s}}{\text{mi/h}} = \boxed{2.20\text{ m/s}^2}$$

Insight: The instantaneous acceleration might vary from 2.20 m/s^2, but we can calculate only average acceleration from the net change in velocity and time elapsed.

29. **Picture the Problem**: The runner accelerates uniformly along a straight track.

Strategy: The change in velocity is the average acceleration multiplied by the elapsed time.

Solution: 1. (a) Multiply the acceleration by the time:

$$v = v_0 + at = 0\text{ m/s} + (1.9\text{ m/s}^2)(2.0\text{ s}) = \boxed{3.8\text{ m/s}}$$

2. (b) Multiply the acceleration by the time:

$$v = v_0 + at = 0\text{ m/s} + (1.9\text{ m/s}^2)(5.2\text{ s}) = \boxed{9.9\text{ m/s}}$$

Insight: World class sprinters have top speeds over 10 m/s, so this athlete isn't bad, but it took him a whole 5.2 seconds to get up to speed. He should work on his acceleration!

30. **Picture the Problem**: The airplane slows down uniformly along a straight runway as it travels towards the east.

Strategy: The average acceleration is the change of the velocity divided by the elapsed time. Assume that east is in the positive direction

Solution: 1. Divide the change in velocity by the time: $|a_{av}| = \frac{|\Delta v|}{\Delta t} = \frac{|0-115 \text{ m/s}|}{13.0 \text{ s}} = \boxed{8.85 \text{ m/s}^2}$

2. We note from the previous step that the acceleration is negative. Since east is the positive direction, negative acceleration must be $\boxed{\text{towards the west}}$.

Insight: In physics we almost never talk about deceleration. Instead, we call it *negative acceleration.*

31. **Picture the Problem**: The car travels in a straight line due north, either speeding up or slowing down, depending upon the direction of the acceleration.

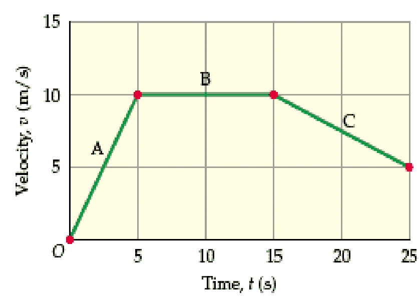
Strategy: Use the definition of acceleration to determine the final velocity over the specified time interval.

Solution: 1. (a) Evaluate equation 2-7 directly: $v = v_0 + at = 18.1 \text{ m/s} + \left(1.30 \text{ m/s}^2\right)\left(7.50 \text{ s}\right) = \boxed{27.9 \text{ m/s north}}$

2. (b) Evaluate equation 2-7 directly: $v = v_0 + at = 18.1 \text{ m/s} + \left(-1.15 \text{ m/s}^2\right)\left(7.50 \text{ s}\right) = \boxed{9.48 \text{ m/s north}}$

Insight: In physics we almost never talk about deceleration. Instead, we call it *negative acceleration*. In this problem south is considered the negative direction, and in part (b) the car is slowing down or undergoing negative acceleration.

32. **Picture the Problem**: Following the motion specified in the velocity-versus-time graph, the motorcycle is speeding up, then moving at constant speed, then slowing down.



Strategy: Determine the acceleration from the slope of the graph.

Solution: 1. (a) Find the slope at A: $a_{av} = \frac{\Delta v}{\Delta t} = \frac{10 \text{ m/s}}{5.0 \text{ s}}$

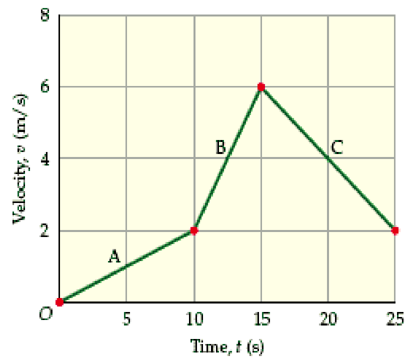
$= \boxed{2.0 \text{ m/s}^2}$

2. (b) Find the slope of the graph at B: $a_{av} = \frac{\Delta v}{\Delta t} = \frac{0 \text{ m/s}}{10.0 \text{ s}} = \boxed{0.0 \text{ m/s}^2}$

3. (c) Find the slope of the graph at C: $a_{av} = \frac{\Delta v}{\Delta t} = \frac{-5.0 \text{ m/s}}{10.0 \text{ s}} = \boxed{-0.50 \text{ m/s}^2}$

Insight: The acceleration during segment A is larger than the acceleration during segments B and C because the slope there has the greatest magnitude.

33. **Picture the Problem**: Following the motion specified in the velocity-versus-time graph, the person on horseback is speeding up, then accelerating at an even greater rate, then slowing down.



Strategy: We could determine the acceleration from the slope of the graph, and then use the acceleration and initial velocity to determine the displacement. Alternatively, we could use the initial and final velocities in each segment to determine the average velocity and the time elapsed to find the displacement during each interval.

Solution: 1. (a) Use the average velocity during interval A to calculate the displacement: $\Delta x = \frac{1}{2}(v_0 + v)t = \frac{1}{2}(0 + 2.0\text{ m/s})(10\text{ s}) = \boxed{10\text{ m}}$

2. (b) Find the slope of the graph at B: $\Delta x = \frac{1}{2}(v_0 + v)t = \frac{1}{2}(2.0 + 6.0\text{ m/s})(5.0\text{ s}) = \boxed{20\text{ m}}$

3. (c) Find the slope of the graph at C: $\Delta x = \frac{1}{2}(v_0 + v)t = \frac{1}{2}(6.0 + 2.0\text{ m/s})(10\text{ s}) = \boxed{40\text{ m}}$

Insight: There are often several ways to solve motion problems involving constant acceleration, some easier than others.

34. **Picture the Problem**: The horse travels in a straight line in the positive direction while accelerating in the negative direction (slowing down.)

Strategy: Use the definition of acceleration to determine the time elapsed for the specified change in velocity.

Solution: Solve equation 2-7 for time: $t = \dfrac{v - v_0}{a} = \dfrac{6.5 - 11\text{ m/s}}{-1.81\text{ m/s}^2} = \boxed{2.5\text{ s}}$

Insight: We bent the rules a little bit on significant figures. Because the +11 m/s is only known to the ones column, the difference between 6.5 and 11 is 4 m/s, only one significant digit. The answer is then properly 2 s. The answer is probably closer to 2.5 s, so that's why we kept the extra digit.

35. **Picture the Problem**: The car travels in a straight line in the positive direction while accelerating in the negative direction (slowing down).

Strategy: Use the constant acceleration equation of motion to determine the time elapsed for the specified change in velocity.

Solution: 1. (a) The time required to come to a stop is the change in velocity divided by the acceleration. In both cases the final velocity is zero, so the change in velocity doubles when you double the initial velocity. Therefore the stopping time will increase by a $\boxed{\text{factor of two}}$ when you double your driving speed.

2. (b) Solve equation 2-7 for time: $t = \dfrac{v - v_0}{a} = \dfrac{0 - 16\text{ m/s}}{-4.2\text{ m/s}^2} = \boxed{3.8\text{ s}}$

3. (c) Solve equation 2-7 for time: $t = \dfrac{v - v_0}{a} = \dfrac{0 - 32\text{ m/s}}{-4.2\text{ m/s}^2} = \boxed{7.6\text{ s}}$

Insight: Note that the deceleration is treated as a negative acceleration in this problem and elsewhere in the text.

36. **Picture the Problem**: The car travels in a straight line in the positive direction while accelerating in the negative direction (slowing down).

Strategy: Use the average velocity and the time elapsed to determine the distance traveled for the specified change in velocity.

Solution: 1. (a) Since the distance traveled is proportional to the square of the time (equation 2-11), or alternatively, since both the time elapsed and the average velocity change by a factor of two, the stopping distance will increase by a factor of four when you double your driving speed.

2. (b) Evaluate equation 2-10 directly: $\Delta x = \frac{1}{2}(v_0 + v)t = \frac{1}{2}(16 + 0 \text{ m/s})(3.8) = \boxed{30 \text{ m}} = 0.030 \text{ km}$

3. (c) Evaluate equation 2-10 directly: $\Delta x = \frac{1}{2}(v_0 + v)t = \frac{1}{2}(32 + 0 \text{ m/s})(7.6) = \boxed{120 \text{ m}} = 0.12 \text{ km}$

Insight: Doubling your speed will quadruple the stopping distance for a constant acceleration. We will learn in chapter 7 that this can be explained in terms of energy; that is, doubling your speed quadruples your kinetic energy.

37. **Picture the Problem**: The train travels in a straight line in the positive direction while accelerating in the positive direction (speeding up).

Strategy: First find the acceleration and then determine the final velocity.

Solution: 1. Use the definition of acceleration: $a = \dfrac{v - v_0}{t} = \dfrac{4.7 - 0 \text{ m/s}}{5.0 \text{ s}} = \underline{\underline{0.94 \text{ m/s}^2}}$

2. Evaluate equation 2-7 directly, using the final speed from the first segment as the initial speed of the second segment: $v = v_0 + at = 4.7 \text{ m/s} + (0.94 \text{ m/s}^2)(6.0 \text{ s})$

$v = \boxed{10.3 \text{ m/s}}$

Insight: Another way to tackle this problem is to set up similar triangles on a velocity-versus-time graph. The answer would then be calculated as (4.7 m/s) × 11 s / 5 s = 10.3 m/s. Try it!

38. **Picture the Problem**: The particle travels in a straight line in the positive direction while accelerating in the positive direction (speeding up).

Strategy: Use the constant acceleration equation of motion to find the initial velocity.

Solution: Solve equation 2-7 for v_0: $v_0 = v - at = 9.31 \text{ m/s} - (6.24 \text{ m/s}^2)(0.300 \text{ s}) = \boxed{7.44 \text{ m/s}}$

Insight: As expected the initial velocity is less than the final velocity because the particle is speeding up.

39. **Picture the Problem**: The jet travels in a straight line towards the south while accelerating in the northerly direction (slowing down).

Strategy: Use the relationship between acceleration, velocity, and displacement (equation 2-12). The acceleration should be negative if we take the direction of the jet's motion (to the south) to be positive.

Solution: Solve equation 2-12 for acceleration: $a = \dfrac{v^2 - v_0^2}{2\Delta x} = \dfrac{0^2 - (81.9 \text{ m/s})^2}{2(949 \text{ m})} = \boxed{-3.53 \text{ m/s}^2}$

In other words, the acceleration of the jet is $\boxed{3.53 \text{ m/s}^2 \text{ to the north}}$.

Insight: The negative acceleration indicates the jet is slowing down during that time interval. Note that equation 2-12 is a good choice for problems in which no time information is given.

40. **Picture the Problem**: The car travels in a straight line toward the west while accelerating in the easterly direction (slowing down).

Strategy: The average velocity is simply half the sum of the initial and final velocities because the acceleration is uniform.

Solution: Calculate half the sum of the velocities: $v_{av} = \frac{1}{2}(v_0 + v) = \frac{1}{2}(12 + 0 \text{ m/s}) = \boxed{6.0 \text{ m/s}}$

Insight: The average velocity of any object that slows down and comes to a stop is just half the initial velocity.

41. **Picture the Problem**: The car travels in a straight line towards the west while accelerating in the easterly direction (slowing down).

Strategy: The average velocity is simply half the sum of the initial and final velocities because the acceleration is uniform. Use the average velocity together with equation 2-10 to find the time.

Solution: Solve equation 2-10 for time: $t = \dfrac{\Delta x}{\frac{1}{2}(v_0 + v)} = \dfrac{35 \text{ m}}{\frac{1}{2}(12 + 0 \text{ m/s})} = \boxed{5.8 \text{ s}}$

Insight: The distance traveled is always the average velocity multiplied by the time. This stems from the definition of average velocity.

42. **Picture the Problem**: The boat travels in a straight line with constant positive acceleration.

Strategy: The average velocity is simply half the sum of the initial and final velocities because the acceleration is uniform.

Solution: 1. (a) Calculate half the sum of the velocities: $v_{av} = \frac{1}{2}(v_0 + v) = \frac{1}{2}(0 + 4.12 \text{ m/s}) = \boxed{2.06 \text{ m/s}}$

2. (b) The distance traveled is the average velocity multiplied by the time elapsed: $d = v_{av}t = (2.06 \text{ m/s})(4.77 \text{ s}) = \boxed{9.83 \text{ m}}$

Insight: The average velocity of any object that speeds up from rest is just half the final velocity.

43. **Picture the Problem**: The cheetah runs in a straight line with constant positive acceleration.

Strategy: The average velocity is simply half the sum of the initial and final velocities because the acceleration is uniform. The distance traveled is the average velocity multiplied by the time elapsed.

Solution: 1. (a) Calculate half the sum of the velocities: $v_{av} = \frac{1}{2}(v_0 + v) = \frac{1}{2}(0 + 25.0 \text{ m/s}) = \underline{\underline{12.5 \text{ m/s}}}$

2. Use the average velocity to find the distance: $d = v_{av}t = (12.5 \text{ m/s})(6.22 \text{ s}) = \boxed{77.8 \text{ m}}$

3. (b) For a constant acceleration the velocity varies linearly with time. Therefore we expect the velocity to be equal to $\boxed{12.5 \text{ m/s}}$ after half the time (3.11 s) has elapsed.

4. (c) Calculate half the sum of the velocities: $v_{av,1} = \frac{1}{2}(v_0 + v) = \frac{1}{2}(0 + 12.5 \text{ m/s}) = \boxed{6.25 \text{ m/s}}$

5. Calculate half the sum of the velocities: $v_{av,2} = \frac{1}{2}(v_0 + v) = \frac{1}{2}(12.5 + 25.0 \text{ m/s}) = \boxed{18.8 \text{ m/s}}$

6. (d) Use the average velocity to find the distance: $d_1 = v_{av,1}\,t = (6.25 \text{ m/s})(3.11 \text{ s}) = \boxed{19.4 \text{ m}}$

7. Use the average velocity to find the distance: $d_2 = v_{av,2}\,t = (18.8 \text{ m/s})(3.11 \text{ s}) = \boxed{58.5 \text{ m}}$

Insight: The distance traveled is always the average velocity multiplied by the time. This stems from the definition of average velocity.

44. **Picture the Problem**: The child slides down the hill in a straight line with constant positive acceleration.

Strategy: Use the known acceleration and times to determine the positions of the child. In each case x_0 and v_0 are zero.

Solution: 1. (a) Evaluate equation 2-11 directly: $x = x_0 + v_0 t + \frac{1}{2}at^2 = 0 + 0 + \frac{1}{2}(1.8\text{ m/s}^2)(1.0\text{ s})^2 = \boxed{0.90\text{ m}}$

2. (b) Evaluate equation 2-11 directly: $x = x_0 + v_0 t + \frac{1}{2}at^2 = 0 + 0 + \frac{1}{2}(1.8\text{ m/s}^2)(2.0\text{ s})^2 = \boxed{3.6\text{ m}}$

3. (c) Evaluate equation 2-11 directly: $x = x_0 + v_0 t + \frac{1}{2}at^2 = 0 + 0 + \frac{1}{2}(1.8\text{ m/s}^2)(3.0\text{ s})^2 = \boxed{8.1\text{ m}}$

Insight: The position varies with the square of the time for constant acceleration.

45. **Picture the Problem**: The passengers slide down the ride in a straight line with constant positive acceleration.

Strategy: Use the known initial and final velocities and the elapsed time to find the acceleration.

Solution: Evaluate equation 2-5 directly: $a = \frac{v_f - v_i}{\Delta t} = \frac{(45 - 0\text{ mi/h})}{2.2\text{ s}} \times \frac{0.447\text{ m/s}}{\text{mi/h}} = \boxed{9.1\text{ m/s}^2}$

Insight: The acceleration here is just less than that for a free-falling object. What a thrill!

46. **Picture the Problem**: The air bag expands outward with constant positive acceleration.

Strategy: Assume the air bag has a thickness of 1 ft or about 0.3 m. It must expand that distance within the given time of 10 ms. Employ the relationship between acceleration, displacement, and time (equation 2-11) to find the acceleration.

Solution: Solve equation 2-11 for *a*: $a = \frac{2\Delta x}{t^2} = \frac{2(0.3\text{ m})}{(10\text{ ms} \times 0.001\text{ s/ms})^2} = 6000\text{ m/s}^2 \times \frac{1\,g}{9.81\text{ m/s}^2} \simeq \boxed{600g}$

Insight: The very large acceleration of an expanding airbag can cause severe injury to a small child whose head is too close to the bag when it deploys. Children are safest in the back seat!

47. **Picture the Problem**: The spaceship accelerates from rest down the barrel of the cannon.

Strategy: Employ the relationship between acceleration, displacement, and velocity (equation 2-12) to find the acceleration.

Solution: Solve equation 2-12 for *a*: $a = \frac{v^2 - v_0^2}{2\Delta x} = \frac{(12000\text{ yd/s} \times 3\text{ ft/yd} \times 0.305\text{ m/ft})^2 - 0^2}{2(700\text{ ft} \times 0.305\text{ m/ft})} = \boxed{2.8 \times 10^5\text{ m/s}^2}$

Insight: An acceleration this great would tear the occupants of the spacecraft apart! Note that equation 2-12 is a good choice for problems in which no time information is given.

48. **Picture the Problem**: The bacterium accelerates from rest in the forward direction.

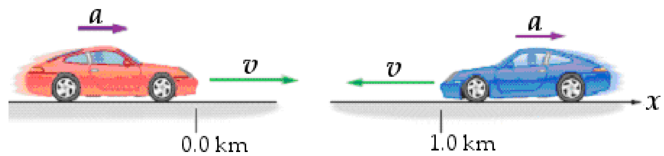
Strategy: Employ the definition of acceleration to find the time elapsed, and the relationship between acceleration, displacement, and velocity (equation 2-12) to find the distance traveled.

Solution: 1. (a) Solve equation 2-5 for time: $t = \frac{v - v_0}{a} = \frac{12 - 0\ \mu\text{m/s}}{156\ \mu\text{m/s}^2} = \boxed{0.077\text{ s}}$

2. (b) Solve equation 2-12 for displacement: $\Delta x = \frac{v^2 - v_0^2}{2a} = \frac{(12\ \mu\text{m/s})^2 - 0^2}{2(156\ \mu\text{m/s}^2)} = \boxed{0.46\ \mu\text{m}}$

Insight: The accelerations are tiny but so are the bacteria! The average speed here is about 3 body lengths per second if each bacterium were 2 μm long. If this were a human that would be 6 m/s or 13 mi/h, much faster than we can swim!

49. **Picture the Problem**: The two cars are traveling in opposite directions.



Strategy: Write the equations of motion based upon equation 2-11, and set them equal to each other to find the time at which the two cars pass each other.

Solution: 1. (a) Write equation 2-11 for car 1: $x_1 = x_{0,1} + v_{0,1}t + \frac{1}{2}a_1t^2 = 0 + (20.0\text{ m/s})t + (1.25\text{ m/s}^2)t^2$

2. Write equation 2-11 for car 2: $x_2 = x_{0,2} + v_{0,2}t + \frac{1}{2}a_2t^2 = 1000\text{ m} - (30.0\text{ m/s})t + (1.6\text{ m/s}^2)t^2$

3. (b) Set $x_1 = x_2$ and solve for *t*:

$$(20.0\text{ m/s})t + (1.25\text{ m/s}^2)t^2 = 1000\text{ m} - (30.0\text{ m/s})t + (1.6\text{ m/s}^2)t^2$$

$$0 = 1000 - 50t + 0.35t^2$$

$$t = \frac{50 \pm \sqrt{50^2 - 4(0.35)(1000)}}{0.70} = 24,\ 119\text{ s} \Rightarrow \boxed{24\text{ s}}$$

Insight: We take the smaller of the two roots, which corresponds to the first time the cars pass each other. Later on the larger acceleration of car 2 means that it'll come to rest, speed up in the positive direction, and overtake car 1 at 119 s.

50. **Picture the Problem**: The meteorite accelerates from a high speed to rest after impacting the car.

Strategy: Employ the relationship between acceleration, displacement, and velocity (equation 2-12) to find the acceleration.

Solution: Solve equation 2-12 for acceleration: $|a| = \frac{|v^2 - v_0^2|}{2|\Delta x|} = \frac{|0^2 - (130\text{ m/s})^2|}{2(0.22\text{ m})} = \boxed{3.8\times10^4\text{ m/s}^2}$

Insight: The high stiffness of steel is responsible for the tremendous (negative) acceleration of the meteorite.

51. **Picture the Problem**: The rocket accelerates straight upward.

Strategy: Employ the relationship between acceleration, displacement, and time (equation 2-11) to find the acceleration. Because the rocket was at rest before blast off, the initial velocity v_0 is zero, and so is the initial position x_0. Once the acceleration is known, we can use the constant acceleration equation of motion (equation 2-7) to find the speed.

Solution: 1. (a) Use equation 2-11: $x = x_0 + v_0t + \frac{1}{2}at^2$

2. Let $x_0 = v_0 = 0$ and solve for acceleration: $a = \frac{2x}{t^2} = \frac{2(77\text{ m})}{(3.0\text{ s})^2} = \boxed{17\text{ m/s}^2\text{ upward}}$

3. (b) Evaluate equation 2-7 directly: $v = 0 + at = (17\text{ m/s}^2)(3.0\text{ s}) = \boxed{51\text{ m/s}}$

Insight: Equation 2-11 becomes a very simple relationship between distance, acceleration, and time if the initial position and the initial velocity are zero.

52. **Picture the Problem**: You drive in a straight line and then slow down to a stop.

Strategy: Employ the relationship between acceleration, displacement, and velocity (equation 2-12) to find the displacement. Equation 2-12 is a good choice for problems in which no time information is given. In this case the acceleration is negative because the car is slowing down.

Solution: 1. (a) Solve equation 2-12 for Δx :

$$\Delta x = \frac{v^2 - v_0^2}{2a} = \frac{0^2 - v_0^2}{2a} = -\frac{v_0^2}{2a} = -\frac{(12.0 \text{ m/s})^2}{2(-3.5 \text{ m/s}^2)} = \boxed{21 \text{ m}}$$

2. (b) Since velocity is proportional to the square root of displacement, cutting the distance in half will reduce the velocity by $\sqrt{2}$, not 2. Therefore the speed will be $\boxed{\text{greater than 6.0 m/s}}$ after traveling half the distance.

3. Solve equation 2-12 for *v*:

$$v = \sqrt{v_0^2 + 2a\frac{\Delta x}{2}} = \sqrt{v_0^2 + a\left(-\frac{v_0^2}{2a}\right)} = \frac{v_0}{\sqrt{2}} = \frac{12.0 \text{ m/s}}{\sqrt{2}} = \boxed{8.49 \text{ m}}$$

Insight: For constant acceleration, the velocity changes linearly with time but nonlinearly with distance.

53. **Picture the Problem**: You drive in a straight line and then slow down to a stop.

Strategy: Use the constant acceleration equation of motion (equation 2-7) to find the time. Once the time is known, we can use the same equation to find the speed. In this case, the acceleration is negative because the car is slowing down.

Solution: 1. (a) Solve equation 2-7 for *t*:

$$t = \frac{v - v_0}{a} = \frac{0 - 16 \text{ m/s}}{-3.2 \text{ m/s}^2} = \boxed{5.0 \text{ s}}$$

2. (b) Since the velocity varies linearly with time for constant acceleration, the velocity will be half the initial velocity when you have braked for half the time. Therefore the speed after braking 2.5 s will be equal to $\boxed{8.0 \text{ m/s}}$.

3. Evaluate equation 2-7 directly:

$$v = v_0 + at = 16 \text{ m/s} + (-3.2 \text{ m/s}^2)(2.5 \text{ s}) = \boxed{8.0 \text{ m/s}}$$

4. (c) The total distance traveled is the distance the car travels at 16 m/s before you hit the brakes (a time interval given by your reaction time) plus the distance covered as the car stops.

$$\Delta x = v_0\, t_{\text{react}} + v_{\text{av}} t_{\text{stop}}$$

$$t_{\text{react}} = \frac{\Delta x - v_{\text{av}} t_{\text{stop}}}{v_0} = \frac{55 \text{ m} - (8.0 \text{ m/s})(5.0 \text{ s})}{16 \text{ m/s}} = \boxed{0.94 \text{ s}}$$

Insight: For constant acceleration, the velocity changes linearly with time, but nonlinearly with distance.

54. **Picture the Problem**: The chameleon's tongue accelerates in a straight line until it is extended to its full length.

Strategy: Employ the relationship between acceleration, displacement, and time (equation 2-11) to find the acceleration. Let the initial velocity v_0 and the initial position x_0 of the tongue each be zero..

Solution: 1. (a) Let $x_0 = v_0 = 0$ and solve equation 2-11 for acceleration:

$$a = \frac{2x}{t^2} = \frac{2(0.16 \text{ m})}{(0.10 \text{ s})^2} = \boxed{32 \text{ m/s}^2}$$

2. (b) Since the displacement varies with the square of the time for constant acceleration, the displacement will be less than half its final value when half the time has elapsed. Most of the displacement occurs in the latter portions of time when the tongue's speed is greatest. Therefore we expect the tongue to have extended $\boxed{\text{less than 8.0 cm}}$ after 0.050 s.

3. Evaluate equation 2-11 directly, with $x_0 = v_0 = 0$:

$$x = \tfrac{1}{2}at^2 = \tfrac{1}{2}(32 \text{ m/s}^2)(0.050 \text{ s})^2 = \boxed{4.0 \text{ cm}}$$

Insight: For constant acceleration, the displacement changes nonlinearly with both time and velocity. Note that the acceleration of the chameleon's tongue is over three times the acceleration of gravity!

55. **Picture the Problem**: The bicycle travels in a straight line, slowing down at a uniform rate as it crosses the sandy patch.

Strategy: Use the time-free relationship between displacement, velocity, and acceleration (equation 2-12) to find the acceleration. The time can be determined from the average velocity and the distance across the sandy patch.

Solution: 1. (a) Solve equation 2-12 for acceleration:

$$a = \frac{v^2 - v_0^2}{2\Delta x} = \frac{(6.4\text{ m/s})^2 - (8.4\text{ m/s})^2}{2(7.2\text{ m})} = -2.1\text{ m/s}^2$$

where the negative sign means $\boxed{2.1\text{ m/s}^2\text{ due east}}$.

2. (b) Solve equation 2-10 for *t*:

$$t = \frac{\Delta x}{\frac{1}{2}(v + v_0)} = \frac{7.2\text{ m}}{\frac{1}{2}(8.4 + 6.4\text{ m/s})} = \boxed{0.97\text{ s}}$$

3. (c) Examining $v^2 = v_0^2 + 2a\Delta x$ (equation 2-12) in detail, we note that the acceleration is negative, and that the final velocity is the square root of the difference between v_0^2 and $|2a\Delta x|$. Since $|2a\Delta x|$ is constant because the sandy patch doesn't change, it now represents a larger fraction of the smaller v_0^2, and the final velocity *v* will be more than 2.0 m/s different than v_0. We therefore expect a final speed of $\boxed{\text{less than 3.4 m/s}}$.

Insight: In fact, if you try to calculate *v* in part (c) with equation 2-12 you end up with the square root of a negative number, because the bicycle will come to rest in a distance $\Delta x = \frac{0^2 - v_0^2}{2a} = \frac{-(5.4\text{ m/s})^2}{2(-2.1\text{ m/s}^2)} = 6.9\text{ m}$, less than the 7.2 m length of the sandy patch.

56. **Picture the Problem**: David Purley travels in a straight line, slowing down at a uniform rate until coming to rest.

Strategy: Use the time-free relationship between displacement, velocity, and acceleration (equation 2-12) to find the acceleration.

Solution: Solve equation 2-12 for acceleration:

$$a = \frac{v^2 - v_0^2}{2\Delta x} = \frac{0^2 - \left(173\text{ km/h} \times \frac{0.278\text{ m/s}}{1\text{ km/h}}\right)^2}{2(0.66\text{ m})}$$

$$a = -1800\text{ m/s}^2 \times \frac{1.00g}{9.81\text{ m/s}^2} = \boxed{180g}$$

Insight: Mr. Purley was lucky to escape death when experiencing an acceleration this large! We'll learn in Chapter 5 that a large acceleration implies a large force, which in this case must have been applied to his body in just the right way to produce a non-lethal injury.

57. **Picture the Problem**: The boat slows down at a uniform rate as it coasts in a straight line.

Strategy: Since the initial and final velocities are known, the time can be determined from the average velocity and the distance traveled. Then use the constant acceleration equation of motion (equation 2-7) to find the acceleration.

Solution: 1. (a) Solve equation 2-10 for time:

$$t = \frac{\Delta x}{\frac{1}{2}(v + v_0)} = \frac{12\text{ m}}{\frac{1}{2}(1.6 + 2.6\text{ m/s})} = \boxed{5.7\text{ s}}$$

2. (b) Solve equation 2-7 for acceleration:

$$a = \frac{v - v_0}{t} = \frac{1.6 - 2.6\text{ m/s}}{5.7\text{ s}} = \boxed{-0.18\text{ m/s}^2}$$

where the negative sign means opposite the direction of motion.

3. (c) From $v^2 = v_0^2 + 2a\Delta x$ (equation 2-12), we see that the velocity varies as $\sqrt{\Delta x}$, so we expect that when the displacement is cut in half, the velocity will be reduced by less than half the total change (less than 0.5 m/s in this case, because the total change was 1.0 m/s). We therefore expect the velocity will be $\boxed{\text{more than 2.1 m/s}}$. If you work out equation 2-12 you find the velocity is 2.15 m/s after traveling 6.0 m.

Insight: For constant acceleration, the velocity changes linearly with time but nonlinearly with distance.

58. **Picture the Problem**: The rocket accelerates straight upward at a constant rate.

Strategy: Since the initial and final velocities are known, the time can be determined from the average velocity and the distance traveled. The constant acceleration equation of motion (equation 2-7) can then be used to find the acceleration. Once that is known, the position of the rocket as a function of time is given by equation 2-11, and the velocity as a function of time is given by equation 2-7.

Solution: 1. (a) Solve equation 2-10 for time: $t = \dfrac{\Delta x}{\frac{1}{2}(v+v_0)} = \dfrac{3.2\text{ m}}{\frac{1}{2}(0+26.0\text{ m/s})} = \boxed{0.25\text{ s}}$

2. (b) Solve equation 2-7 for acceleration: $a = \dfrac{v-v_0}{t} = \dfrac{26.0-0\text{ m/s}}{0.25\text{ s}} = \boxed{110\text{ m/s}^2} = 0.11\text{ km/s}^2$

3. (c) Evaluate equation 2-11 directly, with $x_0 = v_0 = 0$: $x = \frac{1}{2}at^2 = \frac{1}{2}(110\text{ m/s}^2)(0.10\text{ s})^2 = \boxed{0.55\text{ m}}$

4. Evaluate equation 2-7 directly, with $v_0 = 0$: $v = 0 + at = (110\text{ m/s}^2)(0.10\text{ s}) = \boxed{11\text{ m/s}}$

Insight: Model rockets accelerate at very large rates, but only for a very short time. Still, even inexpensive starter rockets can reach 1500 ft in altitude and can be great fun to build and launch!

59. **Picture the Problem**: The chicken slides along a straight line and comes to rest.

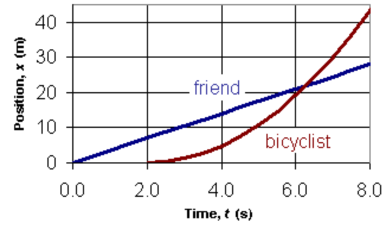
Strategy: Since the initial and final velocities and the time elapsed are known, the acceleration can be determined from the constant acceleration equation of motion (equation 2-7). The distance traveled can be found from the average velocity and the time elapsed (equation 2-10).

Solution: 1. (a) Solve equation 2-7 for acceleration: $a = \dfrac{v-v_0}{t} = \dfrac{0-5.8\text{ m/s}}{1.1\text{ s}} = \boxed{-5.3\text{ m/s}^2}$, where the negative sign means opposite the direction of motion, or $\boxed{\text{toward third base}}$.

2. (b) Evaluate equation 2-10 directly: $\Delta x = \frac{1}{2}(v+v_0)t = \frac{1}{2}(0+5.8\text{ m/s})(1.1\text{ s}) = \boxed{3.2\text{ m}}$

Insight: If the dirt had accelerated the chicken at a lesser rate, the chicken would have had nonzero speed as it crossed home plate. A larger magnitude acceleration would stop the chicken before reaching the plate, and it would be out!

60. **Picture the Problem**: The distance-versus-time plot at right shows how the bicyclist can overtake his friend by pedaling at constant acceleration.



Strategy: To find the time elapsed when the two bicyclists meet, we must set the constant velocity equation of motion of the friend (equation 2-8) equal to the constant acceleration equation of motion (equation 2-11) of the bicyclist. Once the time is known, the displacement and velocity of the bicyclist can be determined from equations 2-10 and 2-7, respectively.

Solution: 1. (a) Set the two equations of motion equal to each other. For the friend, use equation 2-8 with $x_0 = 0$ and for the bicyclist, use equation 2-11 with $x_0 = 0$ and $v_0 = 0$:

$$x_{\text{friend}} = x_{\text{bicyclist}}$$
$$v_f t = 0 + 0 + \tfrac{1}{2} a_b (t-2)^2$$

2. Solve for *t*:

$$v_{\text{friend}} t = \tfrac{1}{2} a_b \left(t^2 - 4t + 4\right)$$
$$0 = t^2 - \left[4 + \frac{2v_{\text{friend}}}{a_b}\right] t + 4 = t^2 - \left[4 + \frac{2(3.5 \text{ m/s})}{2.4 \text{ m/s}^2}\right] t + 4$$
$$0 = t^2 - 6.92t + 4$$

3. Now use the quadratic formula:

$$t = \frac{+6.92 \pm \sqrt{6.92^2 - 4(1)(4)}}{2} = 6.3,\ 0.64 \text{ s}$$

4. We choose the larger root because the time must be greater than 2.0 s, the time at which the bicyclist began pursuing his friend. The bicyclist will overtake his friend $\boxed{6.3 \text{ s}}$ after his friend passes him.

5. (b) Use equation 2-8 to find *x*:

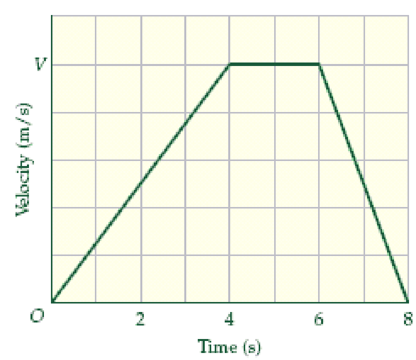
$$x = v_0 t = (3.5 \text{ m/s})(6.3 \text{ s}) = \boxed{22 \text{ m}}$$

6. (c) Use equation 2-7 to find *v*. Keep in mind that $v_0 = 0$ and that the bicyclist doesn't begin accelerating until two seconds have elapsed.:

$$v = 0 + a(t-2) = \left(2.4 \text{ m/s}^2\right)(6.3 - 2.0 \text{ s}) = \boxed{10 \text{ m/s}}$$

Insight: Even a smaller acceleration would allow the bicyclist to catch up to the friend, because the speed is always increasing for any nonzero acceleration, and so the bicyclist's speed would eventually exceed the friend's speed and the two would meet.

61. **Picture the Problem**: The velocity-versus-time plot at right indicates the car accelerates in the forward direction, maintains a constant speed, and then rapidly slows down to a stop.



Strategy: The distance traveled by the car is equal to the area under the velocity-versus-time plot. Since the distance traveled is known to be 13 m, we can use that fact to determine the unknown speed *V*. Once we know the velocity as a function of time we can answer any other question about its motion during the time interval.

Solution: 1. (a) Determine the area under the curve by adding the area of the triangle from 0 to 4 s, the rectangle from 4 to 6 s, and the triangle from 6 to 8 s.

$$x = \tfrac{1}{2}(4 - 0 \text{ s})V + (6 - 4 \text{ s})V + \tfrac{1}{2}(8 - 6 \text{ s})V = (5 \text{ s})V$$

2. Set *x* equal to 13 m and solve for *V*:

$$x = (5.0 \text{ s})V = 13 \text{ m} \quad \Rightarrow \quad V = 13/5 \text{ m/s} = \underline{\underline{2.6 \text{ m/s}}}$$

3. (a) Now find the area of the triangle from 0 to 4 s:

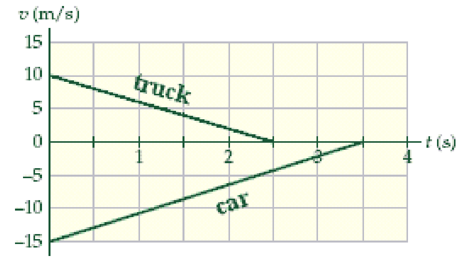
$$x_1 = \tfrac{1}{2}(4 - 0 \text{ s})(2.6 \text{ m/s}) = \boxed{5.2 \text{ m}}$$

4. (b) Find the area of the triangle from 6 to 8 s: $x_1 = \frac{1}{2}(8-6\text{ s})(2.6\text{ m/s}) = \boxed{2.6\text{ m}}$

5. (c) We found the unknown speed in step 2: $V = \boxed{2.6\text{ m/s}}$

Insight: The velocity-versus-time graph is a rich source of information. Besides velocity and time information, you can determine acceleration from the slope of the graph and distance traveled from the area under the graph.

62. **Picture the Problem**: The velocity-versus-time plots of the car and the truck are shown at right. The car begins with a positive position and a negative velocity, so it must be represented by the lower line. The truck begins with a negative position and a positive velocity, so it is represented by the upper line.



Strategy: The distances traveled by the car and the truck are equal to the areas under their velocity-versus-time plots. We can determine the distances traveled from the plots and use the known initial positions to find the final positions and the final separation.

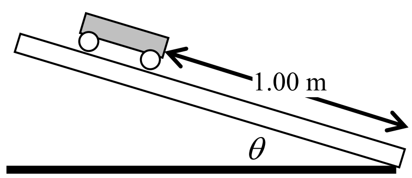
Solution: 1. Find the final position of the truck: $x_{\text{truck}} = x_{0,\text{truck}} + \Delta x_{\text{truck}} = (-35\text{ m}) + \frac{1}{2}(2.5-0\text{ s})(10\text{ m/s}) = \underline{\underline{-22.5\text{ m}}}$

2. Find the final position of the car: $x_{\text{car}} = x_{0,\text{car}} + \Delta x_{\text{car}} = (15\text{ m}) + \frac{1}{2}(3.5-0\text{ s})(-15\text{ m/s}) = \underline{\underline{-11.25\text{ m}}}$

3. Now find the separation: $x_{\text{car}} - x_{\text{truck}} = (-11.25\text{ m}) - (-22.5\text{ m}) = \boxed{11.3\text{ m}}$

Insight: The velocity-versus-time graph is a rich source of information. Besides velocity and time information, you can determine acceleration from the slope of the graph and distance traveled from the area under the graph. In this case, we can see the acceleration of the car (4.29 m/s^2) has a greater magnitude than the acceleration of the truck (−4.00 m/s^2).

63. **Picture the Problem**: The cart slides down the inclined track, each time traveling a distance of 1.00 m along the track.



Strategy: The distance traveled by the cart is given by the constant-acceleration equation of motion for position as a function of time (equation 2-11), where $x_0 = v_0 = 0$. The magnitude of the acceleration can thus be determined from the given distance traveled and the time elapsed in each case. We can then make the comparison with $a = g\sin\theta$.

Solution: 1. Find the acceleration from equation 2-11: $x = 0 + 0 + \frac{1}{2}at^2 \;\Rightarrow\; a = \dfrac{2x}{t^2}$ $\qquad a = g\sin\theta$

2. Now find the values for θ = 10.0°: $a = \dfrac{2.00\text{ m}}{(1.08\text{ s})^2} = \boxed{1.71\text{ m/s}^2}$ $\qquad a = (9.81\text{ m/s}^2)\sin 10.0^\circ = \boxed{1.70\text{ m/s}^2}$

3. Now find the values for θ = 20.0°: $a = \dfrac{2.00\text{ m}}{(0.770\text{ s})^2} = \boxed{3.37\text{ m/s}^2}$ $\qquad a = (9.81\text{ m/s}^2)\sin 20.0^\circ = \boxed{3.35\text{ m/s}^2}$

4. Now find the values for θ = 30.0°: $a = \dfrac{2.00\text{ m}}{(0.640\text{ s})^2} = \boxed{4.88\text{ m/s}^2}$ $\qquad a = (9.81\text{ m/s}^2)\sin 10.0^\circ = \boxed{4.91\text{ m/s}^2}$

Insight: We see very good agreement between the formula $a = g\sin\theta$ and the measured acceleration. The experimental accuracy gets more and more difficult to control as the angle gets bigger because the elapsed times become very small and more difficult to measure accurately. For this reason Galileo's experimental approach (rolling balls down an incline with a small angle) gave him an opportunity to make accurate observations about free fall without fancy electronic equipment.

64. **Picture the Problem**: The apple falls straight downward under the influence of gravity.

Strategy: The distance of the fall is estimated to be about 3.0 m (about 10 ft). Then use the time-free equation of motion (equation 2-12) to estimate the speed of the apple.

Solution: 1. Solve equation 2-12 for v, assuming the apple drops from rest ($v_0 = 0$):

$$v = \sqrt{0 + 2a\Delta x}$$

2. Let $a = g$ and calculate v:

$$v = \sqrt{2\left(9.81\text{ m/s}^2\right)\left(3.0\text{ m}\right)} = \boxed{7.7\text{ m/s}} = 17\text{ mi/h}$$

Insight: Newton supposedly then reasoned that the same force that made the apple fall also keeps the Moon in orbit around the Earth, leading to his universal law of gravity (Chapter 12). One lesson we might learn here is—wear a helmet when sitting under an apple tree!

65. **Picture the Problem**: The car falls straight downward under the influence of gravity.

Strategy: Find the time it takes for a free-falling car to reach 60 mi/h by employing the constant acceleration equation of motion for velocity as a function of time (equation 2-7).

Solution: 1. Solve equation 2-7 for t, assuming the car drops from rest ($v_0 = 0$):

$$t = \frac{v - v_0}{g} = \frac{60 - 0\text{ mi/h}}{9.81\text{ m/s}^2} \times \frac{0.447\text{ m/s}}{1\text{ mi/h}} = \underline{\underline{2.8\text{ s}}} \cong 3\text{ s}$$

2. Since the time is approximately 3 seconds, $\boxed{\text{the statement is accurate}}$.

Insight: Sometimes cartoon physics can be humorously unrealistic, but in this case it is both humorous and realistic!

66. **Picture the Problem**: The car falls straight downward under the influence of gravity.

Strategy: Find the time it takes for a free-falling car to reach 30 mi/h by employing the constant acceleration equation of motion for velocity as a function of time (equation 2-7).

Solution: Solve equation 2-7 for t assuming the car drops from rest ($v_0 = 0$):

$$t = \frac{v - v_0}{g} = \frac{30 - 0\text{ mi/h}}{9.81\text{ m/s}^2} \times \frac{0.447\text{ m/s}}{1\text{ mi/h}} = \boxed{1.4\text{ s}}$$

Insight: Since the speed increases at a constant rate when the acceleration is constant, it takes half the time to achieve half the final velocity of problem 65.

67. **Picture the Problem**: Michael Jordan jumps vertically, the acceleration of gravity slowing him down and bringing him momentarily to rest at the peak of his flight.

Strategy: Since the height of the leap is known, use the time-free equation of motion (equation 2-12) to find the takeoff speed.

Solution: Solve equation 2-12 for v_0:

$$v_0 = \sqrt{v^2 - 2g\Delta x} = \sqrt{0^2 - 2\left(-9.81\text{ m/s}^2\right)\left(48\text{ in} \times 0.0254\text{ m/in}\right)} = \boxed{4.9\text{ m/s}}$$

Insight: That speed is about half of what champion sprinters achieve in the horizontal direction, but is very good among athletes for a vertical leap. High jumpers can jump even higher, but use the running start to their advantage.

68. **Picture the Problem**: The shell falls straight down under the influence of gravity.

Strategy: Since the distance of the fall is known, use the time-free equation of motion (equation 2-12) to find the landing speed.

Solution: Solve equation 2-12 for v. Let $v_0 = 0$ and let downward be the positive direction.

$$v = \sqrt{v_0^2 + 2g\Delta x} = \sqrt{0^2 + 2\left(9.81\text{ m/s}^2\right)\left(14\text{ m}\right)} = \boxed{17\text{ m/s}}$$

Insight: That speed (about 38 mi/h) is sufficient to shatter the shell and provide a tasty meal!

69. **Picture the Problem**: The lava bomb travels upward, slowing down under the influence of gravity, coming to rest momentarily before falling downward.

Strategy: Since the acceleration of gravity is known, the constant acceleration equation of motion (equation 2-7) can be used to find the speed and velocity as a function of time. Let upward be the positive direction.

Solution: 1. (a) Apply equation 2-7 directly with $a = -g$: $v = v_0 - gt = 28\text{ m/s} - (9.81\text{ m/s}^2)(2.0\text{ s}) = \boxed{8.4\text{ m/s}}$

2. (b) Apply equation 2-7 directly with $a = -g$: $v = v_0 - gt = 28\text{ m/s} - (9.81\text{ m/s}^2)(3.0\text{ s}) = \boxed{-1.4\text{ m/s}}$

3. We interpret the answer to (b) as a speed of 1.4 m/s but a velocity of −1.4 m/s, where the negative sign means it is traveling downward.

Insight: We can see the lava bomb must have reached its peak between 2.0 and 3.0 seconds. In fact, it reached it at $t = (0 - 28\text{ m/s})/(-9.81\text{ m/s}^2) = 2.9\text{ s}$.

70. **Picture the Problem**: The material travels straight upward, slowing down under the influence of gravity until it momentarily comes to rest at its maximum altitude.

Strategy: Since the maximum altitude is known, use the time-free equation of motion (equation 2-12) to find the initial velocity. Let upward be the positive direction, so that $a = -1.80\text{ m/s}^2$.

Solution: Solve equation 2-12 for v_0, setting $v = 0$: $v_0 = \sqrt{v^2 - 2a\Delta x} = \sqrt{0^2 - 2(-1.80\text{ m/s}^2)(2.00 \times 10^5\text{ m})} = \boxed{849\text{ m/s}}$

Insight: On Earth that speed would only hurl the material to an altitude of 37 km, as opposed to 200 km on Io. Still, that's a very impressive initial velocity! It is equivalent to the muzzle velocity of a bullet, and is 2.5 times the speed of sound on Earth.

71. **Picture the Problem**: The ruler falls straight down under the influence of gravity.

Strategy: Since the acceleration and initial velocity (zero) of the ruler are known, use the position as a function of time and acceleration equation of motion (equation 2-11) to find the time.

Solution: Solve equation 2-11 for *t*. Let $v_0 = 0$ and let downward be the positive direction. $t = \sqrt{\frac{2\Delta x}{g}} = \sqrt{\frac{2(0.052\text{ m})}{9.81\text{ m/s}^2}} = \boxed{0.10\text{ s}}$

Insight: This is a very good reaction time, about half the average human reaction time of 0.20 s.

72. **Picture the Problem**: The two divers move vertically under the influence of gravity.

Strategy: In both cases we wish to write the equation of motion for position as a function of time and acceleration (equation 2-11). In Bill's case, the initial height $x_0 = 3.0\text{ m}$, but the initial velocity is zero because he steps off the diving board. In Ted's case the initial height $x_0 = 1.0\text{ m}$ and the initial velocity is +4.2 m/s. In both cases the acceleration is -9.81 m/s^2.

Solution: 1. Equation 2-11 for Bill: $x = x_0 + v_0 t + \frac{1}{2}at^2 = 3.0\text{ m} + 0 + \frac{1}{2}(-9.81\text{ m/s}^2)t^2$

$$\boxed{x = (3.0\text{ m}) - (4.9\text{ m/s}^2)t^2}$$

2. Equation 2-11 for Ted: $x = x_0 + v_0 t + \frac{1}{2}at^2 = 1.0\text{ m} + (4.2\text{ m/s})t + \frac{1}{2}(-9.81\text{ m/s}^2)t^2$

$$\boxed{x = (1.0\text{ m}) + (4.2\text{ m/s})t - (4.9\text{ m/s}^2)t^2}$$

Insight: The different initial velocities result in significantly different trajectories for Bill and Ted.

73. **Picture the Problem**: The two divers move vertically under the influence of gravity.

Strategy: In both cases we wish to write the equation of motion for position as a function of time and acceleration (equation 2-11). Here we'll take the origin to be at the level of Bill's board above the water, Ted's diving board to be at +2.0 m, and the water surface at +3.0 m. Downward is the positive direction so that the acceleration is 9.81 m/s^2. In Bill's case, the initial height $x_0 = 0.0$ m and his initial velocity is zero because he steps off the diving board. In Ted's case the initial height $x_0 = +2.0$ m and the initial velocity is -4.2 m/s (upward).

Solution: 1. Equation 2-11 for Bill: $x = x_0 + v_0 t + \frac{1}{2}at^2 = 0.0\text{ m} + 0 + \frac{1}{2}\left(9.81\text{ m/s}^2\right)t^2$

$$\boxed{x = \left(4.9\text{ m/s}^2\right)t^2}$$

2. Equation 2-11 for Ted: $x = x_0 + v_0 t + \frac{1}{2}at^2 = 2.0\text{ m} + \left(-4.2\text{ m/s}\right)t + \frac{1}{2}\left(9.81\text{ m/s}^2\right)t^2$

$$\boxed{x = \left(2.0\text{ m}\right) + \left(-4.2\text{ m/s}\right)t + \left(4.9\text{ m/s}^2\right)t^2}$$

Insight: The different initial velocities result in significantly different trajectories for Bill and Ted.

74. **Picture the Problem**: The swimmers fall straight down from the bridge into the water.

Strategy: The initial velocities of the swimmers are zero because they step off the bridge rather than jump up or dive downward. Use the equation of motion for position as a function of time and acceleration, realizing that the acceleration in each case is 9.81 m/s^2. Set $x_0 = 0$ and let downward be the positive direction for simplicity. The known acceleration can be used to find velocity as a function of time for part (b). Finally, the same equation of motion for part (a) can be solved for time in order to answer part (c).

Solution: 1. (a) Apply equation 2-11 directly: $x = x_0 + v_0 t + \frac{1}{2}at^2 = 0.0\text{ m} + 0 + \frac{1}{2}\left(9.81\text{ m/s}^2\right)\left(1.5\right)^2$

$$\boxed{x = 11\text{ m}}$$

2. (b) Apply equation 2-7 directly: $v = v_0 + at = 0 + \left(9.81\text{ m/s}^2\right)\left(1.5\text{ s}\right) = \boxed{15\text{ m/s}}$

3. (c) Solve equation 2-11 for *t*: $t = \sqrt{\dfrac{2x}{a}} = \sqrt{\dfrac{2\left(11\text{ m} \times 2\right)}{9.81\text{ m/s}^2}} = \boxed{2.1\text{ s}}$

Insight: The time in part (c) doesn't double because it depends upon the square root of the distance the swimmer falls. If you want to double the fall time you must quadruple the height of the bridge.

75. **Picture the Problem**: The water is projected with a large upward velocity, rises straight upward, and momentarily comes to rest before falling straight back down again.

Strategy: By analyzing the time-free equation of motion (equation 2-12) with $v = 0$, we can see that the initial velocity v_0 increases with the square root of the fountain height. The known fountain height and acceleration of gravity can also be used to determine the time it takes for the water to reach the peak using equation 2-11.

Solution: 1. (a) Solve equation 2-12 for v_0, letting $v = 0$ and upward be the positive direction: $0^2 = v_0^2 - 2g\Delta x$

$$v_0 = \sqrt{2g\Delta x} = \sqrt{2\left(9.81\text{ m/s}^2\right)\left(560\text{ ft} \times 0.305\text{ m/ft}\right)} = \boxed{58\text{ m/s}}$$

2. (b) Solve equation 2-11 for *t*: $t = \sqrt{\dfrac{2x}{a}} = \sqrt{\dfrac{2\left(560\text{ ft} \times 0.305\text{ m/ft}\right)}{9.81\text{ m/s}^2}} = \boxed{5.9\text{ s}}$

Insight: The speed of 58 m/s corresponds to 130 mi/h. The fountain is produced by a world-class water pump!

76. **Picture the Problem**: The ball rises straight up, momentarily comes to rest, and then falls straight back down.

Strategy: The time it takes the ball to fall is the same as the time it takes the ball to rise, neglecting any air friction. Therefore the maximum height of the ball is also the distance a ball will fall for 1.4 s. Use the equation of motion for position as a function of time and acceleration, realizing that the acceleration in each case is 9.81 m/s². Set $x_0 = v_0 = 0$ and let downward be the positive direction for simplicity.

Solution: Apply equation 2-11 directly: $x = x_0 + v_0 t + \frac{1}{2}at^2 = 0.0\text{ m} + 0 + \frac{1}{2}\left(9.81\text{ m/s}^2\right)\left(1.4\right)^2 = \boxed{9.6\text{ m}}$

Insight: The 9.6 m height corresponds to 31 ft. The ball must have rebounded from the floor with a speed of 13.7 m/s or 31 mi/h. The player was pretty angry!

77. **Picture the Problem**: The glove rises straight up, momentarily comes to rest, and then falls straight back down.

Strategy: The glove will land with the same speed it was released, neglecting any air friction, so the final velocity $v = -6.0$ m/s. We can use the equation of motion for velocity as a function of time to find the time of flight.

Solution: 1. (a) Solve equation 2-7 for *t*: $t = \dfrac{v - v_0}{a} = \dfrac{(-6.0)-(6.0)\text{ m/s}}{-9.81\text{ m/s}^2} = \boxed{1.22\text{ s}}$

2. (b) The time to reach maximum height: $t = \dfrac{v - v_0}{a} = \dfrac{0 - 6.0\text{ m/s}}{-9.81\text{ m/s}^2} = \boxed{0.61\text{ s}}$

Insight: Throwing the glove upward with twice the speed will double the time of flight but the maximum height attained by the glove (3.66 m for a 6.0 m/s initial speed) will increase by only a factor of $\sqrt{2}$.

78. **Picture the Problem**: The balls fall straight down under the influence of gravity. The first ball falls from rest but the second ball is given an initial downward velocity.

Strategy: Since the fall distance is known in each case, use the time-free equation of motion (equation 2-12) to predict the final velocity. Let downward be the positive direction for simplicity.

Solution: 1. (a) The speed increases linearly with time but nonlinearly with distance. Since the first ball has a lower initial velocity and hence a lower average velocity, it spends more time in the air. The $\boxed{\text{first (dropped) ball}}$ will therefore experience a larger increase in speed.

2. (b) First ball: Solve equation 2-12 for *v*, setting $v_0 = 0$: $v = \sqrt{0^2 + 2g\Delta x} = \sqrt{2\left(9.81\text{ m/s}^2\right)\left(32.5\text{ m}\right)} = \underline{\underline{25.3\text{ m/s}}}$

3. Second ball: Solve equation 2-12 for *v*: $v = \sqrt{v_0^2 + 2g\Delta x} = \sqrt{\left(11.0\text{ m/s}\right)^2 + 2\left(9.81\text{ m/s}^2\right)\left(32.5\text{ m}\right)} = \underline{\underline{27.5\text{ m/s}}}$

4. Compare the Δv values: $\Delta v_1 = 25.3 - 0\text{ m/s } = \boxed{25.3\text{ m/s}}$ for the first ball and

$\Delta v_2 = 27.5 - 11.0\text{ m/s } = \boxed{16.5\text{ m/s}}$ for the second ball.

Insight: The second ball is certainly going faster, but its *change* in speed is less than the first ball.

79. **Picture the Problem**: The arrow rises straight upward, slowing down due to the acceleration of gravity.

Strategy: Since the position, time, and acceleration are all known, we can use the equation of motion for position as a function of time and acceleration (equation 2-11) to find the initial velocity v_0. The same equation could be used to find the time required to rise to a height of 15.0 m above its launch point. Let the launch position $x_0 = 0$ and let upward be the positive direction.

Solution: 1. (a) Solve equation 2-11 for v_0: $v_0 = \dfrac{x - \frac{1}{2}at^2}{t} = \dfrac{30.0\text{ m} - \frac{1}{2}\left(-9.81\text{ m/s}^2\right)\left(2.00\text{ s}\right)^2}{2.00\text{ s}} = \boxed{24.8\text{ m/s}}$

2. (b) Solve equation 2-11 with $x = 15.0$ m:

$$15.0\text{ m} = \left(24.8\text{ m/s}\right)t - \tfrac{1}{2}\left(9.81\text{ m/s}^2\right)t^2$$
$$0 = \left(-4.905\text{ m/s}^2\right)t^2 + \left(24.8\text{ m/s}\right)t - 15.0\text{ m}$$

3. Now use the quadratic formula:

$$t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{-24.8 \pm \sqrt{\left(24.8\right)^2 - 4\left(-4.905\right)\left(-15.0\right)}}{-9.81}$$
$$t = \boxed{0.702\text{ s}},\ 4.36\text{ s}$$

Insight: The second root of the solution to part (b) corresponds to the time when the arrow, after rising to its maximum height, falls back to a position 15.0 m above the launch point.

80. **Picture the Problem**: The book accelerates straight downward and hits the floor of the elevator.

Strategy: The constant speed motion of the elevator does not affect the acceleration of the book. From the perspective of an observer outside the elevator, both the book and the floor have an initial downward velocity of 3.0 m/s. Therefore from your perspective the motion of the book is no different than if the elevator were at rest. Use the position as a function of time and acceleration equation (equation 2-11) to find the time, setting $v_0 = 0$ and letting downward be the positive direction. Then use velocity as a function of time (equation 2-7) to find the speed of the book when it lands.

Solution: 1. (a) Solve equation 2-11 for *t*: $t = \sqrt{\dfrac{2x}{g}} = \sqrt{\dfrac{2\left(1.2\text{ m}\right)}{9.81\text{ m/s}^2}} = \boxed{0.49\text{ s}}$

2. (b) Apply equation 2-7 to find *v*: $v = v_0 + gt = 0 + \left(9.81\text{ m/s}^2\right)\left(0.49\text{ s}\right) = \boxed{4.8\text{ m/s}}$

Insight: The speed in part (b) is relative to you. Relative to the ground the speed of the book is 4.8 + 3.0 = 7.8 m/s.

81. **Picture the Problem**: The camera has an initial downward velocity of 2.0 m/s and accelerates straight downward before striking the ground.

Strategy: One way to solve this problem is to use the quadratic formula to find *t* from the position as a function of time and acceleration equation (equation 2-11). Then the definition of acceleration can be used to find the final velocity. Here's another way: Find the final velocity from the time-free equation of motion (equation 2-12) and use the relationship between average velocity, position, and time (equation 2-10) to find the time. We'll therefore be solving this problem backwards, finding the answer to (b) first and then (a). Let upward be the positive direction, so that $v_0 = -2.0\text{ m/s}$ and $\Delta x = x - x_0 = 0 - 45\text{ m} = -45\text{ m}$.

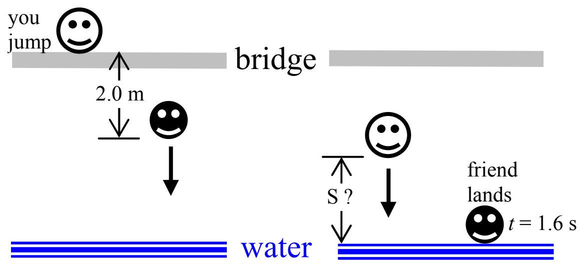
Solution: 1. (a) Solve equation 2-12 for *v*: $v = \sqrt{v_0^2 + 2g\Delta x} = \sqrt{\left(-2.0\text{ m/s}\right)^2 + 2\left(-9.81\text{ m/s}^2\right)\left(-45\text{ m}\right)} = \underline{\underline{-30\text{ m/s}}}$

2. Solve equation 2-10 for *t*: $t = \dfrac{\Delta x}{\frac{1}{2}\left(v + v_0\right)} = \dfrac{-45\text{ m}}{\frac{1}{2}\left(-30 - 2.0\text{ m/s}\right)} = \boxed{2.8\text{ s}}$

3. (b) We found *v* in step 1: $v = \boxed{-30\text{ m/s}} = -0.030\text{ km/s}$

Insight: There is often more than one way to approach constant acceleration problems, some easier than others.

82. **Picture the Problem**: You and your friend both accelerate from rest straight downward, but at different times. You step off the bridge when your friend has fallen 2.0 m, and your friend hits the water while you are still in the air.



Strategy: First find the time it takes for your friend to fall 2.0 m using the equation of motion for position as a function of time and acceleration (equation 2-11). Subtract that time from 1.6 s to find the time elapsed between when you jump and when your friend hits the water. Use equation 2-11 and the times found above to find the positions of you and your friend at the time your friend lands. Then determine the separation from the known positions.

Solution: 1. (a) Because your friend has a greater average speed than you do during the time between when you jump and your friend lands, the separation between the two of you will increase to a value $\boxed{\text{more than 2.0 m}}$.

2. (b) Find the time it takes to fall 2.0 m from equation 2-11 with $v_0 = 0$:

$$t = \sqrt{\frac{2\Delta x}{g}} = \sqrt{\frac{2(2.0\text{ m})}{9.81\text{ m/s}^2}} = \underline{\underline{0.64\text{ s}}}$$

3. Find the distance your friend fell in 1.6 s:

$$x_{\text{friend}} = \tfrac{1}{2}gt^2 = \tfrac{1}{2}\left(9.81\text{ m/s}^2\right)\left(1.6\text{ s}\right)^2 = \underline{\underline{13\text{ m}}}$$

4. Find the distance you fell in the shorter time:

$$x_{\text{you}} = \tfrac{1}{2}g\left(t - t_{2.0\text{ m}}\right)^2 = \tfrac{1}{2}\left(9.81\text{ m/s}^2\right)\left(1.6 - 0.64\text{ s}\right)^2 = \underline{\underline{4.5\text{ m}}}$$

5. Find the difference in your positions:

$$S = x_{\text{friend}} - x_{\text{you}} = 13 - 4.5\text{ m} = \boxed{8\text{ m}}$$

Insight: Because of her head start, your friend will always have a higher average velocity than you, and the separation between you and her will continue to increase the longer you both fall.

83. **Picture the Problem**: The rocket rises straight upward, accelerating over a distance of 26 m and then slowing down and coming to rest at some altitude higher than 26 m.

Strategy: Use the given acceleration and distance and the time-free equation of motion (equation 2-12) to find the velocity of the rocket at the end of its acceleration phase, when its altitude is 26 m. Use that as the initial velocity of the free fall stage in order to find the maximum altitude (equation 2-12 again). Then apply the equation 2-12 once again to find the velocity of the rocket when it returns to the ground. The given and calculated positions at various stages of the flight can then be used to find the elapsed time in each stage and the total time of flight.

Solution: 1. (a) Find the velocity at the end of the boost phase using equation 2-12:

$$v_{boost} = \sqrt{v_0^2 + 2g\Delta x} = \sqrt{0^2 + 2\left(12\text{ m/s}^2\right)\left(26\text{ m}\right)} = \underline{\underline{25\text{ m/s}}}$$

2. Find the height change during the boost phase using equation 2-12 and a final speed of zero:

$$0^2 = v_{boost}^2 - 2g\Delta x_{boost} \Rightarrow \Delta x_{boost} = \frac{v_{boost}^2}{2g}$$

3. Now find the overall maximum height:

$$h_{max} = 26\text{ m} + \frac{v_{boost}^2}{2g} = 26\text{ m} + \frac{\left(25\text{ m/s}\right)^2}{2\left(9.81\text{ m/s}^2\right)} = 26 + 32\text{ m} = \boxed{58\text{ m}}$$

4. (b) Apply equation 2-12 once again between the end of the boost phase and the point where it hits the ground:

$$v^2 = v_{boost}^2 - 2g\Delta x$$

$$v = \sqrt{v_{boost}^2 - 2g\Delta x} = \sqrt{\left(25\text{ m/s}\right)^2 - 2\left(9.81\text{ m/s}^2\right)\left(-26\text{ m}\right)} = \boxed{34\text{ m/s}}$$

5. (c) First find the duration of the boost phase. Use the known positions and equation 2-10:

$$t_{boost} = \frac{\Delta x_{boost}}{\frac{1}{2}\left(v_0 + v_{boost}\right)} = \frac{26\text{ m}}{\frac{1}{2}\left(0 + 25\text{ m/s}\right)} = \underline{\underline{2.1\text{ s}}}$$

6. Now find the time for the rocket to reach its maximum altitude from the end of the boost phase:

$$t_{up} = \frac{\Delta x_{up}}{\frac{1}{2}\left(v_{boost} + v_{top}\right)} = \frac{32\text{ m}}{\frac{1}{2}\left(25 + 0\text{ m/s}\right)} = \underline{\underline{2.6\text{ s}}}$$

7. Now find the time for the rocket to fall back to the ground:

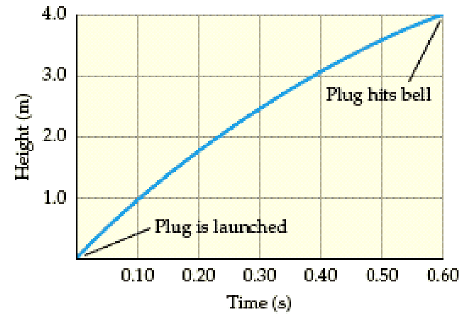
$$t_{down} = \frac{\Delta x_{down}}{\frac{1}{2}\left(v_{top} + v_{ground}\right)} = \frac{58\text{ m}}{\frac{1}{2}\left(0 + 34\text{ m/s}\right)} = \underline{\underline{3.4\text{ s}}}$$

8. Sum the times to find the time of flight:

$$t_{total} = t_{boost} + t_{up} + t_{down} = 2.1 + 2.6 + 3.4\text{ s} = \boxed{8.1\text{ s}}$$

Insight: Notice how knowledge of the initial and final velocities in each stage, and the distance traveled in each stage, allowed the calculation of the elapsed times using the relatively simple equation 2-10, as opposed to the quadratic equation 2-11. Learning to recognize the easiest route to the answer is an important skill to obtain.

84. **Picture the Problem**: The height-versus-time plot of the plug is shown at right. The plug starts with a high velocity and begins to slow down when it hits the bell after 0.60 s.



Strategy: The average velocity is the distance traveled by the plug divided by the time (equation 2-10). Assuming there is no friction, the time and acceleration can be used to find the change in velocity (equation 2-7). The initial velocity can then be determined from the change in velocity and average velocities by combining equations 2-7 and 2-9.

Solution: 1. (a) Find the average velocity using equation 2-10:

$$v_{av} = \frac{x - x_0}{t} = \frac{4.0 - 0 \text{ m}}{0.60 \text{ s}} = \boxed{6.7 \text{ m/s}}$$

2. (b) Find the change in velocity using equation 2-7:

$$\Delta v = v - v_0 = at = \left(-9.81 \text{ m/s}^2\right)\left(0.60 \text{ s}\right) = \boxed{-5.9 \text{ m/s}}$$

3. (c) Combine equations 2-7 and 2-9 to solve for v_0:

$v_0 = v - at$ from equation 2-7

$v = 2v_{av} - v_0$ from equation 2-9. Substitute into the above:

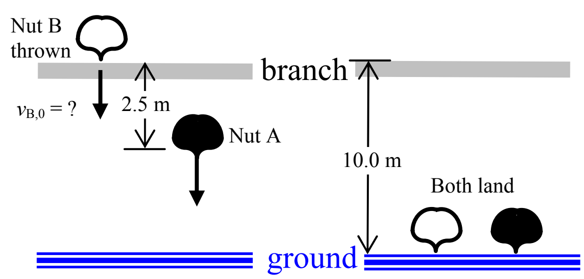
$v_0 = \left(2v_{av} - v_0\right) - at$ and now solve for v_0 :

$$v_0 = \tfrac{1}{2}\left(2v_{av} - at\right) = \tfrac{1}{2}\left[2\left(6.7 \text{ m/s}\right) - \left(-9.81 \text{ m/s}^2\right)\left(0.60 \text{ s}\right)\right]$$

$$v_0 = \boxed{9.6 \text{ m/s}}$$

Insight: There are several other ways of finding these speeds, including graphical analysis. Try measuring the slope of the graph at the launch point and the point at which the plug hits the bell to find the initial and final speeds.

85. **Picture the Problem**: Nut A is dropped from rest. When it has fallen 2.5 m, nut B is thrown downward with an initial speed $v_{B,0}$. Both nuts land at the same time after falling 10.0 m.



Strategy: First find the time it takes for nut A to fall 2.5 m using the equation of motion for position as a function of time and acceleration (equation 2-11). Also find the time required for nut A to fall the entire 10.0 m. Subtract the first time from the second to find the time interval over which nut B must reach the ground in order to land at the same instant as nut A. Then use equation 2-11 again to find the initial velocity $v_{B,0}$ required in order for nut B to reach the ground in that time.

Solution: 1. Find the time it takes for nut A to fall 2.5 m by solving equation 2-11 for t and setting $v_{A,0} = 0$.

$$t_{A,1} = \sqrt{\frac{2\Delta x}{g}} = \sqrt{\frac{2\left(2.5 \text{ m}\right)}{9.81 \text{ m/s}^2}} = \underline{\underline{0.714 \text{ s}}}$$

2. Find the time it takes for nut A to fall the entire 10.0 m:

$$t_{A,\text{total}} = \sqrt{\frac{2\Delta x}{g}} = \sqrt{\frac{2\left(10.0 \text{ m}\right)}{9.81 \text{ m/s}^2}} = \underline{\underline{1.428 \text{ s}}}$$

3. Subtract the times to find the time over which nut B must reach the ground:

$$t_{B,\text{total}} = t_{A,\text{total}} - t_{A,1} = 1.428 - 0.714 \text{ s} = \underline{\underline{0.714 \text{ s}}}$$

4. Solve equation 2-11 for $v_{B,0}$:

$$v_{B,0} = \frac{\Delta x - \frac{1}{2} g t_{B,\text{total}}^2}{t_{B,\text{total}}} = \frac{10.0 \text{ m} - \frac{1}{2}\left(9.81 \text{ m/s}^2\right)\left(0.714 \text{ s}\right)^2}{0.714 \text{ s}}$$

$$v_{B,0} = 10.5 \text{ m/s} \Rightarrow \boxed{11 \text{ m/s}}$$

Insight: In this problem we kept an additional significant figure than is warranted in steps 1, 2, and 3 in an attempt to get a more accurate answer in step 4. However, if you choose not to do so, differences in rounding will lead to an answer of 10 m/s. The specified 2.5 m drop distance for nut A limits the answer to two significant digits, and since the answer is right between 10 and 11 m/s, it could correctly go either way.

86. **Picture the Problem**: Phileas Fogg travels in a straight line all the way around the world.

Strategy: The average speed is the distance divided by elapsed time. We will estimate that Mr. Fogg travels a distance equal to the equatorial circumference of the Earth. This is an approximation, because his path was most likely much more complicated than that, but we were asked only for the approximate speed.

Solution: Find the circumference of the Earth: $d = 2\pi r = 2\pi\left(6370\times10^3 \text{ m}\right) = \underline{\underline{4.0\times10^7 \text{ m}}}$

Divide the distance by the time: $s = \dfrac{\text{distance}}{\text{time}} = \dfrac{4.0\times10^7 \text{ m}}{80 \text{ d} \times 24 \text{ h/d} \times 3600 \text{ s/h}} = \boxed{5.8 \text{ m/s}}$

Insight: This speed corresponds to about 13 mi/h and is faster than humans can walk. Giving time for sleeping, eating, and other delays, Mr. Fogg needs a relatively fast means of travel.

87. **Picture the Problem**: The rock accelerates from rest straight downward and lands on the surface of the Moon.

Strategy: Employ the relationship between acceleration, displacement, and velocity (equation 2-12) to find the final velocity.

Solution: Solve equation 2-12 for velocity v: $v = \sqrt{v_0^2 + 2a\Delta x} = \sqrt{0^2 + 2\left(1.62 \text{ m/s}^2\right)\left(1.25 \text{ m}\right)} = \boxed{2.01 \text{ m/s}}$

Insight: On Earth the rock would be traveling 4.95 m/s, but the weaker gravity on the Moon doesn't accelerate the rock nearly as much as would the Earth's gravity.

88. **Picture the Problem**: You accelerate from rest straight downward and land, bending your knees so that your center of mass comes to rest over a short vertical distance.

Strategy: Employ the relationship between acceleration, displacement, and velocity (equation 2-12) to find your final velocity just before landing. Then estimate the distance your center of mass will move after your feet contact the ground, and use that distance to estimate your deceleration rate.

Solution: 1. Solve equation 2-12 for velocity v: $v = \sqrt{v_0^2 + 2a\Delta x} = \sqrt{0^2 + 2\left(9.81 \text{ m/s}^2\right)\left(1.5 \text{ m}\right)} = \underline{\underline{5.4 \text{ m/s}}}$

2. Estimate your center of mass moves downward about 0.5 m after your feet contact the ground and you bend your knees into a crouching position. Solve equation 2-12 for acceleration: $a = \dfrac{v^2 - v_0^2}{2\Delta y} = \dfrac{0^2 - \left(5.4 \text{ m/s}\right)^2}{2\left(0.50 \text{ m}\right)} = \boxed{-29 \text{ m/s}^2} = -3.0g$

Insight: When a gymnast lands from an even higher altitude, she might try to bend her knees even less in order to impress the judges. If she lands from an altitude of 3.0 m and bends her knees so her center of mass moves only 0.2 m, her acceleration is $-15g$!

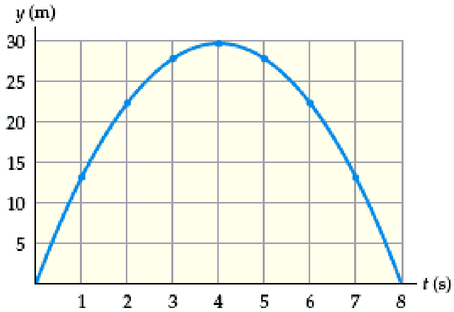
89. **Picture the Problem**: The water accelerates from rest (in the vertical direction, that is) straight downward and impacts the ground or water below.

Strategy: Employ the relationship between acceleration, displacement, and velocity (equation 2-12) to find the height from which the water must fall so that its final velocity just before landing is 340 m/s.

Solution: Solve equation 2-12 for velocity Δx: $\Delta x = \dfrac{v^2 - v_0^2}{2g} = \dfrac{\left(340 \text{ m/s}\right)^2 - 0^2}{2\left(9.81 \text{ m/s}^2\right)} = 5900 \text{ m} = \boxed{5.9 \text{ km}}$

Insight: This height corresponds to 3.7 miles or over 19,000 feet! With air resistance, however, an even higher altitude would be required to obtain speeds this great.

90. **Picture the Problem**: The height-versus-time plot of the rock is shown at right. The rock starts with a high velocity upward, slows down and momentarily comes to rest after about 4.0 seconds of flight, and then falls straight down and lands at about 8.0 seconds.



Strategy: The equation of motion for position as a function of time and acceleration (equation 2-11) can be used to find the acceleration from the second half of the trajectory, where the rock falls 30 m from rest and lands 4.0 seconds later. Once acceleration is known, the final velocity can be determined from equation 2-7. Let downward be the positive direction.

Solution: 1. (a) Solve equation 2-11 for acceleration, assuming $v_0 = 0$ and the rock falls 30 m in 4.0 s:

$$a = \frac{2\Delta x}{t^2} = \frac{2(30\text{ m})}{(4.0\text{ s})^2} = \boxed{3.8\text{ m/s}^2}$$

2. (b) Find the final velocity using equation 2-7:

$$v = v_0 + at = 0 + (3.8\text{ m/s}^2)(4.0\text{ s}) = \boxed{15\text{ m/s}}$$

Insight: There are several other ways of finding the answers, including graphical analysis. Try measuring the slope of the graph at the launch point and the point at which the rock lands to find the initial and final velocities. Those values can then be used to find the acceleration.

91. **Picture the Problem**: The lander falls straight downward, accelerating over a distance of 4.3 ft before impacting the lunar surface.

Strategy: Use the given acceleration and distance and the time-free equation of motion (equation 2-12) to find the velocity of the lander just before impact. Use the known initial and final velocities, together with the distance of the fall, to find the time elapsed using equation 2-10.

Solution: 1. (a) Find the velocity just before impact using equation 2-12:

$$v_{\text{land}} = \sqrt{v_0^2 + 2a\Delta x} = \sqrt{(0.50\text{ ft/s})^2 + 2(1.62\text{ m/s}^2 \times 3.28\text{ ft/m})(4.3\text{ ft})} = \boxed{6.8\text{ ft/s}}$$

2. (b) Solve equation 2-10 for *t*:

$$t_{\text{fall}} = \frac{\Delta x_{\text{fall}}}{\frac{1}{2}(v_0 + v_{\text{land}})} = \frac{4.3\text{ ft}}{\frac{1}{2}(0.50 + 6.8\text{ ft/s})} = \boxed{1.2\text{ s}}$$

Insight: Assuming the lander feet had little in the way of shock absorbers, the lander came to rest in a distance given by the amount the lunar dust compacted underneath the feet. Supposing it was about 2 cm, the astronauts experienced a brief deceleration of 106 m/s^2 = 11*g*! Bam!

92. **Picture the Problem**: The package falls straight downward, accelerating for 2.2 seconds before impacting the air bags.

Strategy: Find the distance the package will fall from rest in 2.2 seconds by using equation 2-11. Use the known acceleration and time to find the velocity of the package just before impact by using equation 2-7. Finally, use the known initial and final velocities, together with the distance over which the package comes to rest when in contact with the air bags, to find the stopping acceleration using equation 2-12.

Solution: 1. (a) Find the distance the package falls from rest in 2.2 s using equation 2-11:

$$\Delta x = v_0 t + \tfrac{1}{2} g t^2 = 0 + \tfrac{1}{2}(9.81\text{ m/s}^2)(2.2\text{ s})^2 = \boxed{24\text{ m}}$$

2. (b) Find the velocity just before impact using eq. 2-7:

$$v_{\text{land}} = v_0 + gt = 0 + (9.81\text{ m/s}^2)(2.2\text{ s}) = \boxed{22\text{ m/s}} = 48\text{ mi/h!}$$

3. (c) Solve equation 2-12 for *a*:

$$a = \frac{v^2 - v_0^2}{2\Delta x} = \frac{0^2 - (22\text{ m/s})^2}{2(0.75\text{ m})} = \boxed{-320\text{ m/s}^2} = -33g$$

Insight: Increasing the stopping distance will decrease the stopping acceleration. We will return to this idea when we discuss impulse and momentum in Chapter 9.

93. **Picture the Problem**: The child rises straight upward, slows down, and momentarily comes to rest before falling straight downward again.

Strategy: Find the time of flight by exploiting the symmetry of the situation. If it takes time t for gravity to slow the child down from her initial speed v_0 to zero, it will take the same amount of time to accelerate her back to the same speed. She therefore lands at the same speed v_0 with which she took off. Use this fact together with equation 2-7 to find the time of flight. The maximum height she achieves is related to the square of v_0, as indicated by equation 2-12.

Solution: 1. (a) Since the time of flight depends linearly upon the initial velocity, doubling v_0 will increase her time of flight by a factor of $\boxed{2}$.

2. (b) Since the time of flight depends upon the square of the initial velocity, doubling v_0 will increase her maximum altitude by a factor of $\boxed{4}$.

3. (c) The time of flight for $v_0 = 2.0$ m/s, using eq. 2-7:

$$t = \frac{v - v_0}{-g} = \frac{(-v_0) - v_0}{-g} = \frac{2v_0}{g} = \frac{2(2.0\text{ m/s})}{9.81\text{ m/s}^2} = \boxed{0.41\text{ s}}$$

4. The time of flight for $v_0 = 4.0$ m/s:

$$t = \frac{2v_0}{g} = \frac{2(4.0\text{ m/s})}{9.81\text{ m/s}^2} = \boxed{0.82\text{ s}}$$

5. The maximum height for $v_0 = 2.0$ m/s, using eq. 2-12:

$$\Delta x = \frac{v^2 - v_0^2}{-2g} = \frac{0^2 - v_0^2}{-2g} = \frac{v_0^2}{2g} = \frac{(2.0\text{ m/s})^2}{2(9.81\text{ m/s}^2)} = \boxed{0.20\text{ m}}$$

6. The maximum height for $v_0 = 4.0$ m/s:

$$\Delta x = \frac{v_0^2}{2g} = \frac{(4.0\text{ m/s})^2}{2(9.81\text{ m/s}^2)} = \boxed{0.82\text{ m}}$$

Insight: The reason the answer in step 6 is not exactly four times larger than the answer in step 5 is due to the rounding required by the fact that there are only two significant digits. If you recalculate using 2.00 m/s and 4.00 m/s, the answers are 0.204 and 0.816 m, respectively.

94. **Picture the Problem**: The ball rolls in a straight line, decreasing its speed at a constant rate until it comes to rest.

Strategy: You could find the (negative) acceleration by using equation 2-12 and the known initial and final velocities and the distance traveled. Then employ equation 2-12 again using the same acceleration, but solving for the v_0 required to go the longer distance. Instead, we'll present a way to calculate the same answer using a ratio.

Solution: 1. (a) Calculate the ratio of initial velocities based upon equation 2-12:

$$\frac{v_{b,0}}{v_{a,0}} = \frac{\sqrt{v^2 - 2a\Delta x_b}}{\sqrt{v^2 - 2a\Delta x_a}} = \frac{\sqrt{0^2 - 2a\Delta x_b}}{\sqrt{0^2 - 2a\Delta x_a}} = \sqrt{\frac{\Delta x_b}{\Delta x_a}}$$

2. Now solve for $v_{b,0}$:

$$v_{b,0} = v_{a,0}\sqrt{\frac{\Delta x_b}{\Delta x_a}} = (1.57\text{ m/s})\sqrt{\frac{20.5\text{ ft}}{20.5 - 6.00\text{ ft}}} = \boxed{1.87\text{ m/s}}$$

3. (b) Employ the same ratio with different distances:

$$v_{b,0} = v_{a,0}\sqrt{\frac{\Delta x_b}{\Delta x_a}} = (1.57\text{ m/s})\sqrt{\frac{6.00\text{ ft}}{20.5 - 6.00\text{ ft}}} = \boxed{1.01\text{ m/s}}$$

Insight: Calculating ratios can often be a convenient and simple way to solve a problem. In this case a three-step solution became two steps when we calculated the ratio, and furthermore we never needed to convert feet to meters because the units cancel out in the ratio. Learning to calculate ratios in this manner is a valuable skill in physics.

95. **Picture the Problem**: The person is thrown straight upward, slows down, and momentarily comes to rest before falling straight downward again.

Strategy: Find the time of flight by exploiting the symmetry of the situation. If it takes time t for gravity to slow the person down from her initial speed v_0 to zero, it will take the same amount of time to accelerate her back to the same speed. It therefore takes the same amount of time for her to rise to the peak of her flight than it does for her to return to the blanket. Use this fact together with equation 2-11 with $v_0 = 0$ (corresponding to the second half of her flight, from the peak back down to the blanket) to find the time of flight. The time above and below 14.0 ft can be found using the same equation.

Solution: 1. (a) The time of flight can be found from equation 2-11:

$$t = 2\times t_{\text{down}} = 2\times\sqrt{\frac{2\Delta x}{g}} = 2\sqrt{\frac{2(28.0\text{ ft }\times 0.305\text{ m/ft})}{9.81\text{ m/s}^2}} = \boxed{2.64\text{ s}}$$

2. (b) The person's average speed is less during the upper half of her trajectory, so the time she spends in that portion of her flight is $\boxed{\text{more than}}$ the time she spends in the lower half of her flight.

3. (c) The time she spends above 14.0 ft is the same time of her flight if her maximum height were 14.0 ft:

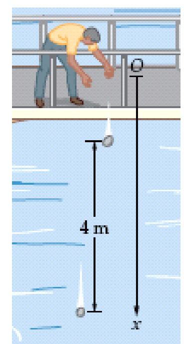
$$t_{\text{above}} = 2\times\sqrt{\frac{2\Delta x}{g}} = 2\sqrt{\frac{2(14.0\text{ ft }\times 0.305\text{ m/ft})}{9.81\text{ m/s}^2}} = \boxed{1.87\text{ s}}$$

4. The time spent below 14.0 ft is the remaining portion of the total time of flight:

$$t_{\text{below}} = t_{\text{total}} - t_{\text{above}} = 2.64 - 1.87\text{ s } = \boxed{0.77\text{ s}}$$

Insight: The symmetry of the motion of a freely falling object can often be a useful tool for solving problems quickly.

96. **Picture the Problem**: The two rocks fall straight downward along a similar path except at different times.



Strategy: First find the time elapsed between the release of the two rocks by finding the time required for the first rock to fall 4.00 m, using the equation of motion for position as a function of time and acceleration (equation 2-11). The positions as a function of time for each rock can then be compared to find a separation distance as a function of time.

Solution: 1. (a) Find the time required for rock A to fall 4.00 m:

$$t_4 = \sqrt{\frac{2\Delta x}{g}} = \sqrt{\frac{2(4.00\text{ m})}{9.81\text{ m/s}^2}} = \underline{\underline{0.903\text{ s}}}$$

2. Let t represent the time elapsed from the instant rock B is dropped. The position of rock A (equation 2-11) is thus:

$$x_A = 0 + \tfrac{1}{2}g(t+t_4)^2 = \tfrac{1}{2}gt^2 + g\,t\,t_4 + \tfrac{1}{2}gt_4^2$$

4. The position of rock B (equation 2-11) is:

$$x_B = 0 + \tfrac{1}{2}gt^2 = \tfrac{1}{2}gt^2$$

5. Find the separation between the rocks:

$$\Delta x = x_A - x_B = \left(\tfrac{1}{2}gt^2 + g\,t\,t_4 + \tfrac{1}{2}gt_4^2\right) - \tfrac{1}{2}gt^2$$

$$\Delta x = g\,t\,t_4 + \tfrac{1}{2}gt_4^2 = (9.81\text{ m/s}^2)t(0.903\text{ s}) + \tfrac{1}{2}(9.81\text{ m/s}^2)(0.903\text{ s})^2$$

$$\Delta x = (8.86\text{ m/s})t + 4.00\text{ m}$$

6. Find Δx for $t = 1.0$ s:

$$\Delta x = (8.86\text{ m/s})(1.0\text{ s}) + 4.00\text{ m} = \boxed{12.9\text{ m}}$$

7. (b) Find Δx for $t = 2.0$ s:

$$\Delta x = (8.86\text{ m/s})(2.0\text{ s}) + 4.00\text{ m} = \boxed{22\text{ m}}$$

8. (c) Find Δx for $t = 1.0$ s:

$$\Delta x = (8.86\text{ m/s})(3.0\text{ s}) + 4.00\text{ m} = \boxed{31\text{ m}}$$

9. (d) The linear dependence of Δx upon t can be verified by examining the equation derived in step 5.

Insight: The only way for rock B to catch up to rock A would be for rock B to thrown downward with a large initial speed. In that case the separation becomes $\Delta x = (8.86\text{ m/s} - v_{B,0})t + 4.00\text{ m}$, which decreases to zero as long as $v_{B,0}$ is greater than 8.86 m/s.

97. **Picture the Problem**: After release by the gull the shell rises straight upward, slows down, and momentarily comes to rest before falling straight downward again.

Strategy: Find the extra altitude attained by the shell due to its upward initial velocity upon release, and add that value to 12.5 m to find the maximum height it reaches above ground. The time-free equation for velocity as a function of acceleration and distance (equation 2-12) can be employed for this purpose. The time the shell spends going up and the time it spends going down can each be found from the known heights and speeds (equations 2-7 and 2-11). Then the speed upon landing can be determined from the known time it spends falling (equation 2-7). Let upward be the positive direction throughout the problem.

Solution: 1. (a) The motion of the shell is influenced only by gravity once it has been released by the gull. Therefore its acceleration will be $\boxed{9.81 \text{ m/s}^2 \text{ downward}}$ from the moment it is released, even though it is moving upward at the release.

2. (b) Use equation 2-12, setting the final speed $v = 0$, to find the extra altitude gained by the shell due to its initial upward speed, and add it to the 12.5 m:

$$y_{\max} = 12.5 \text{ m} + \frac{v^2 - v_0^2}{-2g} = 12.5 \text{ m} + \frac{0^2 - (5.20 \text{ m/s})^2}{-2(9.81 \text{ m/s}^2)}$$

$$y_{\max} = 12.5 \text{ m} + 1.38 \text{ m} = \boxed{13.9 \text{ m}}$$

3. (c) The time the shell travels upward is the time it takes gravity to bring the speed to zero (equation 2-7):

$$t = \frac{v - v_0}{-g} = \frac{0 - 5.2 \text{ m/s}}{-9.81 \text{ m/s}^2} = \underline{\underline{0.53 \text{ s}}}$$

4. The time the shell travels down is governed by the distance and the acceleration (equation 2-11):

$$x = x_0 + v_0 t - \tfrac{1}{2} g t^2 \quad \Rightarrow \quad 0 = x_0 + 0 - \tfrac{1}{2} g t^2$$

$$t = \sqrt{\frac{2x_0}{g}} = \sqrt{\frac{2(13.9 \text{ m})}{9.81 \text{ m/s}^2}} = \underline{\underline{1.68 \text{ s}}}$$

5. The total time of flight is the sum:

$$t_{\text{total}} = t_{\text{up}} + t_{\text{down}} = 0.53 + 1.68 \text{ s} = \boxed{2.21 \text{ s}}$$

6. (d) The speed of the shell upon impact is given by the acceleration of gravity and the fall time (equation 2-7):

$$v = v_0 - gt = 0 - (9.81 \text{ m/s}^2)(1.68 \text{ s}) = -16.5 \text{ m/s}$$

$$|v| = \boxed{16.5 \text{ m/s}}$$

Insight: There are a variety of other ways to solve this problem. For instance, you can find the final velocity of 16.5 m/s in part (d) by using equation 2-12 with $v_0 = 5.2$ m/s and $\Delta x = -12.5$ m without using any time information. Try it!

98. **Picture the Problem**: The liquid squirts straight upward, slows down, and momentarily comes to rest before falling straight downward again.

Strategy: Find the time of flight by exploiting the symmetry of the situation. If it takes time t for gravity to slow the liquid drops down from their initial speed v_0 to zero, it will take the same amount of time to accelerate them back to the same speed. They therefore land at the same speed v_0 with which they were squirted. Use this fact together with equation 2-7 to find the time of flight. The maximum height the drops achieve is related to the square of v_0, as indicated by equation 2-12.

Solution: 1. (a) The time of flight for $v_0 = 1.5$ m/s, using eq. 2-7:

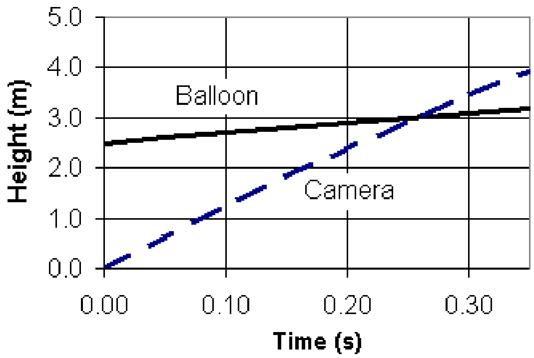
$$t = \frac{v - v_0}{-g} = \frac{(-v_0) - v_0}{-g} = \frac{2v_0}{g} = \frac{2(1.5 \text{ m/s})}{9.81 \text{ m/s}^2} = \boxed{0.31 \text{ s}}$$

2. (b) The maximum height for $v_0 = 1.5$ m/s, using eq. 2-12:

$$\Delta x = \frac{v^2 - v_0^2}{-2g} = \frac{0^2 - v_0^2}{-2g} = \frac{v_0^2}{2g} = \frac{(1.5 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)} = \boxed{0.11 \text{ m}}$$

Insight: The symmetry of the motion of a freely falling object can often be a useful tool for solving problems quickly.

99. **Picture the Problem**: The trajectories of the balloon and camera are shown at right. The balloon rises at a steady rate while the camera's speed is continually slowing down under the influence of gravity. The camera is caught when the two trajectories meet.



Strategy: The equation of motion for position as a function of time and velocity (equation 2-10) can be used to describe the balloon, while the equation for position as a function of time and acceleration (equation 2-11) can be used to describe the camera's motion. Set these two equations equal to each other to find the time at which the camera is caught. Then find the height of the balloon at the instant the camera is caught.

Solution: 1. Write equation 2-10 for the balloon: $x_b = x_{b,0} + v_b t$

2. Write equation 2-11 for the camera: $x_c = 0 + v_{c,0}\,t - \frac{1}{2}gt^2$

3. Set $x_b = x_c$ and solve for *t*:

$$x_{b,0} + v_b t = v_{c,0}t - \tfrac{1}{2}gt^2$$
$$0 = -x_{b,0} + \left(v_{c,0} - v_b\right)t - \tfrac{1}{2}gt^2$$

4. Multiply by −1 and insert the numbers:

$$0 = 2.5\text{ m } - \left(13 - 2.0\text{ m/s}\right)t + \tfrac{1}{2}\left(9.81\text{ m/s}^2\right)t^2$$
$$0 = 2.5 - 11t + 4.9t^2$$

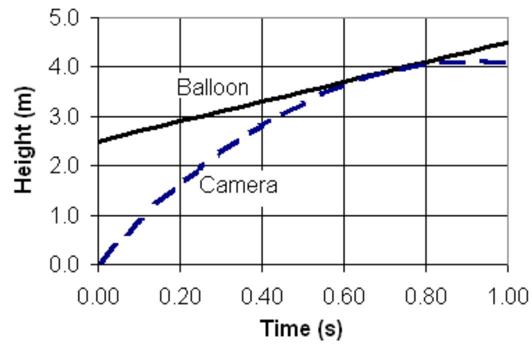
5. Apply the quadratic formula and solve for *t*. The larger root corresponds to the time when the camera would pass the balloon a second time, on its way down back to the ground.

$$t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{+11 \pm \sqrt{11^2 - 4(4.9)(2.5)}}{9.8}$$
$$t = \underline{\underline{0.26}} \text{ or } 2.0\text{ s}$$

6. Find the height of the balloon at that time: $x_b = x_{b,0} + v_b t = 2.5\text{ m} + (2.0\text{ m/s})(0.26\text{ s}) = \boxed{3.0\text{ m}}$

Insight: If the passenger misses the camera the first time, she has another shot at it after 2.0 s (from the time it is thrown) when the camera is on its way back toward the ground.

100. **Picture the Problem**: The trajectories of the balloon and camera are shown at right. The balloon rises at a steady rate while the camera's speed is continually slowing down under the influence of gravity. The camera is caught when the two trajectories meet.



Strategy: The camera meets the balloon when the positions are equal, so that is our starting point. For the case when the camera just barely meets the balloon, the velocity of the camera must match the velocity of the balloon (2.0 m/s). We use this fact to find the time the two must meet, and substitute that into the position equation. We can then solve for the initial velocity of the camera.

Solution: 1. Write equation 2-10 for the balloon: $x_b = x_{b,0} + v_b t$

2. Write equation 2-12 for the camera: $x_c = \dfrac{v_c^2 - v_{c,0}^2}{-2g}$

3. Set $x_b = x_c$ and solve for $v_{c,0}$: $x_{b,0} + v_b t = \dfrac{v_c^2 - v_{c,0}^2}{-2g} \quad \Rightarrow \quad v_{c,0}^2 = v_c^2 + 2g\left(x_{b,0} + v_b t\right)$

4. As indicated above, the camera will be caught not only when its at the same position as the balloon, but when its velocity is the same as well, so set $v_c = v_b$

$$v_{c,0}^2 = v_b^2 + 2g x_{b,0} + 2g v_b t$$

5. The two will meet at a time when their velocities are equal. Write equation 2-7 for the camera and set its final velocity equal to the balloon's velocity, and find the time.

$$v_c = v_{c,0} - gt = v_b$$
$$t = \frac{v_{c,0} - v_b}{g}$$

6. Substitute the time into the equation in step 4:

$$v_{c,0}^2 = v_b^2 + 2g x_{b,0} + 2v_b\left(v_{c,0} - v_b\right)$$
$$v_{c,0}^2 - 2v_b v_{c,0} + v_b^2 - 2g x_{b,0} = 0$$
$$v_{c,0}^2 - 2\left(2.0 \text{ m/s}\right)v_{c,0} + \left(2.0 \text{ m/s}\right)^2 - 2\left(9.81 \text{ m/s}^2\right)\left(2.5 \text{ m}\right) = 0$$
$$v_{c,0}^2 - 4.0 v_{c,0} - 45 \text{ m}^2/\text{s}^2 = 0$$

7. You can get the roots using the quadratic formula, but you might recognize the simple factors here. Only the positive root corresponds to the camera going *upward*:

$$\left(v_c + 5\right)\left(v_c - 9\right) = 0$$
$$v_c = -5.0, \boxed{9.0 \text{ m/s}}$$

Insight: This is a complicated problem that always ends with a quadratic solution. It required the kind of strategy that must usually be mapped out after trying a few things; don't feel bad if you didn't intuitively choose this strategy. There are other strategies that work, but they are equally complicated.

101. **Picture the Problem**: The water shoots straight upward, slows down, and momentarily comes to rest before falling straight downward again.

Strategy: Find the height of the geyser by exploiting the symmetry of the situation. If it takes time t for gravity to slow the water down from its initial speed v_0 to zero, it will take the same amount of time to accelerate it back to the same speed. The height of the geyser is therefore determined by the distance the water will fall from rest in time t (equation 2-11). Gravity will slow the water down from its initial velocity to zero in time t at a known rate (-9.81 m/s^2), so that fact can be used to find the initial velocity (equation 2-7).

Solution: 1. (a) Solve equation 2-11 for x_0, setting $x = 0$ and $v_0 = 0$ for the case when the water falls from rest in time t:

$$0 = x_0 + 0 - \tfrac{1}{2} g t^2$$
$$x_{\max} = x_0 = \boxed{\tfrac{1}{2} g t^2}$$

2. (b) Use equation 2-7 to find the initial velocity if the final velocity is zero (upward portion of the flight):

$$v = v_0 - g t = 0$$
$$v_0 = \boxed{g t}$$

3. (c) Substitute $t = 1.65$ s into the equation from step 1:

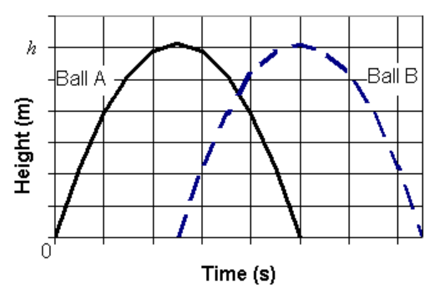
$$x_{\max} = \tfrac{1}{2}\left(9.81\text{ m/s}^2\right)\left(1.65\text{ s}\right)^2 = \boxed{13.4\text{ m}}$$

4. (d) Substitute $t = 1.65$ s into the equation from step 2:

$$v_0 = \left(9.81\text{ m/s}^2\right)\left(1.65\text{ s}\right) = \boxed{16.2\text{ m/s}}$$

Insight: If you round off $g = 10\text{ m/s}^2$, you can impress your friends by memorizing these simple formulae and doing the quick calculations in your head!

102. **Picture the Problem**: The trajectories of the two balls are shown at right. Remember that in each case the balls are traveling straight up and straight down; the graphs look parabolic because time is the x axis. Ball B is tossed upward at the instant ball A reaches the peak of its flight. Ball A has begun its descent when it is passed by ball B, which is still on its way up toward its peak.



Strategy: The positions are equal to each other when the balls cross paths. The launch times are offset by the time it takes the ball to reach the peak of its flight. That time is given by the time it takes gravity to slow the ball from v_0 down to zero (equation 2-7). The time the balls cross is directly between the time ball B is launched and ball A lands. Once we have the time figured out we can find the position of ball A in terms of its maximum height h.

Solution: 1. The plot of x-versus-t for the two balls is shown above.

2. Judging from the plot the balls will cross paths $\boxed{\text{above } h/2}$.

3. Find the time it takes ball A to reach its peak:

$$t = \frac{v - v_0}{-g} = \frac{0 - v_0}{-g} = \frac{v_0}{g}$$

4. Since ball B is launched at time v_0/g and ball A lands at time $2v_0/g$, the two balls will cross at a time midway between these, or at time $t_{\text{cross}} = 3v_0/2g$.

5. Find the position of ball A at time t_{cross} using equation 2-11:

$$x_A = v_0 t_{\text{cross}} - \tfrac{1}{2} g t_{\text{cross}}^2 = v_0\left(\frac{3v_0}{2g}\right) - \tfrac{1}{2} g\left(\frac{3v_0}{2g}\right)^2 = \underline{\underline{\frac{3v_0^2}{8g}}}$$

6. Find the maximum height h using equation 2-12:

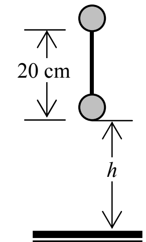
$$0^2 = v_0^2 - 2gh \;\Rightarrow\; h = \frac{v_0^2}{2g}$$

7. Now write x_A in terms of h:

$$\frac{x_A}{h} = \frac{\frac{3v_0^2}{8g}}{\frac{v_0^2}{2g}} = \frac{3}{4} \;\Rightarrow\; x_A = \boxed{\tfrac{3}{4} h}$$

Insight: The balls do not cross right at h / 2 because they spend more time above h / 2 than they do below, because their average speeds are smaller during the top half of their flight.

103. **Picture the Problem**: The two balls fall straight downward from rest along a similar path except at different times.



Strategy: The problem requires that the time to fall a distance *h* from rest (the time between release and the first thud) is the time to fall a distance *h* + 20 cm (second thud) minus the time to fall a distance *h* (first thud). We can set these times equal to each other, use equation 2-11 to write the times in terms of heights, and then solve for *h*.

Solution: 1. Set the time intervals equal to each other: $t_h = t_{h+20} - t_h \;\Rightarrow\; 2t_h = t_{h+20}$

2. Now use equation 2-11 to write the times in terms of the heights: $2\sqrt{\dfrac{2h}{g}} = \sqrt{\dfrac{2(h+20.0\text{ cm})}{g}}$

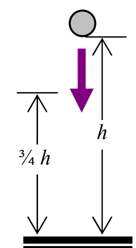
3. Square both sides and multiply by *g* / 2:

$$4h = h + 20.0\text{ cm}$$

$$h = \frac{20.0}{3}\text{ cm } = \boxed{6.67\text{ cm}}$$

Insight: The tension in the string will be zero during the descent because each ball accelerates at the same rate. Therefore the string will have no effect upon the motion of the balls.

104. **Picture the Problem**: The ball falls straight downward from rest at an initial height *h*.



Strategy: The problem requires that the time to fall the final 3/4 *h* from rest is 1.00 s. Find the velocity v_1 at ¾ *h* above the ground using equation 2-12. Use equation 2-11 along with that initial velocity and the time elapsed to determine *h*. Then the total time of fall can be found using equation 2-11 again, this time with an initial velocity of zero.

Solution: 1. (a) Find the velocity v_1 of the ball after falling a distance ¼ *h*: $v_1^2 = 0^2 + 2g\Delta x = 2g\left(\tfrac{1}{4}h\right) \;\Rightarrow\; v_1 = \sqrt{\tfrac{1}{2}gh}$

2. Now insert that velocity as the initial velocity for the remaining portion of the fall into equation 2-11:

$$\Delta x = v_1 t + \tfrac{1}{2}gt^2$$

$$\tfrac{3}{4}h = \left(\sqrt{\tfrac{1}{2}gh}\right)t + \tfrac{1}{2}gt^2$$

3. The time *t* is 1.00 s as given in the problem statement. Rearrange the above equation and square both sides to get a quadratic equation:

$$\tfrac{3}{4}h - \tfrac{1}{2}gt^2 = \left(\sqrt{\tfrac{1}{2}gh}\right)t$$

$$\tfrac{9}{16}h^2 - 2\left(\tfrac{1}{2}gt^2\right)\left(\tfrac{3}{4}h\right) + \tfrac{1}{4}g^2t^4 = \tfrac{1}{2}ght^2$$

$$\tfrac{9}{16}h^2 - \left(\tfrac{5}{4}gt^2\right)h + \tfrac{1}{4}g^2t^4 = 0$$

$$h^2 - \left(\tfrac{20}{9}gt^2\right)h + \tfrac{4}{9}g^2t^4 = 0$$

$$h^2 - \tfrac{20}{9}\left(9.81\text{ m/s}^2\right)\left(1.00\text{ s}\right)^2 h + \tfrac{4}{9}\left(9.81\text{ m/s}^2\right)^2\left(1.00\text{ s}\right)^4 = 0$$

$$h^2 - 21.8h + 42.8 = 0$$

4. Now apply the quadratic formula for *h*:

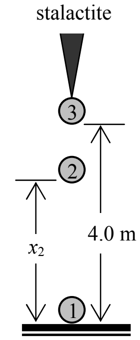
$$h = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{21.8 \pm \sqrt{(21.8)^2 - 4(1)(42.8)}}{2(1)} = 2.18,\ \boxed{19.6\text{ m}}$$

5. (b) Use equation 2-11 again to find the total time of fall:

$$t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2(19.6\text{ m})}{9.81\text{ m/s}^2}} = \boxed{2.00\text{ s}}$$

Insight: The first root in step 4 (2.18 m) is thrown out because the total fall time from that height would be less than 1.00 s, but the ball is supposed to be in the air for longer than 1.00 s. Notice it takes half the total flight time to fall the first quarter of the fall distance, and half to fall the final three quarters.

105. **Picture the Problem**: The three drops are positioned as depicted at right. They all fall straight downward from an initial height of 4.0 m.



Strategy: The time interval between drops is half the time it takes a drop to fall the entire 4.0 m. Use this fact to find the position and velocity of drop 2 when drop 1 hits the pool (equations 2-11 and 2-7). Then the time interval between drops can be used to find the number of drops per minute.

Solution: 1. (a) Find the time interval between drops, using equation 2-11 to find the fall time: $\Delta t = \frac{1}{2}t_{\text{fall}} = \frac{1}{2}\sqrt{\frac{2x}{g}} = \frac{1}{2}\sqrt{\frac{2(4.0\text{ m})}{9.81\text{ m/s}^2}} = \underline{\underline{0.45\text{ s}}}$

2. Now use equation 2-11 to find the position of drop 2: $x_2 = 0 + \frac{1}{2}g(\Delta t)^2 = \frac{1}{2}(9.81\text{ m/s}^2)(0.45\text{ s})^2$

$x_2 = 0.99$ m below the stalactite or

$4.0 - 0.99\text{ m} = \boxed{3.0\text{ m}}$ above the pool

4. Use equation 2-7 to find the speed of drop 2: $v = 0 + g\Delta t = (9.81\text{ m/s}^2)(0.45\text{ s}) = \boxed{4.4\text{ m/s}}$

5. (b) Find the drop rate from the time interval: $D = \frac{1\text{ drop}}{0.45\text{ s}} \times \frac{60\text{ s}}{1\text{ min}} = \boxed{130\text{ drops/min}}$

Insight: Note that it takes half the drop time to fall the first quarter of the drop distance, and half the time to fall the final three quarters of the distance.

106. **Picture the Problem**: The glove falls straight downward from rest, accelerates to a maximum speed under the influence of gravity, then decelerates due to its interaction with the snow before coming to rest at a depth *d* below the surface of the snow.

Strategy: We can find the maximum speed of the glove from its initial height and the acceleration of gravity by using equation 2-12. The same equation can be applied again, this time with a zero final speed instead of zero initial speed, to find the acceleration caused by the snow. Let downward be the positive direction.

Solution: 1. (a) Solve equation 2-12 for *v*, assuming $v_0 = 0$: $v = \sqrt{0^2 + 2gh} = \boxed{\sqrt{2gh}}$

2. (b) Use equation 2-12 to find the acceleration caused by the snow: $0^2 = v_0^2 + 2ad \Rightarrow -2ad = \left(\sqrt{2gh}\right)^2 \Rightarrow a = \boxed{-\frac{h}{d}g}$

3. The negative sign on the acceleration means the glove is accelerated $\boxed{\text{upward}}$ during its interaction with the snow.

Insight: In Chapter 5 we will analyze the motion of objects like this glove in terms of force vectors. This motion can also be explained in terms of energy using the tools introduced in Chapters 7 and 8.

$\boxed{107.}$ **Picture the Problem**: The ball rises straight upward, passes the power line, momentarily comes to rest, and falls back to Earth again, passing the power line a second time on its way down.

Strategy: The ball will reach the peak of its flight at a time directly between the times it passes the power line. The time to reach the peak of flight can be used to find the initial velocity using equation 2-7, and the initial velocity can then be used to find the height of the power lines using equation 2-11.

Solution: 1. Find the time at which the ball reaches its maximum altitude: $t_{\text{peak}} = t_{\text{line up}} + \frac{1}{2}(t_{\text{line down}} - t_{\text{line up}}) = 0.75\text{ s} + \frac{1}{2}(1.5 - 0.75\text{ s})$

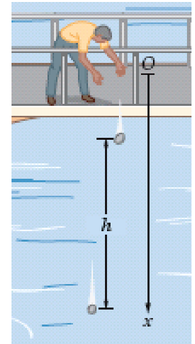
$t_{\text{peak}} = \underline{\underline{1.1\text{ s}}}$

2. Find the initial velocity using equation 2-7: $0 = v_0 - gt_{\text{peak}} \Rightarrow v_0 = (9.81\text{ m/s}^2)(1.1\text{ s}) = \boxed{11\text{ m/s}}$

3. Find the height of the power line using equation 2-11: $x = 0 + v_0 t_{\text{line up}} - \frac{1}{2}gt_{\text{line up}}^2$

$x = (11\text{ m/s})(0.75\text{ s}) - \frac{1}{2}(9.81\text{ m/s}^2)(0.75\text{ s})^2 = \boxed{5.5\text{ m}}$

Insight: As is often the case, there are several other ways to solve this problem. Try setting the heights at 0.75 s and 1.5 s equal to each other and solving for v_0. Can you think of yet another way?



108. **Picture the Problem**: The two rocks fall straight downward along a similar path except at different times.

Strategy: First find the time elapsed between the release of the two rocks by finding the time required for the first rock to fall a distance *h*, using the equation of motion for position as a function of time and acceleration (equation 2-11). The positions as a function of time for each rock can then be compared to find a separation distance as a function of time.

Solution: 1. (a) Find the time required for rock A to fall a distance *h*:

$$t_h = \sqrt{\frac{2\Delta x}{g}} = \sqrt{\frac{2h}{g}}$$

2. Let *t* represent the time elapsed from the instant rock B is dropped. The position of rock A (equation 2-11) is thus:

$$x_A = 0 + \tfrac{1}{2}g\left(t + t_h\right)^2 = \tfrac{1}{2}gt^2 + g\,t\,t_h + \tfrac{1}{2}gt_h^2$$

3. The position of rock B (equation 2-11) is:

$$x_B = 0 + \tfrac{1}{2}gt^2 = \tfrac{1}{2}gt^2$$

4. Find the separation between the rocks:

$$S = x_A - x_B = \left(\tfrac{1}{2}gt^2 + g\,t\,t_h + \tfrac{1}{2}gt_h^2\right) - \tfrac{1}{2}gt^2$$

$$S = g\,t\,t_h + \tfrac{1}{2}gt_h^2 = gt\sqrt{\frac{2h}{g}} + \tfrac{1}{2}g\frac{2h}{g}$$

$$S = t\sqrt{2gh} + h = \boxed{h + \left(\sqrt{2gh}\right)t}$$

Insight: The separation between the two rocks increases linearly with time *t*.

109. **Picture the Problem**: The arrow travels horizontally at 20.0 m/s and impacts the Styrofoam. It continues to travel in the positive direction, but more slowly due to its collision with the Styrofoam. The arrow and the Styrofoam then move together at the same speed in the positive direction.

Strategy: Find the final velocity of the block in terms of the collision time Δt by using equation 2-7. Since this is also the final velocity of the arrow, the collision time Δt can be determined by using the known accelerations and the initial velocity of the arrow. The final velocity and penetration depth traveled can then be found from applying equations 2-7 and 2-11.

Solution: 1. (a) Set the final velocities of the arrow and the block equal to each other and apply equation 2-7 to find Δt:

$$v_a = v_b$$

$$v_{a,0} + a_a\Delta t = 0 + a_b\Delta t$$

$$\Delta t = \frac{-v_{a,0}}{a_a - a_b} = \frac{v_{a,0}}{a_b - a_a} = \frac{20.0 \text{ m/s}}{450 - (-1550) \text{ m/s}^2}$$

$$\Delta t = 0.0100 \text{ s} = \boxed{10.0 \text{ ms}}$$

2. (b) Now apply equation 2-7 to find v_b:

$$v_b = a_b\Delta t = \left(450 \text{ m/s}^2\right)\left(0.0100 \text{ s}\right) = \boxed{4.50 \text{ m/s}}$$

3. (c) The penetration distance is a bit tricky because both the arrow and the block move while they are colliding. The penetration distance is the difference between how far the arrow moves and how far the block moves during the collision time interval.

$$d = \Delta x_{\text{arrow}} - \Delta x_{\text{block}}$$

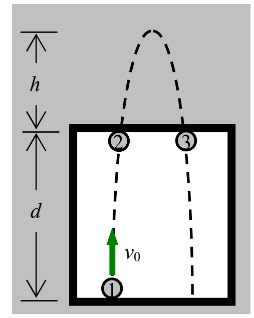
$$= \left(v_{a,0}\Delta t + \tfrac{1}{2}a_a\Delta t^2\right) - \left(\tfrac{1}{2}a_b\Delta t^2\right)$$

$$= \begin{bmatrix} \left(20.0 \text{ m/s}\right)\left(0.0100 \text{ s}\right) + \tfrac{1}{2}\left(-1550 \text{ m/s}^2\right)\left(0.0100 \text{ s}\right)^2 \\ -\tfrac{1}{2}\left(450 \text{ m/s}^2\right)\left(0.0100 \text{ s}\right)^2 \end{bmatrix}$$

$$d = 0.1225 \text{ m} - 0.0225 \text{ m} = 0.100 \text{ m} = \boxed{10.0 \text{ cm}}$$

Insight: We could also analyze this collision using the concept of momentum conservation (Chapter 9) and work and energy (Chapter 7).

110. **Picture the Problem**: The ball appears at the bottom edge of the window, rising straight upward with initial speed v_0. It travels upward, disappearing beyond the top edge of the window, comes to rest momentarily, and then falls straight downward, reappearing some time later at the top edge of the window. In the drawing at right the motion of the ball is offset horizontally for clarity.



Strategy: Let $t = 0$ correspond to the instant the ball first appears at the bottom edge of the window with speed v_0. Write the equation of position as a function of time and acceleration (equation 2-11) for when the ball is at the top edge (position 2) in order to find v_0. Use v_0 to find the time to go from position 1 to the peak of the flight (equation 2-7). Subtract 0.25 s from that time to find the time to go from position 2 to the peak of the flight. The time elapsed between positions 2 and 3 is twice the time to go from position 2 to the peak of the flight. The time from position 2 to the peak can be used to find h from equation 2-11.

Solution: 1. (a) Write equation 2-11 for positions 1 and 2, and solve for v_0:

$$d = v_0 t_2 - \tfrac{1}{2} g t_2^2$$

$$v_0 = \frac{d + \frac{1}{2} g t_2^2}{t_2} = \frac{1.05\text{ m} + \frac{1}{2}\left(9.81\text{ m/s}^2\right)\left(0.25\text{ s}\right)^2}{0.25\text{ s}} = \underline{\underline{5.4\text{ m/s}}}$$

2. Find the time to go from position 1 to the peak of the flight using equation 2-7:

$$\Delta t_{1,p} = \frac{0 - v_0}{-g} = \frac{5.4\text{ m/s}}{9.81\text{ m/s}^2} = \underline{\underline{0.55\text{ s}}}$$

3. Subtract 0.25 s to find the time to go from position 2 to the peak of the flight:

$$\Delta t_{2,p} = \Delta t_{1,p} - \Delta t_{1,2} = 0.55 - 0.25\text{ s} = \underline{\underline{0.30\text{ s}}}$$

4. The time to reappear is twice this time:

$$\Delta t_{2,3} = 2\Delta t_{2,p} = 2\left(0.30\text{ s}\right) = \boxed{0.60\text{ s}}$$

5. (b) The height h can be found from $\Delta t_{2,p}$ and equation 2-11, by considering the ball dropping from rest at the peak to position 3:

$$0 = h + 0 - \tfrac{1}{2} g \Delta t_{2,p}^2$$

$$h = \tfrac{1}{2}\left(9.81\text{ m/s}^2\right)\left(0.30\text{ s}\right)^2 = \boxed{0.44\text{ m}}$$

Insight: As usual there are other ways to solve this problem. Try finding the velocity at position 2 and use it together with the acceleration of gravity and the average velocity from position 2 to the peak to find $\Delta t_{2,3}$ and h.

111. **Picture the Problem**: This exercise considers a generic object traveling in a straight line with constant acceleration.

Strategy: Manipulate the suggested equations with algebra to derive the desired results.

Solution: 1. (a) Begin with equation 2-12:

$$v^2 = v_0^2 + 2a\left(x - x_0\right)$$

2. Set $x = 0$ and solve for v:

$$v = \boxed{\pm\sqrt{v_0^2 - 2ax_0}}$$

3. (b) First write equation 2-7 and substitute for v. Then solve for t:

$$v = v_0 + at$$

$$\pm\sqrt{v_0^2 - 2ax_0} = v_0 + at$$

$$\boxed{\frac{-v_0 \pm \sqrt{v_0^2 - 2ax_0}}{a}} = t$$

4. (c) Write equation 2-11 as given and apply the quadratic formula to solve for t:

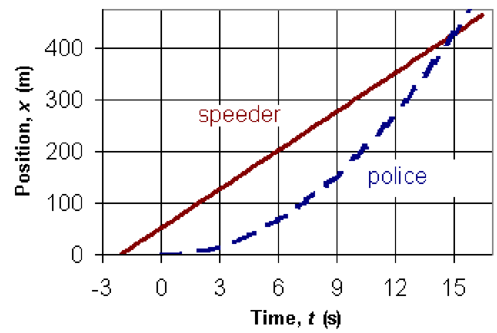
$$0 = x_0 + v_0 t + \tfrac{1}{2} a t^2$$

$$t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{-v_0 \pm \sqrt{v_0^2 - 4\left(\frac{1}{2}a\right)\left(x_0\right)}}{2\left(\frac{1}{2}a\right)}$$

$$t = \boxed{\frac{-v_0 \pm \sqrt{v_0^2 - 2ax_0}}{a}}$$

Insight: When an object undergoes uniform acceleration its position is a quadratic function of time. The quadratic formula is therefore an appropriate one to describe the motion of the object.

112. **Picture the Problem**: The trajectories of the speeder and police car are shown at right. The speeder moves at a constant velocity while the police car has a constant acceleration, except the police car is delayed in time from when the speeder passes it at $x = 0$.



Strategy: The equation of motion for position as a function of time and velocity (equation 2-10) can be used to describe the speeder, while the equation for position as a function of time and acceleration (equation 2-11) can be used to describe the police car's motion. Set these two equations equal to each other and solve the resulting equation to find the speeder's head-start x_{shs}.

Solution: 1. Write equation 2-10 for the speeder, with $t = 0$ corresponding to the instant it passes the police car: $x_{\text{s}} = x_{\text{shs}} + v_{\text{s}}\, t$

2. Write equation 2-11 for the police car: $x_{\text{p}} = 0 + 0 + \frac{1}{2} a_{\text{p}} t^2$

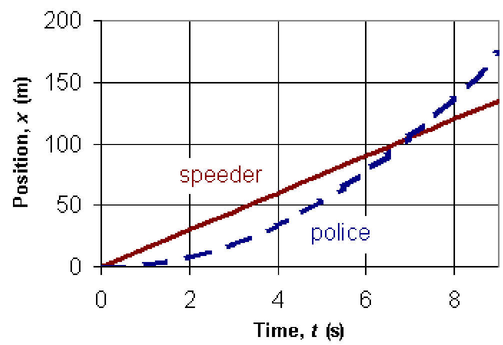
3. Set $x_{\text{p}} = x_{\text{s}}$ and solve for x_{shs}: $\frac{1}{2} a_{\text{p}} t^2 = x_{\text{shs}} + v_{\text{s}}\, t$

$$x_{\text{shs}} = \tfrac{1}{2} a_{\text{p}} t^2 - v_{\text{s}}\, t = \tfrac{1}{2}\left(3.8\text{ m/s}^2\right)\left(15\text{ s}\right)^2 - \left(25\text{ m/s}\right)\left(15\text{ s}\right)$$

$$x_{\text{shs}} = \boxed{53\text{ m}}$$

Insight: This head start corresponds to about 2.10 seconds (verify for yourself, and/or examine the plot) so the police officer has to be ready to start the chase very soon after the speeder passes by!

113. **Picture the Problem**: The trajectories of the speeder and police car are shown at right. The speeder moves at a constant velocity while the police car has a constant acceleration.



Strategy: The equation of motion for position as a function of time and velocity (equation 2-10) can be used to describe the speeder, while the equation for position as a function of time and acceleration (equation 2-11) can be used to describe the police car's motion. Set these two equations equal to each other and solve the resulting equation for the acceleration of the police car.

Solution: 1. Write equation 2-10 for the speeder, with $t = 0$ corresponding to the instant it passes the police car: $x_{\text{s}} = 0 + v_{\text{s}}\, t$

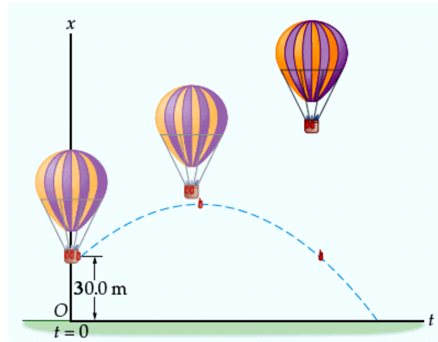
2. Write equation 2-11 for the police car: $x_{\text{p}} = 0 + 0 + \frac{1}{2} a_{\text{p}} t^2$

3. Set $x_{\text{p}} = x_{\text{s}}$ and solve for a_{p}: $\frac{1}{2} a_{\text{p}} t^2 = v_{\text{s}}\, t$

$$a_{\text{p}} = \frac{2v_{\text{s}}}{t} = \frac{2\left(15\text{ m/s}\right)}{7.0\text{ s}} = \boxed{4.3\text{ m/s}^2}$$

Insight: A faster acceleration of the police car would allow it to catch the speeder in less than 7.0 s.

114. **Picture the Problem**: The trajectory of the bag of sand is shown at right. After release from the balloon it rises straight up and comes momentarily to rest before accelerating straight downward and impacting the ground.



Strategy: Since the initial velocity, acceleration, and altitude are known, we need only use equation 2-12 to find the final velocity.

Solution: 1. (a) Since the upward speed of the sandbag is the same, it will gain the same additional 2 m in altitude as it did in the original Example 2-12. Therefore the maximum height will be $\boxed{\text{equal to 32 m}}$.

2. (b) Apply equation 2-12 to find the final velocity:

$$v^2 = v_0^2 + 2a\Delta x$$

$$v = \sqrt{(6.5\text{ m/s})^2 + 2(-9.81\text{ m/s}^2)(-30.0\text{ m})} = \boxed{25\text{ m/s}}$$

Insight: Another way to find the final velocity just before impact is to allow the sandbag to fall from rest a distance of 32 m. Try it!

115. **Picture the Problem**: The bag of sand has an initial downward velocity when it breaks free from the balloon, and is accelerated by gravity until it hits the ground.

Strategy: Since the initial velocity, acceleration, and altitude are known, we need only use equation 2-12 to find the final velocity. The time can then be found from the average velocity and the distance.

Solution: 1. (a) Apply equation 2-12 to find the final *v*:

$$v^2 = v_0^2 + 2a\Delta x$$

$$v = \sqrt{(4.2\text{ m/s})^2 + 2(-9.81\text{ m/s}^2)(-35.0\text{ m})} = \underline{\underline{26.5\text{ m/s}}}$$

2. Use equation 2-10 to find the time:

$$t = \frac{x - x_0}{\frac{1}{2}(v_0 + v)} = \frac{0 - 35\text{ m}}{\frac{1}{2}(-4.5 - 26.5\text{ m/s})} = \boxed{2.3\text{ s}}$$

3. (b) Apply equation 2-12 again to find *v* at $x = 15$ m:

$$v^2 = v_0^2 + 2a\Delta x$$

$$v = \sqrt{(4.2\text{ m/s})^2 + 2(-9.81\text{ m/s}^2)(15 - 35\text{ m})} = \boxed{20\text{ m/s}}$$

Insight: Another way to find the descent time of the bag of sand is to solve equation 2-11 using the quadratic formula. Try it!