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Chapter 2
Linear Motion

Conceptual Questions

2.1 An object will slow down when its acceleration vector points in the opposite direction to its velocity vector. Recall that acceleration is the change in velocity over the change in time.

2.2 A ball is thrown straight up, stops in midair, and then falls back toward your hand. The velocity of the ball when it leaves your hand is large and points upward. The ball's speed decreases until it reaches its highest point. At this spot, its velocity is zero. The velocity of the ball then increases and points downward on its trip back to your hand. Since the ball is undergoing free fall, its acceleration is constant—it has a magnitude of g = 9.80 m/s^2 and points downward.

2.3 Average velocity is a vector quantity—the *displacement* over the time interval. Average speed is a scalar quantity—the *distance* over the time interval.

2.4 The magnitude of the displacement and the distance traveled will be the same when an object travels in one direction in a straight line or when the object is stationary. They will be different in all other cases.

2.5 Speed and velocity have the same SI units (m/s). Speed is the magnitude of the velocity vector. If the velocity points completely in the positive direction, then the two can be interchanged. If the velocity is not fixed in direction, then the correctly signed component of the velocity will need to be used to avoid confusion.

2.6 We need to convert these into the same unit system (say, m/s) in order to determine which is largest.

$$1\frac{\text{km}}{\text{h}} \times \frac{1\ \text{h}}{3600\ \text{s}} \times \frac{1000\ \text{m}}{1\ \text{km}} = 0.3\frac{\text{m}}{\text{s}}$$

$$1\frac{\text{mi}}{\text{h}} \times \frac{1\ \text{h}}{3600\ \text{s}} \times \frac{1.61\ \text{km}}{1\ \text{mi}} \times \frac{1000\ \text{m}}{1\ \text{km}} = 0.4\frac{\text{m}}{\text{s}}$$

The largest speed—1 m/s—will give the largest displacement in a fixed time.

2.7 One advantage is that people in countries that use the metric system will have a chance of understanding the distance part of the unit. The disadvantages are that no country lists speed limits in m/s, so it is hard to figure out how long it takes to get to highway speeds. (For comparison, 65.0 mph = 105 km/h = 29.1 m/s.) Further, the raw numbers will be smaller than if another unit system were used, so careless readers not comparing units will get the impression that the car accelerates slowly. It would be better to use km/h/s, as speed limits around the world are generally expressed in km/h. The best plan would be to tailor the units to the individual market.

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2.8 The acceleration due to gravity is constant in both magnitude (g) and direction (down). When a ball is thrown straight up, its acceleration vector points in the opposite direction to its velocity vector, which means it slows down and eventually stops. Assuming the braking acceleration of the car is constant in magnitude (g) and points opposite to the car's velocity vector, the car, too, will slow down and eventually stop. If the ball and the car start at the same initial speed and have the same acceleration, the ball and the car will take the same amount of time to come to rest.

2.9 The average velocity of a moving object will be the same as the instantaneous velocity if the object is moving at a constant velocity (both magnitude and direction). Also, if the average velocity is taken over a period of constant acceleration, the instantaneous velocity will match it for one moment in the middle of that period.

2.10 No, there is no way to tell whether the video is being played in reverse. An object being thrown up in the air will undergo the same acceleration, time of flight, and so on as an object falling from its maximum height.

2.11 The acceleration of a ball thrown straight up in the air is constant because it is under the influence of Earth's gravity.

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2.12 It's always a good idea to include the units of every quantity throughout your calculation. Eventually, once they become more comfortable, most people will convert all of their values into SI units and stop including them in the intermediate steps of the calculation. Using SI units in all calculations minimizes calculation errors and ensures the answer will be in SI units as well.

2.13 Assuming the initial speed of the ball is the same in both cases, the velocity of the second ball will be the same as the velocity of the first ball. The upward trajectory of the first ball involves the ball going up and reversing itself back toward its initial location. At that point, the trajectories of the two balls are identical as the balls hit the ground.

2.14 Graphs are reported as "y-axis versus x-axis," so the SI units for each slope will be the SI units of the y-axis divided by the SI units of the x-axis:

A) Displacement versus time: m/s.

B) Velocity versus time: m/s^2.

C) Distance versus time: m/s.

2.15 There is no reason why "up" cannot be labeled as "negative" or "left" as "positive." Usually, *up* and *right* are chosen as positive since these correspond to positive x and y in a standard Cartesian coordinate system.

Multiple-Choice Questions

2.16 **D.**

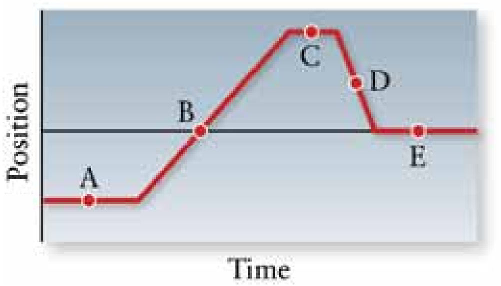

Figure 2-1 Problem 16

The slope of a position versus time plot gives information regarding the speed of the object. Point D has the largest slope, which means the object is moving the fastest there.

2.17 **B.** The slope of a position versus time plot gives information regarding the speed of the object. Point B has a slope of zero, which means the object is momentarily stationary. When determining if an object is "faster" or "slower" than another object, we only need to consider the magnitude of the slope, *not* its sign.

2.18 **A** (increasing). If the car's velocity and acceleration vectors point in the same direction, the car will speed up.

2.19 **E** (decreasing but then increasing). Initially the velocity and acceleration of the car point in opposite directions, which means the car will slow down. Eventually the car will come to a stop, turn around, and start to move faster and faster in this direction. Therefore, the speed decreases and then increases. Remember that the speed is the magnitude of the velocity vector.

2.20 **C** (the two balls hit the ground at the same time). Both balls are undergoing free fall, which means they both accelerate at the same rate equal to the acceleration due to gravity. The mass of the object does not factor into this calculation.

2.21 **C** ($v = 0$, but $a = 9.80\ \text{m/s}^2$). Right before the ball reaches its highest point, it is moving upward. Right after, it is moving downward. Because the ball changes its direction, its velocity must equal zero at that point. The ball is always under the influence of Earth's gravity, so its acceleration is equal to $9.80\ \text{m/s}^2$.

Estimation/Numerical Analysis

2.22 A step stool is about 0.3 m tall. A painter falling from rest would hit the ground at a speed of

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$$

$$v_y = \sqrt{(v_{0y})^2 + 2a_y(\Delta y)} = \sqrt{0^2 + 2\left(-9.80\frac{\text{m}}{\text{s}^2}\right)(-0.3\ \text{m})} = 2.42\frac{\text{m}}{\text{s}}$$

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If he lands with his knees locked, he comes to rest much faster than if he were to bend his knees while landing. Let's say he comes to rest in 0.1 s when his knees are locked but 1 s when his knees are bent. The magnitudes of the acceleration in both cases are

$$a_{\text{locked},y} = \frac{\Delta v_y}{\Delta t} = \frac{2.42\frac{\text{m}}{\text{s}}}{0.1\ \text{s}} = \boxed{20\frac{\text{m}}{\text{s}^2}}$$

$$a_{\text{bent},y} = \frac{\Delta v_y}{\Delta t} = \frac{2.42\frac{\text{m}}{\text{s}}}{1\ \text{s}} = \boxed{2\frac{\text{m}}{\text{s}^2}}$$

2.23 The average car takes about 10–15 s to reach highway speeds. Cars can brake faster than this, say, 5–10 s.

2.24 A marathon is just over 26 miles in length, and a runner completes it in 5 hours. The average speed of the runner is equal to the total distance she covered divided by the time it took to do so:

$$v_{\text{average},x} = \frac{26\ \text{mi}}{5\ \text{h}} = \boxed{5\ \text{mph}} \times \frac{1\ \text{h}}{3600\ \text{s}} \times \frac{1600\ \text{m}}{1\ \text{mi}} = \boxed{2\frac{\text{m}}{\text{s}}}$$

2.25 The fastest time for the 100-m race for men was set by Usain Bolt (9.58 s) and for women by Florence Griffith-Joyner (10.49 s). These times correspond to top speeds of 10.4 m/s and 9.533 m/s, respectively. A runner who falls in the mud will take much longer to come to rest than one who falls on a running track. Let's assume it takes 2.0 s to come to rest in the mud but only 0.50 s on a track. The magnitudes of the acceleration for each case are

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$$a_{\text{Bolt,mud}} = \frac{\Delta v_x}{\Delta t} = \frac{10.4\frac{\text{m}}{\text{s}}}{2.0\ \text{s}} = \boxed{5.2\frac{\text{m}}{\text{s}^2}}$$

$$a_{\text{FloJo,mud}} = \frac{\Delta v_x}{\Delta t} = \frac{9.533\frac{\text{m}}{\text{s}}}{2.0\ \text{s}} = \boxed{4.8\frac{\text{m}}{\text{s}^2}}$$

$$a_{\text{Bolt,track}} = \frac{\Delta v_x}{\Delta t} = \frac{10.4\frac{\text{m}}{\text{s}}}{0.50\ \text{s}} = \boxed{21\frac{\text{m}}{\text{s}^2}}$$

$$a_{\text{Flojo,track}} = \frac{\Delta v_x}{\Delta t} = \frac{9.533\frac{\text{m}}{\text{s}}}{0.50\ \text{s}} = \boxed{19\frac{\text{m}}{\text{s}^2}}$$

2.26 A 1000-km airline trip takes 3 h in total. Of those 3 h, the plane is airborne for 2.5 h. The average speed of the airplane is

$$v_{\text{average},x} = \frac{1000\ \text{km}}{2.5\ \text{h}} = \boxed{400\frac{\text{km}}{\text{h}}}$$

2.27 We first need to determine the speed with which the cat leaves the floor. Say the cat just lands on a 1-m-tall countertop. Its initial speed was

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$$

$$(0)^2 - v_{0y}^2 = 2(-g)(\Delta y)$$

$$v_{0y} = \sqrt{2\left(9.80\frac{\text{m}}{\text{s}^2}\right)(1\ \text{m})} = 4.5\frac{\text{m}}{\text{s}}$$

It takes a cat about 0.5 s to accelerate from rest to just before it leaves the ground, which makes its acceleration

$$a_y = \frac{\Delta v_y}{\Delta t} = \frac{4.5\frac{\text{m}}{\text{s}} - 0}{0.5\ \text{s}} = \boxed{9\frac{\text{m}}{\text{s}^2}}$$

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2.28 Earth is 1.5×10^8 km from the Sun. Assuming Earth's orbit is circular, the total distance Earth travels in one rotation is $2\pi(1.5 \times 10^8\ \text{km}) \approx 1 \times 10^{10}$ km. Earth completes one rotation around the Sun in 1 year $\left(1\ \text{y} \times \frac{365.25\ \text{d}}{1\ \text{y}} \times \frac{24\ \text{h}}{1\ \text{d}} = 8766\ \text{h}\right)$.

We can assume that the speed of Earth is constant, which means the instantaneous speed is equal to the average speed. The average speed of Earth is

$$v_{\text{average},x} = \frac{1 \times 10^{10}\ \text{km}}{8766\ \text{h}} = \boxed{1.1 \times 10^6\frac{\text{km}}{\text{h}}}.$$

2.29 On the open sea, a cruise ship travels at a speed of approximately 10 m/s. We need to estimate the time it takes the ship to reach its cruising speed from rest. We should expect that it takes more than a few minutes but less than a full hour; let's estimate the time to be 0.5 h. The magnitude of the average acceleration of the cruise ship is the change in the ship's speed divided by the time interval over which that change occurs:

$$a_{\text{average},x} = \frac{\Delta v_x}{\Delta t} = \frac{10\frac{\text{m}}{\text{s}}}{0.5\ \text{h}} \times \frac{1\ \text{h}}{3600\ \text{s}} = \boxed{0.006\frac{\text{m}}{\text{s}^2}}$$

2.30 Part a) Displacement is a vector quantity. Chances are a swimmer will swim across the length of the pool and then back to the starting point. If so, the displacement is equal to zero. At best, the swimmer's displacement will be the length of the pool.

Part b) Distance, on the other hand, is a scalar quantity. An Olympic-size swimming pool is 50 m long. A swimmer who completes 100 laps (a single lap is from one side of the pool to the other) travels a distance of 5 km.

2.31 Part a) A pitcher can throw a fastball around 90 mph, which is around 40 m/s. The pitcher's windup takes a few seconds, say, 3 s. Therefore, the acceleration of the baseball is $a_x = \frac{\Delta v_x}{\Delta t} = \frac{40\frac{\text{m}}{\text{s}} - 0}{3\ \text{s}} \approx \boxed{10\frac{\text{m}}{\text{s}^2}}$.

Part b) The speed of a soccer ball is much less than a fastball, but it reaches its top speed in a much shorter time. We'll say a soccer ball has a speed of 10 m/s and attains that speed from rest in 0.1 s: $a_x = \frac{\Delta v_x}{\Delta t} = \frac{10\frac{\text{m}}{\text{s}} - 0}{0.1\ \text{s}} = \boxed{100\frac{\text{m}}{\text{s}^2}}$.

2.32

SET UP

A list of position data as a function of time is given. We need to make a plot with position on the y-axis and time on the x-axis. The average speed of the horse over the given intervals is equal to the distance the horse traveled divided by the time interval.

SOLVE

Plot of position versus time:

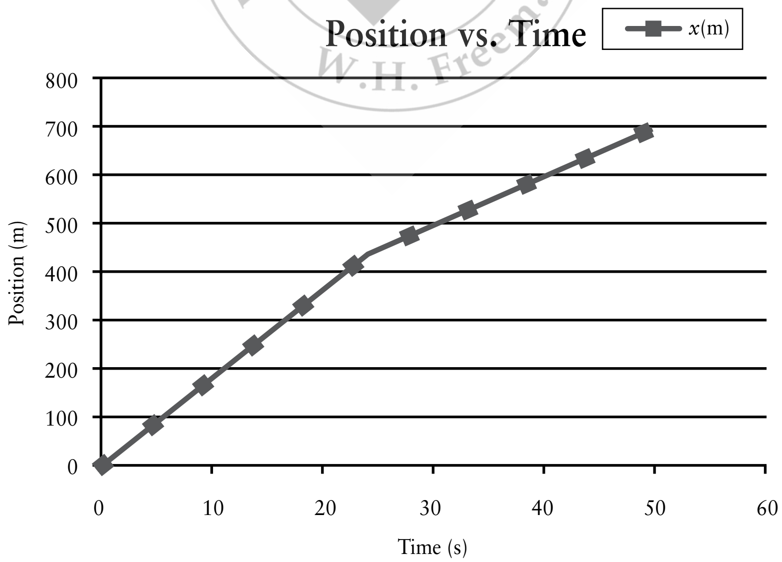

Figure 2-2 Problem 32

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Part a)

$$v_{\text{average},x} = \frac{x_{10\text{ s}} - x_{0\text{ s}}}{t_{10\text{ s}} - t_{0\text{ s}}} = \frac{180\text{ m}}{10\text{ s}} = \boxed{18\frac{\text{m}}{\text{s}}}$$

Part b)

$$v_{\text{average},x} = \frac{x_{30\text{ s}} - x_{10\text{ s}}}{t_{30\text{ s}} - t_{10\text{ s}}} = \frac{(500\text{ m}) - (180\text{ m})}{(30\text{ s}) - (10\text{ s})} = \frac{320\text{ m}}{20\text{ s}} = \boxed{16\frac{\text{m}}{\text{s}}}$$

Part c)

$$v_{\text{average},x} = \frac{x_{50\text{ s}} - x_{0\text{ s}}}{t_{50\text{ s}} - t_{0\text{ s}}} = \frac{700\text{ m}}{50\text{ s}} = \boxed{14\frac{\text{m}}{\text{s}}}$$

REFLECT

Remember that graphs are described as "*y*-axis" versus "*x*-axis." The speed of the horse is given by the slope of the position versus time plot. The horse's speed is constant over two intervals: 0–25 s and 25–50 s. We can easily see from the plot that the horse was slower in the second half compared to the first half.

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2.33 We can make a plot of position versus time and determine the equations for each region by manually calculating the slope and *y* intercepts or by using a computer program to fit the data in each time interval.

t(s)	*x*(m)
0	−12
1	−6
2	0
3	6
4	12
5	15
6	15
7	15
8	15
9	18
10	24
11	33
12	45
13	60
14	65
15	70
16	75
17	80
18	85
19	90
20	95
21	100
22	90
23	80
24	70
25	70

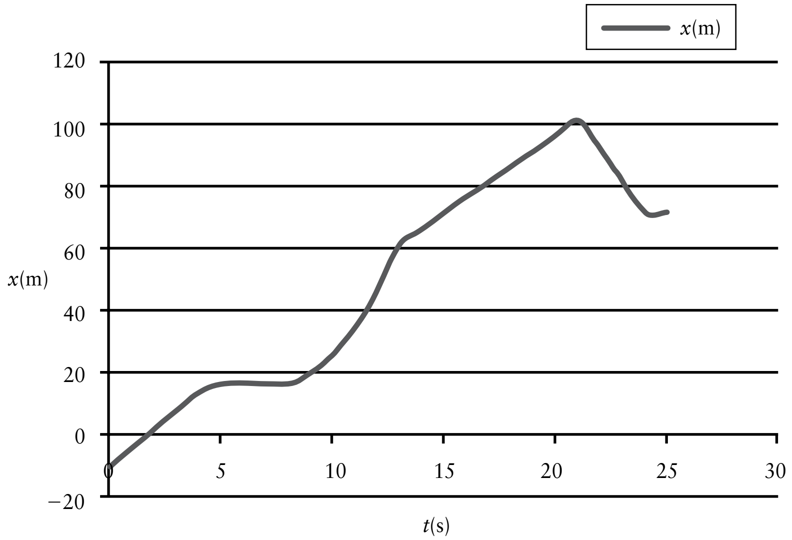

Figure 2-3 Problem 33

Between $t = 0$ s and $t = 4.5$ s:

$$x(t) = \frac{12\ \text{m} - (-12\ \text{m})}{4\ \text{s}}(t - (2\ \text{s})) = \left(6\frac{\text{m}}{\text{s}}\right)(t - (2\ \text{s}))$$

Between $t = 4.5$ s and $t = 8$ s: $x(t) = 15$ m.

Between $t = 8$ s and $t = 13$ s:

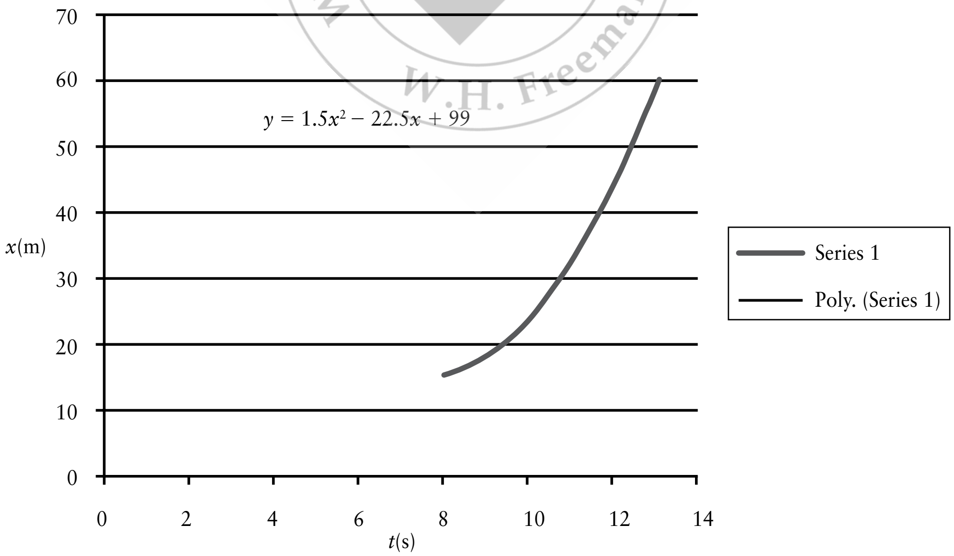

Figure 2-4 Problem 33

We can fit the data to a parabola in order to get position versus time in this region:

$$x(t) = \left(1.5\frac{\text{m}}{\text{s}^2}\right)t^2 - \left(22.5\frac{\text{m}}{\text{s}}\right)t + (99\ \text{m}) = \left(1.5\frac{\text{m}}{\text{s}^2}\right)(t - 7.5\ \text{s})^2 + (14.6\ \text{m})$$

Between $t = 13$ s and $t = 21$ s:

$$x(t) = \frac{100\text{ m} - 60\text{ m}}{8\text{ s}}(t - 13\text{ s}) + (60\text{ m}) = \left(5\frac{\text{m}}{\text{s}}\right)(t - 13\text{ s}) + (60\text{ m})$$

Between $t = 21$ s and $t = 24$ s:

$$x(t) = \frac{70\text{ m} - 100\text{ m}}{3\text{ s}}(t - 21\text{ s}) + (100\text{ m}) = \left(-10\frac{\text{m}}{\text{s}}\right)(t - 21\text{ s}) + (100\text{ m})$$

Between $t = 24$ s and $t = 25$ s: $x(t) = 70$ m.

2.34

SET UP

A coconut is dropped from a tall tree. We can assume that the location of the coconut on the tree is $y = 0$ and that the coconut starts from rest. Once the coconut is released, it undergoes free fall and has a constant acceleration $a = -g = -9.80\text{ m/s}^2$. We can calculate the position of the coconut as a function of time from $y(t) = y_0 + v_{0y}t + \frac{1}{2}a_y t^2 = 0 + 0 + \frac{1}{2}(-g)t^2$ and its velocity from $v_y(t) = v_{0y} + a_y t = 0 + (-g)t$.

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SOLVE

t(s)	y(m)	v_y(m/s)	a_y(m/s^2)
0	0	0	0
1	−4.90	−9.80	−9.80
2	−19.6	−19.6	−9.80
3	−44.1	−29.4	−9.80
4	−78.4	−39.2	−9.80
5	−122	−49.0	−9.80
10	−490	−98.0	−9.80

REFLECT

Because the initial location of the coconut is chosen to be $y = 0$, the position of the coconut will always be negative as it falls toward the ground. The velocity is always negative because the coconut is moving downward.

Problems

2.35

SET UP

A list of speeds is given in various units. We need to convert between common units of speed. Some of the units (for example, m/s, km/h, mi/h) are more common units of speed than others (for example, mi/min). The conversions 1 mi = 1.61 km and 1 mi = 5280 ft will be useful.

SOLVE

A) $$30.0\frac{\text{m}}{\text{s}} \times \frac{3600\text{ s}}{1\text{ h}} \times \frac{1\text{ km}}{1000\text{ m}} = \boxed{108\frac{\text{km}}{\text{h}}}$$

B) $$14.0\frac{\text{mi}}{\text{h}} \times \frac{1.61\text{ km}}{1\text{ mi}} = \boxed{22.5\frac{\text{km}}{\text{h}}}$$

C) $$90.0\frac{\text{km}}{\text{s}} \times \frac{3600\text{ s}}{1\text{ h}} \times \frac{1\text{ mi}}{1.61\text{ km}} = \boxed{2.01 \times 10^5\frac{\text{mi}}{\text{h}}}$$

D) $$88.0\frac{\text{ft}}{\text{s}} \times \frac{1\text{ mi}}{5280\text{ ft}} \times \frac{3600\text{ s}}{1\text{ h}} = \boxed{60.0\frac{\text{mi}}{\text{h}}}$$

E) $$100\frac{\text{mi}}{\text{h}} \times \frac{1\text{ h}}{3600\text{ s}} \times \frac{1.61\text{ km}}{1\text{ mi}} \times \frac{1000\text{ m}}{1\text{ km}} = \boxed{40\frac{\text{m}}{\text{s}}}$$ (to one significant figure)

REFLECT

A good conversion to know: To convert from m/s into mi/h multiply by 2.2. This will help build intuition when working with speeds in SI units.

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2.36

SET UP

A bowling ball starts at a position of $x_1 = 3.50$ cm and ends at $x_2 = -4.70$ cm. It takes the ball 2.50 s for it to move from x_1 to x_2. The average velocity of the ball is equal to the displacement of the ball divided by the time interval. The displacement is the (final position) – (initial position). The ball only moves in one dimension, so we can use a positive or negative sign to denote the direction of the velocity.

SOLVE

$$v_{\text{average},x} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{(-4.70\text{ cm}) - (3.50\text{ cm})}{(5.50\text{ s}) - (3.00\text{ s})} = \frac{-8.20\text{ cm}}{2.50\text{ s}} = \boxed{-3.28\frac{\text{cm}}{\text{s}}}$$

REFLECT

The bowling ball moves toward negative x, which is consistent with the sign of the average velocity.

2.37

SET UP

A jogger runs 13.0 km in 3.25 h. We can calculate his average speed directly from these data: the distance he covered divided by the time it took him.

SOLVE

$$v_{\text{average},x} = \frac{13.0\text{ km}}{3.25\text{ h}} = \boxed{4.00\frac{\text{km}}{\text{h}}}$$

REFLECT

This corresponds to about 2.5 mph, which is a little slow for a jogging pace.

2.38

SET UP

The Olympic record for the marathon, which is 26.2 mi long, is 2 h, 6 min, and 32 s. After converting the time into hours and the distance into kilometers, we can divide the two to find the runner's average speed.

SOLVE

$$6\text{ min} \times \frac{1\text{ h}}{60\text{ min}} = 0.1\text{ h}$$

$$32\text{ s} \times \frac{1\text{ h}}{3600\text{ s}} = 0.0089\text{ h}$$

Total time elapsed:

$$(2.00\text{ h}) + (0.10\text{ h}) + (0.0089\text{ h}) = 2.11\text{ h}$$

$$v_{\text{average},x} = \frac{26.2\text{ mi}}{2.11\text{ h}} \times \frac{1.61\text{ km}}{1\text{ mi}} = \boxed{20.0\frac{\text{km}}{\text{h}}}$$

REFLECT

This is little more than 12 mph. This is an extremely fast running pace, which makes sense since it is the Olympic record pace! At that pace, the runner would complete 1 mi in about 5 min.

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2.39

SET UP

Kevin swims 4000 m in 1.00 h. Because he ends at the same location as he starts, his total displacement is 0 m. This means his average velocity, which is his displacement divided by the time interval, is also zero. His average *speed*, on the other hand, is nonzero. The average speed takes the total distance covered into account.

SOLVE

Part a) Displacement = 0 m, so his $\boxed{\text{average velocity} = 0}$.

Part b)

$$v_{\text{average},x} = \frac{\Delta x}{\Delta t} = \frac{4000\text{ m}}{1.00\text{ h}} \times \frac{1\text{ km}}{1000\text{ m}} = \boxed{4.00\frac{\text{km}}{\text{h}}}$$

Part c)

$$v_{\text{average},x} = \frac{\Delta x}{\Delta t} = \frac{25.0\text{ m}}{9.27\text{ s}} \times \frac{1\text{ km}}{1000\text{ m}} \times \frac{3600\text{ s}}{1\text{ h}} = \boxed{9.71\frac{\text{km}}{\text{h}} = 2.70\frac{\text{m}}{\text{s}}}$$

REFLECT
Usually the terms “velocity” and “speed” are used interchangeably in everyday English, but the distinction between the two is important in physics. Kevin’s average speed of 4 km/h is about 2.5 mph. For comparison, Michael Phelps’s record in the 100-m butterfly is 49.82 s, which gives him an average speed of 7.2 km/h or 4.5 mph.

2.40

SET UP
The distance between the lecture hall and the student’s house is 12.2 km. It takes the student 21.0 min to bike from campus to her house and 13.0 min to bike from her house back to campus. The displacement for her round trip is zero because she starts and ends at the same location (the lecture hall). This means her average velocity for the round trip is zero, since velocity depends on the displacement (rather than the distance). The problem requires us to determine average speed, not velocity, for the trips home and back. So, we do not need to establish a positive and negative direction. The average speed of her entire trip is equal to the total distance she covers divided by the time it takes.

SOLVE

Part a) Displacement = 0 m; therefore, $\boxed{\text{average velocity} = 0}$.

Part b)

$$v_{\text{average},x} = \frac{12.2\text{ km}}{21.0\text{ min}} \times \frac{60\text{ min}}{1\text{ h}} = \boxed{34.9\frac{\text{km}}{\text{h}}}$$

Part c)

$$v_{\text{average},x} = \frac{12.2\text{ km}}{13.0\text{ min}} \times \frac{60\text{ min}}{1\text{ h}} = \boxed{56.3\frac{\text{km}}{\text{h}}}$$

Part d)

$$v_{\text{average},x} = \frac{24.4\text{ km}}{34.0\text{ min}} \times \frac{60\text{ min}}{1\text{ h}} = \boxed{43.0\frac{\text{km}}{\text{h}}}$$

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REFLECT
Average velocity takes the direction of the motion into account, while the average speed does not.

2.41

SET UP
The magnitude of a school bus’s average velocity is 56.0 km/h, and it takes 0.700 h to arrive at school. We can use the definition of average velocity to determine the bus’s displacement.

SOLVE

$$\Delta x = (v_{\text{average},x})(\Delta t) = \left(56.0\frac{\text{km}}{\text{h}}\right)(0.700\text{ h}) = \boxed{39.2\text{ km}}$$

REFLECT

A speed of 56 km/h is about 35 mph.

2.42

SET UP

A car is traveling at 80.0 km/h and is 1500 m (1.500 km) behind a truck traveling at 70.0 km/h. We can consider the relative motion of the car with respect to the truck; this is the same, albeit easier, question as the original one. The car is moving 10 km/h faster than the truck, which means we can consider the truck to be stationary and the car traveling at a speed of 10.0 km/h. Now we can calculate the time it takes for a car traveling at a speed of 10.0 km/h to cover 1.500 km.

SOLVE

$$v_{\text{relative},x} = \frac{\Delta x}{\Delta t}$$

$$\Delta t = \frac{\Delta x}{v_{\text{relative},x}} = \frac{1.500\text{ km}}{10.0\dfrac{\text{km}}{\text{h}}} = 0.150\text{ h} \times \frac{60\text{ min}}{1\text{ h}} = \boxed{9.00\text{ min}}$$

REFLECT

We could have solved this question algebraically. Treating the car as the origin, the position of the car as a function of time is $x_{\text{car}} = \left(80\dfrac{\text{km}}{\text{h}}\right)t$ and the position of the truck is $x_{\text{truck}} = \left(70\dfrac{\text{km}}{\text{h}}\right)t + (1.5\text{ km})$. The two positions are equal to one another when the car overtakes the truck. Solving for t will give the time it takes for the car to reach the truck.

2.43

SET UP

It takes a sober driver 0.320 s to hit the brakes, while a drunk driver takes 1.00 s to hit the brakes. In both cases the car is initially traveling at 90.0 km/h. Assuming it takes the same distance to come to a stop once the brakes are applied, the drunk driver travels for an extra $(1.00 - 0.320)\text{ s} = 0.680\text{ s}$ at 90.0 km/h before hitting the brakes. We can use the definition of average speed to calculate the extra distance the drunk driver travels.

SOLVE

$$v_{\text{average},x} = \frac{\Delta x}{\Delta t}$$

$$\Delta x = (v_{\text{average},x})(\Delta t) = \left(90.0\frac{\text{km}}{\text{h}} \times \frac{1\text{ h}}{3600\text{ s}} \times \frac{1000\text{ m}}{1\text{ km}}\right)(0.680\text{ s}) = \boxed{17.0\text{ m}}$$

REFLECT

The impaired driver travels an extra distance of over 55 ft before applying the brakes.

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2.44

SET UP

A jet travels 3000 km from San Francisco to Chicago. It waits 1 h and then flies back to San Francisco. The entire trip (flight + layover) is 9 h, 52 min, or 9.87 h. The westbound trip (from Chicago to San Francisco) takes 24 min (0.40 h) longer than the eastbound trip. We'll call the duration of the westbound trip t_{WB} and the duration of the eastbound trip t_{EB}. We know that the sum of these two legs is equal to the flight time, which is the total trip time minus the layover time, or 8.87 h. Now we have two equations and two unknowns and can solve for the duration of each leg.

The average speed of the overall trip is the total distance traveled, which is 6000 km, divided by the total time.

SOLVE

Calculating the time for each leg:

$$t_{WB} + t_{EB} = \left(8\frac{52}{60}\text{ h}\right) = 8.87\text{ h}$$

$$t_{WB} = t_{EB} + \left(\frac{24}{60}\text{ h}\right) = t_{EB} + (0.40\text{ h})$$

$$(t_{EB} + 0.40\text{ h}) + t_{EB} = 8.87\text{ h}$$

$$t_{EB} = \frac{8.87\text{ h}}{2} = \boxed{4.24\text{ h}}$$

$$t_{WB} = t_{EB} + (0.40\text{ h}) = (4.24\text{ h}) + (0.40\text{ h}) = \boxed{4.64\text{ h}}$$

Average speed for the overall trip:

$$v_{\text{average},x} = \frac{2(3000\text{ km})}{9.87\text{ h}} = \boxed{600\frac{\text{km}}{\text{h}}}$$

Average speed, not including the layover:

$$v_{\text{average},x} = \frac{2(3000\text{ km})}{8.87\text{ h}} = \boxed{700\frac{\text{km}}{\text{h}}}$$

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REFLECT

It makes sense that the average speed of the plane is higher when we don't include the layover time in our calculation.

2.45

SET UP

A plot of a red blood cell's position versus time is provided and we are asked to determine the instantaneous velocity of the blood cell at $t = 10$ ms. The instantaneous velocity is equal to the slope of a position versus time graph. It is difficult to estimate

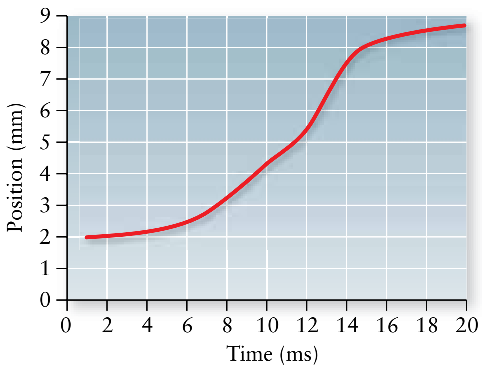

Figure 2-5 Problem 45

the slope of a tangent line. Fortunately, the slope of the graph looks to be reasonably constant between $t = 8$ ms and $t = 11.25$ s. We can determine the slope over this region and use that to approximate the instantaneous velocity at $t = 10$ s.

SOLVE

$$v_{\text{instantaneous},x} \approx \frac{x_{11.25\text{ ms}} - x_{8\text{ ms}}}{t_{11.25\text{ ms}} - t_{8\text{ ms}}} = \frac{(5.00\text{ mm}) - (3.25\text{ mm})}{(11.25\text{ ms}) - (8.00\text{ ms})} = \frac{1.75\text{ mm}}{3.25\text{ ms}} = \boxed{0.54\frac{\text{mm}}{\text{ms}} = 0.54\frac{\text{m}}{\text{s}}}$$

REFLECT

The red blood cell is moving toward positive x as time goes on, which corresponds to the positive sign of the instantaneous velocity. The ratio between millimeters and milliseconds is the same as the ratio between meters and seconds.

2.46

SET UP

Paola starts from rest and launches herself off the ground with a speed of 4.43 m/s. The distance over which she accomplishes this acceleration is 20.0 cm (0.200 m). Assuming her acceleration is constant, we can calculate the acceleration by rearranging $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$.

SOLVE

$$v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$$

$$a_x = \frac{v_x^2 - v_{0x}^2}{2(\Delta x)} = \frac{\left(4.43\frac{\text{m}}{\text{s}}\right)^2 - (0)^2}{2(0.200\text{ m})} = \boxed{49.1\frac{\text{m}}{\text{s}^2}}$$

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REFLECT

We can quickly estimate the expected acceleration in order to double-check our solution. The final speed is 4.43 m/s, which we need to square. The square of 4 is 16 and the square of 5 is 25. The square of 4.43 should be in between those values but closer to 16; let's choose 20. (The actual square of 4.43 is 19.6, so this is a good assumption.) The denominator is 4×10^{-1}, so 20 divided by 4 is 5, which we divide by 10^{-1} (which is the same as multiplying by 10^1). This gives an estimate of 50 m/s^2, which is consistent with our calculation.

2.47

SET UP

A runner starts from rest and reaches a top speed of 8.97 m/s. Her acceleration is 9.77 m/s^2, which is a constant. We know her initial speed, her final speed, and her acceleration, and we are interested in the time it takes for her to reach that speed. We can rearrange $v_x = v_{0x} + a_x t$ and solve for t.

SOLVE

$$v_x = v_{0x} + a_x t$$

$$t = \frac{v_x - v_{0x}}{a_x}$$

$$t = \frac{8.97\frac{\text{m}}{\text{s}} - 0}{9.77\frac{\text{m}}{\text{s}^2}} = \boxed{0.918 \text{ s}}$$

REFLECT

An acceleration of 9.77 m/s^2 means that her speed changes by 9.77 m/s every second. In this problem her speed changed a little less than that, so we expect the time elapsed to be a little less than a second.

2.48

SET UP

We are asked to compare the acceleration and displacement of a car over two 5.00-s time intervals. During the first interval, (interval A), the car starts at 35.0 km/h and accelerates up to 45.0 km/h. In the second interval, (interval B), the car starts at 65.0 km/h and accelerates up to 75.0 km/h. We are told the accelerations are constant, which means the average acceleration is equal to the instantaneous acceleration. The average acceleration is the change in the velocity over the time interval. Once we have the acceleration for each interval, we can use the constant acceleration equation $x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2$ to calculate the displacement of the car in each interval.

SOLVE

Part a)

$$a_{Ax} = \frac{\Delta v_{Ax}}{\Delta t} = \frac{\left(45.0\frac{\text{km}}{\text{h}} - 35.0\frac{\text{km}}{\text{h}}\right) \times \frac{1 \text{ h}}{3600 \text{ s}} \times \frac{1000 \text{ m}}{1 \text{ km}}}{5.00 \text{ s}} = \frac{\left(2.78\frac{\text{m}}{\text{s}}\right)}{5.00 \text{ s}} = \boxed{0.556\frac{\text{m}}{\text{s}^2}}$$

$$a_{Bx} = \frac{\Delta v_{Bx}}{\Delta t} = \frac{\left(75.0\frac{\text{km}}{\text{h}} - 65.0\frac{\text{km}}{\text{h}}\right) \times \frac{1 \text{ h}}{3600 \text{ s}} \times \frac{1000 \text{ m}}{1 \text{ km}}}{5.00 \text{ s}} = \frac{\left(2.78\frac{\text{m}}{\text{s}}\right)}{5.00 \text{ s}} = \boxed{0.556\frac{\text{m}}{\text{s}^2}}$$

Part b)

$$x_A = x_{0A} + v_{0A}t + \frac{1}{2}a_{Ax}t^2 = \left(35.0\frac{\text{km}}{\text{h}} \times \frac{1 \text{ h}}{3600 \text{ s}} \times \frac{1000 \text{ m}}{1 \text{ km}}\right)(5.00 \text{ s}) + \frac{1}{2}\left(0.556\frac{\text{m}}{\text{s}^2}\right)(5.00 \text{ s})^2$$

$$= (48.6 \text{ m}) + (6.95 \text{ m}) = \boxed{55.6 \text{ m}}$$

$$x_B = x_{0B} + v_{0B}t + \frac{1}{2}a_{Bx}t^2 = \left(65.0\frac{\text{km}}{\text{h}} \times \frac{1 \text{ h}}{3600 \text{ s}} \times \frac{1000 \text{ m}}{1 \text{ km}}\right)(5.00 \text{ s}) + \frac{1}{2}\left(0.556\frac{\text{m}}{\text{s}^2}\right)(5.00 \text{ s})^2$$

$$= (90.3 \text{ m}) + (6.95 \text{ m}) = \boxed{97.2 \text{ m}}$$

REFLECT

The accelerations are equal for the two intervals, which makes sense since the speeds increase by 10.0 km/h in 5.00 s for both cases. The car moves farther in the second interval because the car is moving at higher speeds.

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2.49

SET UP

A car starts at rest and reaches a speed of 34.0 m/s in 12.0 s. The average acceleration is the change in the velocity over the time interval.

SOLVE

$$a_{\text{average},x} = \frac{\Delta v_x}{\Delta t} = \frac{\left(34.0\frac{\text{m}}{\text{s}} - 0\right)}{12.0\text{ s}} = \boxed{2.83\frac{\text{m}}{\text{s}^2}}$$

REFLECT

A speed of 34 m/s is equal to about 76 mph, so it takes the car 12 s to go from 0 to 76 mph.

2.50

SET UP

A list of sports cars and the time it takes each one to accelerate to 60.0 mph from rest is given. First, we need to convert 60.0 mph into km/h and then into m/s. Assuming the acceleration of each car is constant, we can calculate each acceleration using the change in the velocity divided by the time interval.

SOLVE

Converting 60.0 mi/h into km/h and m/s:

$$60.0\frac{\text{m}}{\text{h}} \times \frac{1.61\text{ km}}{1\text{ mi}} = \boxed{96.6\frac{\text{km}}{\text{h}}} \times \frac{1\text{ h}}{3600\text{ s}} \times \frac{1000\text{ m}}{1\text{ km}} = \boxed{26.8\frac{\text{m}}{\text{s}}}$$

Accelerations:

$$a_{\text{Bugatti},x} = \frac{26.8\frac{\text{m}}{\text{s}} - 0}{2.40\text{ s}} = \boxed{11.2\frac{\text{m}}{\text{s}^2}}$$

$$a_{\text{Caparo},x} = \frac{26.8\frac{\text{m}}{\text{s}} - 0}{2.50\text{ s}} = \boxed{10.7\frac{\text{m}}{\text{s}^2}}$$

$$a_{\text{Ultimo},x} = \frac{26.8\frac{\text{m}}{\text{s}} - 0}{2.60\text{ s}} = \boxed{10.3\frac{\text{m}}{\text{s}^2}}$$

$$a_{\text{SSC},x} = \frac{26.8\frac{\text{m}}{\text{s}} - 0}{2.70\text{ s}} = \boxed{9.92\frac{\text{m}}{\text{s}^2}}$$

$$a_{\text{Saleen},x} = \frac{26.8\frac{\text{m}}{\text{s}} - 0}{2.80\text{ s}} = \boxed{9.57\frac{\text{m}}{\text{s}^2}}$$

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REFLECT

The Bugatti Veyron Super Sport is the fastest street-legal car in the world. Its top speed of just over 267 mph earned it a spot in the Guinness World Book of Records for the "Fastest Production Car" (http://www.guinnessworldrecords.com/records-1/fastest-production-car/).

2.51

SET UP

A Bugatti Veyron and Saleen S7 can accelerate from 0 to 60.0 mph in 2.40 s and 2.80 s, respectively. Assuming the acceleration of each car is constant, not only over that time interval but also for *any* time interval, we can approximate the acceleration of each car as the average acceleration. We first need to convert 60.0 mph into m/s in order to keep the units consistent. The acceleration is equal to the change in velocity divided by the change in time. We are interested in the distance each car travels when it accelerates from rest to 90.0 km/h. We know the initial speed, the final speed, and the acceleration, so we can use $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ to calculate Δx for each car. (See Problem 2.55 for a derivation of this equation.)

SOLVE

Converting to m/s:

$$60.0\frac{\text{mi}}{\text{h}} \times \frac{1.61\ \text{km}}{1\ \text{mi}} \times \frac{1\ \text{h}}{3600\ \text{s}} \times \frac{1000\ \text{m}}{1\ \text{km}} = 26.8\frac{\text{m}}{\text{s}}$$

Finding the acceleration:

$$a_{\text{average},x} = \frac{\Delta v_x}{\Delta t}$$

$$a_{\text{Bugatti},x} = \frac{26.8\frac{\text{m}}{\text{s}} - 0}{2.40\ \text{s}} = 11.2\frac{\text{m}}{\text{s}^2}$$

$$a_{\text{Saleen},x} = \frac{26.8\frac{\text{m}}{\text{s}} - 0}{2.80\ \text{s}} = 9.57\frac{\text{m}}{\text{s}^2}$$

Finding the distance:

$$v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$$

$$\Delta x = \frac{v_x^2 - v_{0x}^2}{2a_x}$$

$$\Delta x_{\text{Bugatti}} = \frac{\left(90.0\frac{\text{km}}{\text{h}} \times \frac{1000\ \text{m}}{1\ \text{km}} \times \frac{1\ \text{h}}{3600\ \text{s}}\right)^2 - (0)^2}{2\left(11.2\frac{\text{m}}{\text{s}^2}\right)} = \boxed{27.9\ \text{m}}$$

$$\Delta x_{\text{Saleen}} = \frac{\left(90.0\frac{\text{km}}{\text{h}} \times \frac{1000\ \text{m}}{1\ \text{km}} \times \frac{1\ \text{h}}{3600\ \text{s}}\right)^2 - (0)^2}{2\left(9.57\frac{\text{m}}{\text{s}^2}\right)} = \boxed{32.6\ \text{m}}$$

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REFLECT

These values are around 92 ft and 108 ft, respectively. A speed limit of 90 km/h is around 55 mph. Most people don't drive expensive sports cars on the highway every day, so these distances are (obviously) much smaller than we should expect for most everyday cars.

2.52

SET UP

A car is traveling at an initial speed of 30.0 m/s and needs to come to a complete stop within 80.0 m. We can calculate the acceleration necessary to produce this motion by assuming the car's acceleration is constant.

SOLVE

$$v_x^2 - v_{0x}^2 = 2a_x(\Delta x)$$

$$a_x = \frac{v_x^2 - v_{0x}^2}{2(\Delta x)} = \frac{0^2 - \left(30.0\frac{\text{m}}{\text{s}}\right)^2}{2(80.0\text{ m})} = \boxed{-5.62\frac{\text{m}}{\text{s}^2}}$$

REFLECT

The negative sign associated with the acceleration implies the car is slowing down. At this acceleration, it would take the car 5.4 s to come to a stop.

2.53

SET UP

A sperm whale has an initial speed of 1.00 m/s and accelerates up to a final speed of 2.25 m/s at a constant rate of 0.100 m/s^2. Because we know the initial speed, the final speed, and the acceleration, we can calculate the distance over which the whale travels by rearranging $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$.

SOLVE

$$v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$$

$$\Delta x = \frac{v_x^2 - v_{0x}^2}{2a_x} = \frac{\left(2.25\frac{\text{m}}{\text{s}}\right)^2 - \left(1.00\frac{\text{m}}{\text{s}}\right)^2}{2\left(0.100\frac{\text{m}}{\text{s}^2}\right)} = \boxed{20.3\text{ m}}$$

REFLECT

This is a little longer than the average size of an adult male sperm whale (about 16 m). It will take the whale 12.5 s to speed up from 1 m/s to 2.25 m/s.

2.54

SET UP

A horse starts at an initial speed of $v_{0x} = 0$ m/s and accelerates at a constant rate of $a_x = 3.00$ m/s^2. We can use the constant acceleration relationships to calculate the time necessary for the horse to cover a distance of $\Delta x = 25.0$ m.

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SOLVE

$$x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2$$

$$\Delta x = v_{0x}t + \frac{1}{2}a_x t^2 = (0)t + \frac{1}{2}a_x t^2 = \frac{1}{2}a_x t^2$$

$$t = \sqrt{\frac{2\Delta x}{a_x}} = \sqrt{\frac{2(25.0\text{ m})}{\left(3.00\ \frac{\text{m}}{\text{s}^2}\right)}} = 4.08\text{ s}$$

REFLECT

We used the fact that the initial speed was equal to zero first in order to more easily solve the resulting quadratic equation.

2.55

SET UP

We are asked to derive a constant acceleration equation that relates speed, position, and acceleration and eliminates time. Solving for time in the definition of acceleration, we can plug that expression into $x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2$ and rearrange.

SOLVE

Solving for t in the definition of acceleration:

$$a_x = \frac{v_x - v_{0x}}{t}$$

$$t = \frac{v_x - v_{0x}}{a_x}$$

Plugging in t:

$$x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2 = x_0 + v_{0x}\left(\frac{v_x - v_{0x}}{a_x}\right) + \frac{1}{2}a_x\left(\frac{v_x - v_{0x}}{a_x}\right)^2$$

$$xa_x = x_0 a_x + v_{0x}(v_x - v_{0x}) + \frac{1}{2}(v_x - v_{0x})^2$$

$$(x - x_0)a_x = v_{0x}v_x - (v_{0x})^2 + \frac{1}{2}(v_x^2 - 2v_{0x}v_x + (v_{0x})^2)$$

$$2(x - x_0)a_x = 2v_{0x}v_x - 2(v_{0x})^2 + v_x^2 - 2v_{0x}v_x + (v_{0x})^2$$

$$\boxed{2(x - x_0)a_x = v_x^2 - v_{0x}^2}$$

REFLECT

This equation is useful if we don't know or don't care about how long something is traveling.

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2.56

SET UP

A ball is dropped from an initial height $y_0 = 25.0$ m above the ground and undergoes free fall. The initial speed of the ball is zero ($v_{0y} = 0$). Part (a) asks the speed of the ball when it is at a final position of $y = 10.0$ m. We know the initial speed, the initial location, the final location, and the acceleration of the ball ($a_y = -g$) and are interested in the final speed. We can use $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ to solve for v_y. Part (b) asks about the time it takes the ball to fall from its initial position to the ground. Here we know the initial speed, the initial location, the final location, and the acceleration of the ball and are interested in the total time. This suggests that we use $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$.

SOLVE

Part a)

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$$

$$v_y = \sqrt{v_{0y}^2 + 2a_y(\Delta y)} = \sqrt{0^2 + 2\left(-9.80\frac{\text{m}}{\text{s}^2}\right)((10.0\text{ m}) - (25.0\text{ m}))} = \boxed{17.1\frac{\text{m}}{\text{s}}}$$

Part b)

$$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$$

$$t = \sqrt{\frac{2\Delta y}{a_y}} = \sqrt{\frac{2(0 - 25.0\text{ m})}{\left(-9.80\frac{\text{m}}{\text{s}^2}\right)}} = \boxed{2.26\text{ s}}$$

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REFLECT

Remember that value of g is positive and equal to 9.80 m/s^2 and that the acceleration due to gravity points downward, which is usually negative y. A height of 25 m is around 82 ft, so a total time of 2.26 s seems reasonable.

2.57

SET UP

Alex throws a ball straight down (toward $-y$) with an initial speed of $v_{A0y} = 4.00$ m/s from the top of a 50.0-m-tall tree. At the same instant, Gary throws a ball straight up (toward $+y$) with an initial speed of v_{G0y} at a height of 1.50 m off the ground. (We will consider the ground to be $y = 0$, which makes the initial position of Alex's ball $y_{A0} = 50.0$ m and the initial position of Gary's ball $y_{G0} = 1.50$ m). Once Alex and Gary throw their respective balls, their accelerations will be equal to $a_y = -g$. We want to know how fast Gary has to throw his ball such that the two balls cross paths at $y = 25.0$ m at the same time.

We are given more information about Alex's throw than Gary's so that seems to be a reasonable place to start. First, we need to know the time at which Alex's ball is at $y =$ 25.0 m. We can use $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$ with Alex's information to accomplish this. We know that, at this time, Gary's ball *also* has to be at $y = 25.0$ m. We can plug this time into $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$ again—this time with Gary's information—to calculate the initial speed of Gary's ball.

SOLVE

Time it takes Alex's ball to reach $y = 25.0$ m:

$$y = y_{A0} + v_{A0y}t + \frac{1}{2}a_y t^2 = y_{A0} + v_{A0y}t + \frac{1}{2}(-g)t^2$$

$$-\frac{1}{2}gt^2 + v_{A0y}t + (y_{A0} - y) = 0$$

This is a quadratic equation, so we will use the quadratic formula to find t:

$$t = \frac{-v_{A0y} \pm \sqrt{(v_{A0y})^2 - 4\left(-\frac{g}{2}\right)(y_{A0} - y)}}{2\left(-\frac{g}{2}\right)} = \frac{-v_{A0y} \pm \sqrt{(v_{A0y})^2 + 4\left(\frac{g}{2}\right)(y_{A0} - y)}}{-g}$$

$$= \frac{-\left(-4.00\frac{\text{m}}{\text{s}}\right) \pm \sqrt{\left(-4.00\frac{\text{m}}{\text{s}}\right)^2 + 4\left(\frac{9.80\frac{\text{m}}{\text{s}^2}}{2}\right)((50.0\text{ m}) - (25.0\text{ m}))}}{-\left(9.80\frac{\text{m}}{\text{s}^2}\right)} = \left(\frac{4.00 \pm 22.5}{-9.80}\right)\text{s}$$

The minus sign in the numerator gives the only physical answer:

$$t = \left(\frac{4.00 - 22.5}{-9.80}\right)\text{s} = 1.89\text{ s}$$

Speed at which Gary must launch the ball for it to be at $y = 25.0$ m at $t = 1.89$ s:

$$y = y_{G0} + v_{G0y}t + \frac{1}{2}a_y t^2 = y_{G0} + v_{G0y}t + \frac{1}{2}(-g)t^2$$

$$v_{G0y} = \frac{y - y_{G0} + \frac{1}{2}gt^2}{t} = \frac{(25.0\text{ m}) - (1.50\text{ m}) + \frac{1}{2}\left(9.80\frac{\text{m}}{\text{s}^2}\right)(1.89\text{ s})^2}{1.89\text{ s}} = \boxed{21.7\frac{\text{m}}{\text{s}}}$$

REFLECT

Gary needs to throw his ball almost 50 mph in order for it to cross paths with Alex's at $y = 25$ m! The logic behind the way we solved this problem is much more important than the algebra used to solve this problem. Be sure every step makes logical sense; the crux of the argument is that the two balls have the same position at the same time.

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2.58

SET UP

A fox jumps straight up into the air and reaches a maximum height of 85.0 cm (0.850 m) and then comes back down to the ground. The fox's speed is zero at its maximum height. Because we know the total distance the fox travels, its final speed, and its acceleration ($a_y = -g$), we can use $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ to calculate the fox's initial speed. The total time the fox is in the air is twice the time it takes for the fox to jump from the ground to $y = 0.850$ m, since it takes the same amount of time to come back down to the ground.

SOLVE

Part a)

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$$

$$v_{0y} = \sqrt{v_y^2 + 2g(\Delta y)} = \sqrt{0 + 2\left(9.80\frac{\text{m}}{\text{s}^2}\right)(0.850\text{ m})} = \boxed{4.08\frac{\text{m}}{\text{s}}}$$

Part b)

$$v_y = v_{0y} + a_y t = v_{0y} + (-g)t$$

$$t = \frac{v_y - v_{0y}}{-g} = \frac{0 - \left(4.08\frac{\text{m}}{\text{s}}\right)}{-9.80\frac{\text{m}}{\text{s}^2}} = 0.416\text{ s}$$

This is the time it takes for the fox to jump 0.850 m in the air from the ground. The total amount of time the fox is in the air is $2t = \boxed{0.832\text{ s}}$.

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REFLECT

Because the fox started and landed at the same height (the ground, in this case), the total time it was in the air is equal to twice the time it takes for half of the motion. If the fox landed at a different height, then this would not be the case.

2.59

SET UP

A person falls from a height of 6 ft off of the ground. We will call the ground $y = 0$. His initial speed is zero and acceleration is $-g$ because he is undergoing free fall. Using the conversion 1 ft = 0.3048 m and $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$, we can calculate the speed at which he hits the ground.

SOLVE

Converting 6 ft into m:

$$6\text{ ft} \times \frac{0.3048\text{ m}}{1\text{ ft}} = 1.83\text{ m}$$

Solving for the final speed:

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0) = v_{0y}^2 + 2(-g)(\Delta y)$$

$$v_y = \sqrt{v_{0y}^2 - 2g(\Delta y)} = \sqrt{0^2 - 2\left(9.80\frac{\text{m}}{\text{s}^2}\right)(0 - 1.83\text{ m})} = \boxed{6\frac{\text{m}}{\text{s}}}$$

REFLECT

A speed of 6 m/s is about 13 mph. In addition to the speed consideration, it's much easier to topple from the top step than the lower ones, hence, the warning.

2.60

SET UP

Wes and Lindsay start at the same initial height, y_0, and each throw a projectile toward the ground. Wes's projectile starts with an initial velocity of $v_{W0y} = 0$ and it takes t_W s for it to reach the ground ($y = 0$). Lindsay waits 1.25 s and then throws hers with an initial velocity $v_{L0y} = -28.0$ m/s. Her projectile hits at the same time as Wes's, which means $t_L = t_W - 1.25$ s because she waited. We can first solve for the initial position y_0 in terms of t_W. Because Lindsay starts at the same height, we can plug in y_0 in terms of t_W and t_L in terms of t_W in order to solve for t_W. Once we know the time it takes Wes's projectile to hit the ground, we can plug it into our original expression to solve for the initial height.

SOLVE

Initial position in terms of Wes's time:

$$y = y_0 + v_{W0y}t_W + \frac{1}{2}a_y t_W^2$$

$$-y_0 = 0 + \frac{1}{2}(-g)t_W^2 = -\frac{g}{2}t_W^2$$

$$y_0 = \frac{g}{2}t_W^2$$

Determining t_W from Lindsay's data:

$$y = y_0 + v_{L0y}t_L + \frac{1}{2}a_y t_L^2,\text{ but } t_L = t_W - 1.25\text{ s}$$

$$-y_0 = v_{L0y}(t_W - 1.25\text{ s}) + \frac{1}{2}(-g)(t_W - 1.25\text{ s})^2$$

$$-\left(\frac{g}{2}t_W^2\right) = v_{L0y}(t_W - 1.25\text{ s}) - \frac{g}{2}(t_W^2 + (1.25\text{ s})^2 - 2(1.25\text{ s})t_W)$$

$$t_W^2 = \left(-\frac{2}{g}\right)(v_{L0y}(t_W - 1.25\text{ s})) + (t_W^2 + (1.25\text{ s})^2 - 2(1.25\text{ s})t_W)$$

$$0 = \left(-\frac{2}{g}\right)(v_{L0y}(t_W - 1.25\text{ s})) + (1.25\text{ s})^2 - 2(1.25\text{ s})t_W$$

$$= \left(-\frac{2}{g}\right)\left(-28.0\frac{\text{m}}{\text{s}}\right)(t_W - 1.25\text{ s}) + (1.25\text{ s})^2 - 2(1.25\text{ s})t_W$$

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$$t_W = \frac{\frac{70.0\text{ m}}{g} - (1.25\text{ s})^2}{\frac{56.0\frac{\text{m}}{\text{s}}}{g} - 2.50\text{ s}} = 1.74\text{ s}$$

Plugging the time back into Wes's equation:

$$y_0 = \frac{g}{2}t_W^2 = \frac{9.80\frac{\text{m}}{\text{s}^2}}{2}(1.74\text{ s})^2 = \boxed{14.8\text{ m}}$$

REFLECT

We can double-check this answer by solving Lindsay's equation of motion for her initial speed, which we were given. Lindsay's time is equal to $1.74\text{ s} - 1.25\text{ s} = 0.49\text{ s}$. The initial speed is then:

$$v_{L0y} = \frac{y - y_0 - \frac{1}{2}a_y t_L^2}{t_L} = \frac{0 - (14.8\text{ m}) - \frac{1}{2}\left(-9.80\frac{\text{m}}{\text{s}^2}\right)(0.49\text{ s})^2}{0.49\text{ s}} = 28\frac{\text{m}}{\text{s}}\text{, as expected.}$$

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2.61

SET UP

A ball is thrown up with an initial speed of 18.0 m/s. We will consider *up* to be positive motion. We can calculate the velocity of the ball using $v_y(t) = v_{0y} + a_y t = v_{0y} - gt$. The ball has a speed of zero at its maximum height.

SOLVE

$$v_y(t) = v_{0y} + a_y t = v_{0y} - gt$$

Part a)

$$v_y(t = 1\text{ s}) = \left(18.0\frac{\text{m}}{\text{s}}\right) - \left(9.80\frac{\text{m}}{\text{s}^2}\right)(1.00\text{ s}) = \boxed{8.20\frac{\text{m}}{\text{s}}}$$

Part b)

$$v_y(t = 2\text{ s}) = \left(18.0\frac{\text{m}}{\text{s}}\right) - \left(9.80\frac{\text{m}}{\text{s}^2}\right)(2.00\text{ s}) = \boxed{-1.60\frac{\text{m}}{\text{s}}}$$

Part c)

$$v_y(t = 5\text{ s}) = \left(18.0\frac{\text{m}}{\text{s}}\right) - \left(9.80\frac{\text{m}}{\text{s}^2}\right)(5.00\text{ s}) = \boxed{-31.0\frac{\text{m}}{\text{s}}}$$

Part d)

$$v_y(t) = 0 = v_{0y} - gt_{max}$$

$$t_{max} = \frac{-v_{0y}}{-g} = \frac{18.0\frac{\text{m}}{\text{s}}}{9.80\frac{\text{m}}{\text{s}^2}} = \boxed{1.84\text{ s}}$$

REFLECT

A negative velocity in this case refers to the ball coming back down to Earth.

2.62

SET UP

A tennis ball has an initial velocity of 20.0 m/s straight up. The ball starts at the top of a 30-m-tall cliff, moves upward some unspecified amount, comes back through its initial position, and then hits the ground. When the ball passes back through its initial height on its way to the ground, it will have the same speed as it initially did because the motion is symmetric. (You can explicitly calculate this from $v_y^2 = v_{0y}^2 + 2a_y(y - y_0) = v_{0y}^2 + 2(-g)(\Delta y)$ with $\Delta y = 0$.) The ball's path consists of two legs: #1) traveling from its initial position to its maximum height and back to its initial position and #2) traveling from its initial position to the bottom of the cliff. The time and distance the ball travels during leg #1 are twice what it takes to travel from the initial position to the maximum height. At the maximum height, the ball's speed is zero. The time and distance associated with leg #2 can be calculated knowing the ball's initial velocity is 20.0 m/s straight down and it travels 30.0 m straight down. We will need to use the quadratic equation to determine the time for leg #2.

SOLVE

Part a) $\boxed{20.0 \text{ m/s}}$

Part b)

Initial position → maximum height

$$v_y = v_{0y} + a_y t = v_{0y} + (-g)t$$

$$t = \frac{v_y - v_{0y}}{-g} = \frac{0 - 20.0\frac{\text{m}}{\text{s}}}{-9.80\frac{\text{m}}{\text{s}^2}} = 2.04 \text{ s}$$

Maximum height → initial position will also take 2.04 s due to symmetry.

Initial position → bottom of cliff

$$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2 = y_0 + v_{0y}t + \frac{1}{2}(-g)t^2$$

$$\frac{g}{2}t^2 - v_{0y}t + (y - y_0) = 0$$

$$t = \frac{-(-v_{0y}) \pm \sqrt{v_{0y}^2 - 4\left(\frac{g}{2}\right)(y - y_0)}}{2\left(\frac{g}{2}\right)} = \frac{\left(-20.0\frac{\text{m}}{\text{s}}\right) \pm \sqrt{\left(20.0\frac{\text{m}}{\text{s}}\right)^2 - 4\left(\dfrac{9.80\frac{\text{m}}{\text{s}^2}}{2}\right)(0 - 30.0 \text{ m})}}{9.80\frac{\text{m}}{\text{s}^2}}$$

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$$= \frac{-20.0 \pm 31.43}{9.80} = \frac{-20.0 + 31.43}{9.80} = 1.17 \text{ s. (Only the positive root is physically sound.)}$$

Total time to reach the ground $= 2(2.04 \text{ s}) + (1.17 \text{ s}) = \boxed{5.25 \text{ s}}$.

Part c)

Initial position → maximum height

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0) = v_{0y}^2 + 2(-g)(\Delta y)$$

$$\Delta y = \frac{v_y^2 - v_{0y}^2}{-2g} = \frac{0 - \left(20.0\frac{\text{m}}{\text{s}}\right)^2}{-2\left(9.80\frac{\text{m}}{\text{s}^2}\right)} = 20.41 \text{ m}$$

Maximum height → initial position will also take 20.41 m due to symmetry.

Initial position → bottom of cliff is 30.0 m.

Total distance the ball travels $= 2(20.41 \text{ m}) + (30.0 \text{ m}) = \boxed{70.8 \text{ m}}$.

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REFLECT

Thinking about the problem first rather than blindly searching for equations will save you time in the long run. For example, we didn't have to calculate the time or distance the ball travels from its maximum height back to its initial height because we used the symmetry of the problem instead.

2.63

SET UP

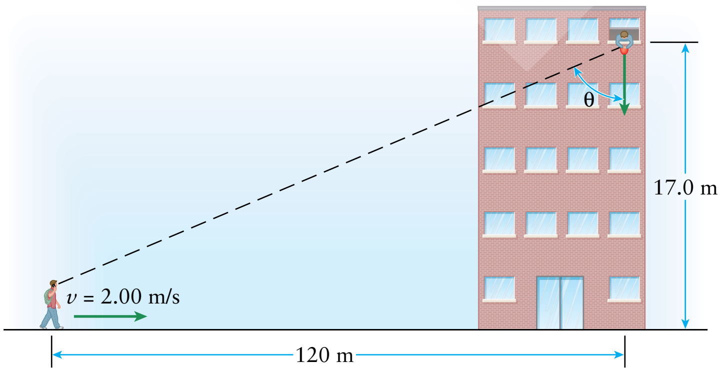

Figure 2-6 Problem 63

Mary is planning on dropping an apple out of her 17.0-m-high window to Bill. Bill is walking at a velocity of 2.00 m/s toward Mary's building and starts 120 m from directly below her window. Mary wants Bill to catch the apple, which means Bill and the apple need to be at the same location at the same time. We can use the constant acceleration equation for free fall to calculate the time it takes the apple to drop from an initial location of $y_0 = 17.0$ m to a final location of $y = 1.75$ m (presumably, Bill's height). Assume the apple has an initial velocity of zero. We can compare this to the time it takes Bill to walk 120 m in order to determine how long Mary should wait to drop the apple. Once we know how long Mary waits, we can find the distance Bill is from Mary since he is walking at a constant speed of 2.00 m/s. Bill's horizontal distance from Mary and the height Mary is in the air are two legs of a right triangle; the angle θ is related to these legs by the tangent.

SOLVE

Part a)

Time it takes Mary's apple to fall to a height of 1.75 m off the ground:

$$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2 = y_0 + 0 + \frac{1}{2}(-g)t^2$$

$$t = \sqrt{\frac{2(y - y_0)}{-g}} = \sqrt{\frac{2((1.75\text{ m}) - (17.0\text{ m}))}{-\left(9.80\frac{\text{m}}{\text{s}^2}\right)}} = 1.76\text{ s}$$

Time it takes Bill to walk 120 m:

$$v_{\text{average},x} = \frac{\Delta x}{\Delta t}$$

$$\Delta t = \frac{\Delta x}{v_{\text{average},x}} = \frac{120\text{ m}}{2.00\text{ m/s}} = 60.0\text{ s}$$

Mary should wait $(60.0\text{ s}) - (1.76\text{ s}) = \boxed{58.2\text{ s}}$ to drop her apple.

Part b) In 58.2 s, Bill travels $(58.2\text{ s})\left(2.00\frac{\text{m}}{\text{s}}\right) = 116$ m, which means he is $\boxed{4\text{ m}}$ horizontally from the window.

Part c)

$$\tan(\theta) = \frac{4\text{ m}}{17\text{ m}}$$

$$\theta = \arctan\left(\frac{4}{17}\right) = \boxed{0.23\text{ rad} = 13°}$$

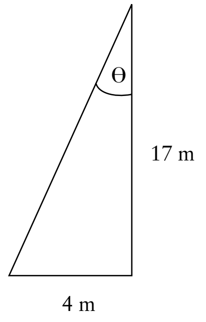

Figure 2-7 Problem 63

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REFLECT

As you would expect, Bill has to be reasonably close to Mary in order for him to catch the apple. If Mary throws the apple (that is, nonzero initial velocity), Bill would need to be even closer in order to catch the apple.

General Problems

2.64

SET UP

A car is driving at 40.0 km/h when the traffic signal changes from green to yellow. It takes the driver 0.750 s before hitting the brake. The car then accelerates at $-5.50\ \text{m/s}^2$ until it stops. The distance the car travels during this process can be split into two parts: the distance traveled before the brake is applied and the distance traveled after the brake is applied. Before the brake is applied, the car is traveling at a constant speed for 0.750 s. While the brake is applied, the car is undergoing constant acceleration so the equation $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ can be used to calculate the distance. The minimum distance necessary to come to a stop is the sum of these two.

SOLVE

Converting from km/h to m/s:

$$40.0\frac{\text{km}}{\text{h}} \times \frac{1\ \text{h}}{3600\ \text{s}} \times \frac{1000\ \text{m}}{1\ \text{km}} = 11.1\frac{\text{m}}{\text{s}}$$

Distance car travels before applying the brake:

$$(0.750\ \text{s})\left(11.1\frac{\text{m}}{\text{s}}\right) = 8.32\ \text{m}$$

Distance car travels while braking:

$$v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$$

$$\Delta x = \frac{v_x^2 - v_{0x}^2}{2a_x} = \frac{0^2 - \left(11.1\frac{\text{m}}{\text{s}}\right)^2}{2\left(-5.50\frac{\text{m}}{\text{s}^2}\right)} = 11.2\ \text{m}$$

Minimum distance necessary for the car to stop: $8.32\ \text{m} + 11.2\ \text{m} = \boxed{19.5\ \text{m}}$.

REFLECT

The car requires at least 19.5 m (64 ft) to come to a stop from a speed of 40 km/h (25 mph). It would take about 2.75 s from the time the light turned yellow until the car stopped.

2.65

SET UP

Two trains are 300 m apart and traveling toward each other. Train 1 has an initial speed of 98.0 km/h and an acceleration of $-3.50\ \text{m/s}^2$. Train 2 has an initial speed of 120 km/h and an acceleration of $-4.20\ \text{m/s}^2$. To determine whether or not the trains collide, we can

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calculate the stopping distance required for each train, add them together, and see if it is less than 300 m. If so, the trains are safe; if not, the trains crash. We know the trains' initial speeds, final speeds, and acceleration, and we are interested in finding the distance, which suggests we use $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$.

SOLVE

Stopping distance for train 1:

$$v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$$

$$\Delta x = \frac{v_x^2 - v_{0x}^2}{2a_x} = \frac{0^2 - \left(98.0\frac{\text{km}}{\text{h}} \times \frac{1\text{ h}}{3600\text{ s}} \times \frac{1000\text{ m}}{1\text{ km}}\right)^2}{2\left(-3.50\frac{\text{m}}{\text{s}^2}\right)} = 106\text{ m}$$

Stopping distance for train 2:

$$v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$$

$$\Delta x = \frac{v_x^2 - v_{0x}^2}{2a_x} = \frac{0^2 - \left(120\frac{\text{km}}{\text{h}} \times \frac{1\text{ h}}{3600\text{ s}} \times \frac{1000\text{ m}}{1\text{ km}}\right)^2}{2\left(-4.20\frac{\text{m}}{\text{s}^2}\right)} = 132\text{ m}$$

Total distance required to stop both trains: 106 m + 132 m = 238 m. This is less than the 300 m separating the trains, which means the $\boxed{\text{trains will not collide}}$. The distance separating the trains is 300 m − 238 m = $\boxed{62\text{ m}}$.

REFLECT

As long as the trains are at least 237 m apart, they will not collide.

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2.66

SET UP

A cheetah can reach a top speed of 29.0 m/s, which we can convert to miles per hour using 1 mi = 1.61 km. The cheetah can accelerate from rest to 20.0 m/s in 2.50 s. We can divide the change in speed by the change in time to find the acceleration because we are assuming the acceleration is constant. Knowing the acceleration and the initial and final speeds allows us to calculate the time it takes the cheetah to reach its top speed and how far it travels in that time. Finally, the cheetah only accelerates until it reaches its top speed and then continues running at a constant speed. We can calculate how long it takes the cheetah to run 120 m with our answers from part (b). After it accelerates to its top speed and covers the distance we calculated in part (b), it runs at a constant speed for the remainder of the 120 m.

SOLVE

Part a)

$$29.0\frac{\text{m}}{\text{s}} \times \frac{3600\text{ s}}{1\text{ h}} \times \frac{1\text{ km}}{1000\text{ m}} \times \frac{1\text{ mi}}{1.61\text{ km}} = \boxed{64.8\frac{\text{mi}}{\text{h}}}$$

Part b)

$$a_x = \frac{\Delta v_x}{\Delta t} = \frac{20.0\frac{\text{m}}{\text{s}}}{2.50 \text{ s}} = 8.00\frac{\text{m}}{\text{s}^2}$$

$$v_x = v_{0x} + a_x t$$

$$t = \frac{v_x - v_{0x}}{a_x} = \frac{29.0\frac{\text{m}}{\text{s}} - 0}{8.00\frac{\text{m}}{\text{s}^2}} = \boxed{3.62 \text{ s}}$$

$$v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$$

$$\Delta x = \frac{v_x^2 - v_{0x}^2}{2a_x} = \frac{\left(29.0\frac{\text{m}}{\text{s}}\right)^2 - 0}{2\left(8.00\frac{\text{m}}{\text{s}^2}\right)} = \boxed{52.6 \text{ m}}$$

Part c) While the cheetah is accelerating to its top speed, it covers 52.6 m in 3.62 s. During the remaining 120 m − 52.6 m = 67.4 m, the cheetah runs at a constant speed:

$$\frac{67.4 \text{ m}}{\left(29.0\frac{\text{m}}{\text{s}}\right)} = 2.32 \text{ s}$$

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The total time it takes the cheetah to run 120 m is 3.62 s + 2.32 s = $\boxed{5.94 \text{ s}}$.

REFLECT

Be sure to reread the problem statement as you solve the various parts of the problem. It is easy to miss an important assumption or piece of data that is invaluable later on. For example, in this problem, we were told that the cheetah's acceleration drops to zero once it reaches its top speed. We didn't need to use this information until part (c) of the problem.

2.67

SET UP

The severity index (SI) is defined as SI = $a^{5/2}t$, where a is the acceleration in multiples of g and t is the time the acceleration lasts. We are given a change in speed and acceleration, so we can use the definition of average acceleration to calculate the time. We need to divide the given acceleration by g before plugging it into the SI equation. After calculating the time and converting the initial speed of 5.00 km/h into m/s, we can find the distance the person moves due to the collision.

SOLVE

Part a)

$$\Delta v_x = 15.0\frac{\text{km}}{\text{h}} \times \frac{1 \text{ h}}{3600 \text{ s}} \times \frac{1000 \text{ m}}{1 \text{ km}} = 4.17\frac{\text{m}}{\text{s}}$$

$$a_x = \frac{\Delta v_x}{\Delta t}\text{, so } \Delta t = \frac{\Delta v_x}{a_x} = \frac{4.17\frac{\text{m}}{\text{s}}}{35.0\frac{\text{m}}{\text{s}^2}} = 0.119\text{ s}$$

$$\text{SI} = a^{5/2}t = \left(\frac{35.0\frac{\text{m}}{\text{s}^2}}{g}\right)^{5/2}(0.119\text{ s}) = \left(\frac{35.0\frac{\text{m}}{\text{s}^2}}{9.80\frac{\text{m}}{\text{s}^2}}\right)^{5/2}(0.119\text{ s}) = \boxed{2.87\text{ s}}$$

Part b)

$$v_{0x} = 5.00\frac{\text{km}}{\text{h}} \times \frac{1\text{ h}}{3600\text{ s}} \times \frac{1000\text{ m}}{1\text{ km}} = 1.39\frac{\text{m}}{\text{s}}$$

$$x = x_0 + v_{0x}t + \frac{1}{2}a_xt^2 = \left(1.39\frac{\text{m}}{\text{s}}\right)(0.119\text{ s}) + \frac{1}{2}\left(35.0\frac{\text{m}}{\text{s}^2}\right)(0.119\text{ s})^2 = \boxed{0.413\text{ m}}$$

REFLECT

An acceleration of 35 m/s^2 is around 3.5*g*, which is a similar *g*-force to what astronauts on the space shuttle experience upon reentry. A head impact with an SI of around 400 can result in a concussion or unconsciousness, and there is a 50% chance of death for an impact with an SI of 1000.

2.68

SET UP

Starting from the front of a stopped train, a man walks 12 steps that are each 82.0 cm (0.820 m) in length. The train then begins to accelerate at a rate of 0.400 m/s^2. After 10.0 s, the man has walked another 20 steps and the end of the moving train has passed him. The total length of the train is the sum of these three distances: the distance the man walked while the train was stopped, the distance the accelerating train covers in 10.0 s, and the distance the man walked while the train was moving. Because the train's acceleration is constant, we can calculate the distance it covers in 10.0 s starting from rest using $x = x_0 + v_{0x}t + \frac{1}{2}a_xt^2$.

SOLVE

Distance the man covered before the train starts to move: (0.820 m)(12) = 9.84 m
Distance the train covers in 10.0 s starting from rest:

$$x = x_0 + v_{0x}t + \frac{1}{2}a_xt^2 = 0 + 0 + \frac{1}{2}\left(0.400\frac{\text{m}}{\text{s}^2}\right)(10.0\text{ s})^2 = 20.0\text{ m}$$

Distance the man covers while train is moving: (0.820 m)(20.0) = 16.4 m
Total distance covered = 9.84 m + 20.0 m + 16.4 m = $\boxed{46.2\text{ m}}$.

REFLECT

This corresponds to around 150 ft. An average train car is around 50 ft in length, so this particular train would have three cars in it, which is small, but reasonable.

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2.69

SET UP

Blythe and Geoff are running a 1.00-km race with different strategies. Blythe runs the first 600 m at a constant speed of 4.00 m/s. She accelerates at a constant rate for 1.00 min (60.0 s) until she reaches her top speed of 7.50 m/s. We can use the definition of average acceleration and $x = x_0 + v_{0x}t + \frac{1}{2}a_xt^2$ to calculate how much distance she covers in that minute. She runs the remainder of the 1.00 km at 7.50 m/s. Geoff, on the other hand, starts from rest and accelerates up to his top speed of 8.00 m/s in 3.00 min (180 s). As with Blythe, we can use the definition of average acceleration and $x = x_0 + v_{0x}t + \frac{1}{2}a_xt^2$ to calculate how much distance he covers in 3.00 min. He runs the remainder of the 1.00 km at 8.00 m/s. To determine who wins the race, we need to calculate who runs 1.00 km in the shorter amount of time.

SOLVE

Blythe

Distance covered while accelerating:

$$a_x = \frac{7.50\frac{\text{m}}{\text{s}} - 4.00\frac{\text{m}}{\text{s}}}{60.0\text{ s}} = 0.0583\frac{\text{m}}{\text{s}^2}$$

$$x = x_0 + v_{0x}t + \frac{1}{2}a_xt^2 = \left(4.00\frac{\text{m}}{\text{s}}\right)(60.0\text{ s}) + \frac{1}{2}\left(0.0583\frac{\text{m}}{\text{s}^2}\right)(60.0\text{ s})^2 = 345\text{ m}$$

Distance covered while running at her top speed: 1000 m − 600 m − 345 m = 55 m.

Total time of Blythe's run:

$$t_{\text{Blythe}} = \frac{600\text{ m}}{4.00\frac{\text{m}}{\text{s}}} + 60.0\text{ s} + \frac{55\text{ m}}{7.50\frac{\text{m}}{\text{s}}} = \boxed{217\text{ s}}$$

Geoff

Distance covered while accelerating:

$$a_x = \frac{8.00\frac{\text{m}}{\text{s}} - 0}{180\text{ s}} = 0.0444\frac{\text{m}}{\text{s}^2}$$

$$x = x_0 + v_{0x}t + \frac{1}{2}a_xt^2 = 0 + \frac{1}{2}\left(0.0444\frac{\text{m}}{\text{s}^2}\right)(180\text{ s})^2 = 719\text{ m}$$

Distance covered while running at his top speed: 1000 m − 719 m = 281 m.

Total time of Geoff's run:

$$t_{\text{Geoff}} = 180\text{ s} + \frac{281\text{ m}}{8.00\frac{\text{m}}{\text{s}}} = \boxed{215\text{ s}}$$

Since he runs 1 km in less time, $\boxed{\text{Geoff wins the race}}$.

REFLECT

Geoff's time is about 3.5 min and his average speed is 10.4 mi/h; Blythe's average speed is 10.3 mi/h. These are respectable times to run a kilometer. Remember that 1 km is around 0.63 mi.

2.70

SET UP

A plot of velocity versus time is given. The instantaneous acceleration at a specific time is equal to the slope of the tangent line to the v versus t plot. Because the velocity appears linear over the various intervals, we can approximate the tangent to the curve as the slope of the line.

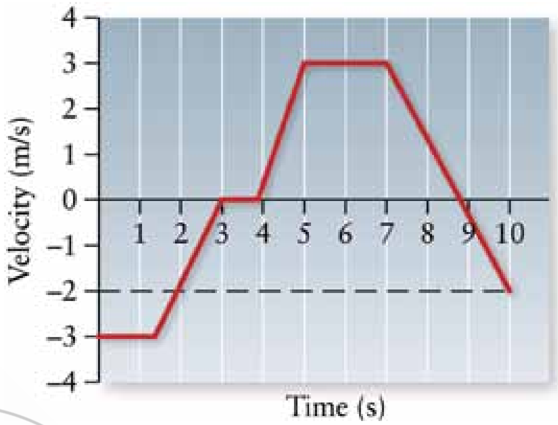

Figure 2-8 Problem 70

SOLVE

Acceleration at $t = 2$ s:

$$a(2\text{ s}) = \frac{0\frac{\text{m}}{\text{s}} - \left(-3\frac{\text{m}}{\text{s}}\right)}{3\text{ s} - 1.5\text{ s}} = \boxed{2\frac{\text{m}}{\text{s}^2}}$$

Acceleration at $t = 4.5$ s:

$$a(4.5\text{ s}) = \frac{3\frac{\text{m}}{\text{s}} - 0\frac{\text{m}}{\text{s}}}{5\text{ s} - 4\text{ s}} = \boxed{3\frac{\text{m}}{\text{s}^2}}$$

Acceleration at $t = 6$ s is $\boxed{0}$.

Acceleration at $t = 8$ s:

$$a(8\text{ s}) = \frac{\left(-2\frac{\text{m}}{\text{s}}\right) - 3\frac{\text{m}}{\text{s}}}{10\text{ s} - 7\text{ s}} = \boxed{1.7\frac{\text{m}}{\text{s}^2}}$$

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REFLECT

Because the acceleration was constant over the various time intervals, the instantaneous acceleration is equal to the average acceleration.

2.71

SET UP

A ball is dropped from an unknown height above your window. You observe that the ball takes 0.180 s to traverse the length of your window, which is 1.50 m. We can calculate the velocity of the ball when it is at the top of the window from the length of the window, the acceleration due to gravity, and the time it takes to pass by the window. Once we have the velocity at that point, we can determine the height the ball needed to fall to achieve that speed, assuming that its initial velocity was zero. Throughout the problem, we will define *down* to be negative.

SOLVE

Speed of ball at top of window:

$$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$$

$$\Delta y = v_{0y}t + \frac{1}{2}(-g)t^2$$

$$v_{0y} = \frac{\Delta y + \frac{1}{2}gt^2}{t} = \frac{(-1.50\text{ m}) + \frac{1}{2}\left(9.80\frac{\text{m}}{\text{s}^2}\right)(0.180\text{ s})^2}{(0.180\text{ s})} = -7.45\frac{\text{m}}{\text{s}}$$

Distance the ball drops to achieve a speed of 7.45 m/s:

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$$

$$v_y^2 = v_{0y}^2 + 2(-g)(\Delta y)$$

$$\Delta y = \frac{v_y^2 - v_{0y}^2}{2(-g)} = \frac{\left(-7.45\frac{\text{m}}{\text{s}}\right)^2 - 0}{2\left(-9.80\frac{\text{m}}{\text{s}^2}\right)} = -2.83\text{ m}$$

The ball started at a distance of $\boxed{2.83\text{ m}}$ above your window.

REFLECT

Be careful with the signs of Δy, a, and v in this problem.

2.72

SET UP

A ball is tossed straight up into the air at an initial speed of 15.0 m/s. Because the ball is under the influence of gravity, we can calculate the time(s) at which the ball is 5.00 m and 7.00 m above its release point using $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$. The equation $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ will let us find the speed of the ball 7.00 m above its release point.

SOLVE

Part a)

$$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2 = y_0 + v_{0y}t + \frac{1}{2}(-g)t^2$$

$$\frac{-g}{2}t^2 + v_{0y}t - \Delta y = 0$$

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$$t = \frac{-v_{0y} \pm \sqrt{v_{0y}^2 - 4\left(-\frac{g}{2}\right)(-\Delta y)}}{2\left(-\frac{g}{2}\right)} = \frac{-v_{0y} \pm \sqrt{v_{0y}^2 - 2g(\Delta y)}}{-g}$$

$$= \frac{-\left(15.0\frac{\text{m}}{\text{s}}\right) \pm \sqrt{\left(15.0\frac{\text{m}}{\text{s}}\right)^2 - 2\left(9.80\frac{\text{m}}{\text{s}^2}\right)(5.00\text{ m})}}{-\left(9.80\frac{\text{m}}{\text{s}^2}\right)} = \frac{-\left(15.0\frac{\text{m}}{\text{s}}\right) \pm \left(11.3\frac{\text{m}}{\text{s}}\right)}{-\left(9.80\frac{\text{m}}{\text{s}^2}\right)} = \boxed{0.378\text{ s and }2.68\text{ s}}$$

Part b)

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0) = v_{0y}^2 + 2(-g)(\Delta y)$$

$$|v_y| = |\sqrt{(v_{0y})_0^2 - 2g(\Delta y)}| = \left|\sqrt{\left(15.0\frac{\text{m}}{\text{s}}\right)^2 - 2\left(9.80\frac{\text{m}}{\text{s}^2}\right)(7.00\text{ m})}\right| = \boxed{9.37\frac{\text{m}}{\text{s}}}$$

Part c)

$$y = y_0 + v_{0y}t + \frac{1}{2}a_yt^2 = y_0 + v_{0y}t + \frac{1}{2}(-g)t^2$$

$$\frac{-g}{2}t^2 + v_{0y}t - \Delta y = 0$$

$$t = \frac{-v_{0y} \pm \sqrt{v_{0y}^2 - 4\left(-\frac{g}{2}\right)(-\Delta y)}}{2\left(-\frac{g}{2}\right)} = \frac{-v_{0y} \pm \sqrt{v_{0y}^2 - 2g(\Delta y)}}{-g}$$

$$= \frac{-\left(15.0\frac{\text{m}}{\text{s}}\right) \pm \sqrt{\left(15.0\frac{\text{m}}{\text{s}}\right)^2 - 2\left(9.80\frac{\text{m}}{\text{s}^2}\right)(7.00\text{ m})}}{-\left(9.80\frac{\text{m}}{\text{s}^2}\right)} = \frac{-\left(15.0\frac{\text{m}}{\text{s}}\right) \pm \left(9.37\frac{\text{m}}{\text{s}}\right)}{-\left(9.80\frac{\text{m}}{\text{s}^2}\right)}$$

$$= \boxed{0.574\text{ s and }2.49\text{ s}}$$

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REFLECT

There are two answers to parts (a) and (c) because the ball passes through those points on both its way up into the air and its way back down. There is only one answer to part (b) because we are asked about the ball's *speed*, not velocity.

2.73

SET UP

Coraline drops a rock into a well of unknown depth, which we will call Δy. After dropping it, she hears the sound of the rock hitting the bottom $t_{\text{total}} = 5.50$ s later. We can split this time up into two parts: #1) the rock falling a distance Δy in a time $t_{\text{free fall}}$ and #2) the sounds traveling a distance Δy in a time t_{sound}. We can write each time in terms of the common Δy and add them together to give t_{total}. From this we can solve for the depth of the well.

SOLVE

$$t_{\text{total}} = t_{\text{free fall}} + t_{\text{sound}} = 5.50\text{ s}$$

Free fall:

$$y = y_0 + v_{0y}t_{\text{free fall}} + \frac{1}{2}a_y t_{\text{free fall}}^2$$

$$\Delta y = 0 + \frac{1}{2}(-g)t_{\text{free fall}}^2$$

$$t_{\text{free fall}} = \sqrt{\left|\frac{2(\Delta y)}{-g}\right|}$$

(The absolute value sign is there since we are only interested in the distance and not the displacement.)

Sound:

$$v_{\text{sound}} = \frac{\Delta y}{t_{\text{sound}}}$$

$$t_{\text{sound}} = \frac{\Delta y}{v_{\text{sound}}}$$

Solving for Δy:

$$t_{\text{total}} = t_{\text{free fall}} + t_{\text{sound}} = \sqrt{\frac{2(\Delta y)}{g}} + \frac{\Delta y}{v_{\text{sound}}}$$

This is a quadratic equation in terms of the variable $\sqrt{(\Delta y)}$:

$$\frac{\Delta y}{v_{\text{sound}}} + \sqrt{\frac{2(\Delta y)}{g}} - t_{\text{total}} = 0 = \frac{1}{v_{\text{sound}}}(\sqrt{\Delta y})^2 + \sqrt{\frac{2}{g}}\sqrt{(\Delta y)} - t_{\text{total}}$$

Using the quadratic formula:

$$\sqrt{(\Delta y)} = \frac{-\sqrt{\frac{2}{g}} \pm \sqrt{\frac{2}{g} - 4\left(\frac{1}{v_{\text{sound}}}\right)(-t_{\text{total}})}}{2\left(\frac{1}{v_{\text{sound}}}\right)} = \frac{-\sqrt{\frac{2}{g}} \pm \sqrt{\frac{2}{g} + \frac{4t_{\text{total}}}{v_{\text{sound}}}}}{\frac{2}{v_{\text{sound}}}}$$

$$= \frac{-\sqrt{\frac{2}{\left(9.80\frac{\text{m}}{\text{s}^2}\right)}} \pm \sqrt{\frac{2}{\left(9.80\frac{\text{m}}{\text{s}^2}\right)} + \frac{4(5.50\text{ s})}{\left(340\frac{\text{m}}{\text{s}}\right)}}}{\frac{2}{\left(340\frac{\text{m}}{\text{s}}\right)}} = \frac{-0.452 \pm 0.518}{0.00588}\text{ m}^{1/2}$$

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Taking the positive root,

$$\sqrt{(\Delta y)} = \frac{-0.452 + 0.518}{0.00588}\ \text{m}^{1/2} = 11.2\ \text{m}^{1/2}$$

We need to square this to get Δy:

$$\Delta y = (11.2\ \text{m}^{1/2})^2 = \boxed{125\ \text{m}}$$

REFLECT

Rather than solving the quadratic formula for $\sqrt{(\Delta y)}$, you could have squared the expression to get rid of the square root first. The majority of the time is due to the rock falling. It takes 5.1 s for the rock to fall to the water and only 0.4 s for the sound to reach Coraline's ears.

2.74

SET UP

Ten washers are tied to a long string at various locations. Washer #1 is 10 cm off the ground. When the string is dropped, the washers hit the floor with equal time intervals. This means that it takes t_1 s for washer #1 to fall to the ground, $t_2 = t_1 + t_1 = 2t_1$ for washer #2 to fall, and so on. Because all of the washers are undergoing free fall, we can relate the height of each washer above the floor to the time it takes it to hit the floor using $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$.

The distance y_n between neighboring washers is equal to the difference in the heights of the neighboring washers.

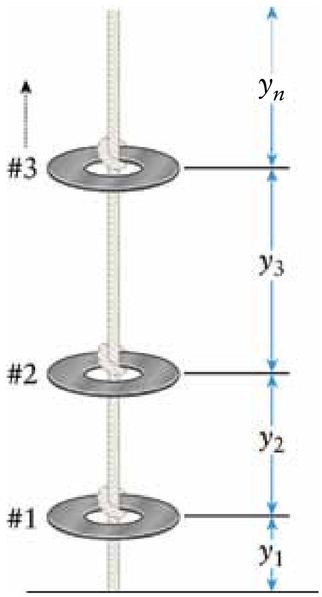

Figure 2-9 Problem 74

SOLVE

Let t_n be the time it takes the nth washer to hit the ground from a height h_n off the ground. Since all of the washers start at rest, we can relate h_n and t_n by:

$$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$$

$$0 - h_n = 0 + \frac{1}{2}(-g)t_n^2$$

$$h_n = \frac{1}{2}gt_n^2$$

We know that the washers hit the floor in equal time intervals. This means that it takes t_1 for washer #1 to fall to the ground, $t_2 = t_1 + t_1 = 2t_1$ for washer #2 to fall, and so on. In general, the nth washer will take nt_1 seconds to fall from a height h_n.

Plugging this information into our general height relationship:

$$h_n = \frac{1}{2}gt_n^2 = \frac{1}{2}g(nt_1)^2 = n^2\left(\frac{1}{2}gt_1^2\right) = n^2 h_1,\ \text{where } h_1 = 10\ \text{cm}$$

We are interested in the distance, y_n, between the nth washer and the washer below it ("nth $-$ 1"). This distance is related to their heights above the ground:

$$y_n = h_n - h_{n-1} = n^2h_1 - (n-1)^2h_1 = n^2h_1 - (n^2 - 2n + 1)h_1 = \boxed{(2n-1)h_1}$$

REFLECT

It is always a good idea to work through some simple cases to make sure your generalized answer is correct. For example, we can calculate y_1, the distance washer #1 is off the ground: $y_1 = (2 \cdot 1 - 1)h_1 = (1)h_1 = h_1 = 10$ cm, which is true. We can also calculate the time it takes washers #1 and #2 to fall and make sure the time intervals are equal:

$$h_1 = \frac{1}{2}gt_1^2$$

$$t_1 = \sqrt{\frac{2h_1}{g}} = 0.143 \text{ s}$$

$$h_2 = (2)^2 h_1 = 4h_1 = \frac{1}{2}gt_2^2$$

$$t_2 = \sqrt{\frac{8h_1}{g}} = 0.286 \text{ s}$$

Washer #1 takes 0.143 s to fall and washer #2 takes twice that time, which is consistent with the problem statement.

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2.75

SET UP

A rocket with two stages of rocket fuel is launched straight up into the air from rest. Stage 1 lasts 10.0 s and provides a net upward acceleration of 15.0 m/s^2. Stage 2 lasts 5.00 s and provides a net upward acceleration of 12.0 m/s^2. After Stage 2 finishes, the rocket continues to travel upward under the influence of gravity alone until it reaches its maximum height and then falls back toward Earth. We can split the rocket's flight into four parts: (1) Stage 1, (2) Stage 2, (3) between the end of Stage 2 and reaching the maximum height, and (4) falling from the maximum height back to Earth's surface. The acceleration of the rocket is constant over each of these legs, so we can use the constant acceleration equations to determine the total distance covered in each leg and the duration of each leg. The initial speed for legs #1 and #4 is zero, but we will need to calculate the initial speeds for legs #2 and #3. The maximum altitude is equal to the distance covered in legs #1–#3; the time required for the rocket to return to Earth is equal to the total duration of its flight, which is the sum of the durations of legs #1–#4.

SOLVE

Maximum altitude

Distance traveled in Stage 1:

$$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$$

$$\Delta y = 0 + \frac{1}{2}\left(15.0\frac{\text{m}}{\text{s}^2}\right)(10.0 \text{ s})^2 = 750 \text{ m}$$

Speed after Stage 1:

$$v_y = v_{0y} + a_y t = 0 + \left(15.0\frac{\text{m}}{\text{s}^2}\right)(10.0\text{ s}) = 150\frac{\text{m}}{\text{s}}$$

Distance traveled in Stage 2:

$$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$$

$$\Delta y = \left(150\frac{\text{m}}{\text{s}}\right)(5.00\text{ s}) + \frac{1}{2}\left(12.0\frac{\text{m}}{\text{s}^2}\right)(5.00\text{ s})^2 = 900\text{ m}$$

Speed after Stage 2:

$$v_y = v_{0y} + a_y t = \left(150\frac{\text{m}}{\text{s}}\right) + \left(12.0\frac{\text{m}}{\text{s}^2}\right)(5.00\text{ s}) = 210\frac{\text{m}}{\text{s}}$$

Distance traveled after Stage 2:

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$$

$$\Delta y = \frac{v_y^2 - v_{0y}^2}{2a_y} = \frac{0 - \left(210\frac{\text{m}}{\text{s}}\right)^2}{2\left(-9.80\frac{\text{m}}{\text{s}^2}\right)} = 2250\text{ m}$$

Maximum altitude: 750 m + 900 m + 2250 m = $\boxed{3.90 \times 10^3\text{ m}}$.

Time required to return to the surface

Time after Stage 2:

$$v_y = v_{0y} + a_y t$$

$$t = \frac{v_y - v_{0y}}{a_y} = \frac{0 - \left(210\frac{\text{m}}{\text{s}}\right)}{\left(-9.80\frac{\text{m}}{\text{s}^2}\right)} = 21.4\text{ s}$$

Time from maximum height to the ground:

$$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2 = y_0 + v_{0y}t + \frac{1}{2}(-g)t^2$$

$$t = \sqrt{\frac{2(\Delta y)}{-g}} = \sqrt{\frac{2(-3.90 \times 10^3\text{ m})}{-\left(9.80\frac{\text{m}}{\text{s}^2}\right)}} = 28.2\text{ s}$$

Total time of flight: 10.0 s + 5.00 s + 21.4 s + 28.2 s = $\boxed{64.6\text{ s}}$.

REFLECT

An altitude of 3900 m is around 2.5 mi. The simplest way of solving this problem was to split it up into smaller, more manageable calculations and then put all of the information together.

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2.76

SET UP

A lacrosse ball has an initial velocity of v_{0y} straight up when it leaves a stick that is 2.00 m above the ground. It travels past a 1.25-m-high window in 0.400 s. The base of the window is 13.0 m above the ground, or 11.0 m above the stick. From the information about the window, we can calculate the speed of the ball when it is at the base of the window. Once we know the speed of the ball at the base of the window, we can calculate the necessary initial launch speed of the ball.

SOLVE

Speed at the base of the window:

$$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$$

$$v_{0y} = \frac{\Delta y - \frac{1}{2}a_y t^2}{t} = \frac{(1.25 \text{ m}) - \frac{1}{2}\left(-9.80\frac{\text{m}}{\text{s}^2}\right)(0.400 \text{ s})^2}{(0.400 \text{ s})} = 5.08\frac{\text{m}}{\text{s}}$$

Initial speed:

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$$

$$v_{0y} = \sqrt{v_y^2 - 2a_y(\Delta y)} = \sqrt{\left(5.08\frac{\text{m}}{\text{s}}\right)^2 - 2\left(-9.80\frac{\text{m}}{\text{s}^2}\right)(11.0 \text{ m})} = \boxed{15.5\frac{\text{m}}{\text{s}}}$$

REFLECT

A speed of 15.5 m/s is around 35 mph. Some lacrosse shots on goal can be 100 mph!

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2.77

SET UP

A black mamba snake has a length of 4.30 m and a top speed of 8.90 m/s. It starts at rest nose-to-nose with a mongoose. The snake accelerates straight forward from rest at a constant rate of 18.0 m/s^2. We can calculate the time it takes the snake to reach its top speed using $v_x = v_{0x} + a_x t$ and then the distance the snake travels during this time using $x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2$. Then, we can determine the time it takes the snake to travel the full length of its body. This will tell us the reaction time the mongoose must have in order to catch the snake.

SOLVE

Part a)

$$v_x = v_{0x} + at_x$$

$$t = \frac{v_x - v_{0x}}{a_x} = \frac{8.90\frac{\text{m}}{\text{s}} - 0}{18.0\frac{\text{m}}{\text{s}^2}} = \boxed{0.494 \text{ s}}$$

Part b)

$$x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2 = 0 + 0 + \frac{1}{2}\left(18.0\frac{\text{m}}{\text{s}^2}\right)(0.494\ \text{s})^2 = \boxed{2.20\ \text{m}}$$

Part c)

The snake reaches its top speed in 0.494 s. In this time, it travels a distance of 2.20 m. In order to travel the full length of its body, which is 4.60 m, it will travel an additional an additional distance at its maximum speed, 8.90 m/s.

Distance snake travels at maximum speed:
460 m − 220 m = 2.4 m
Time over which the snake travels at maximum speed:

$$v_{\text{average},x} = \frac{\Delta x}{\Delta t}$$

$$\Delta t = \frac{\Delta x}{v_{\text{average},x}} = \frac{2.40\ \text{m}}{8.90\ \text{m/s}} = 0.270\ \text{s}$$

Total time for snake to travel the length of its body:

$$0.494\ \text{s} + 0.270\ \text{s} = 0.764\ \text{s}$$

Thus, the mongoose has 0.764 s to catch the snake before the snake travels past.

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REFLECT

The black mamba's top speed is nearly 20 mph!

2.78

SET UP

Kharissia wants to complete a 1000-m race with an average speed of 8.00 m/s. She has already completed 750 m with an average speed of 7.20 m/s. We can use a weighted average to determine how fast she needs to run the final 250 m in order to have an overall average speed of 8.00 m/s. She completed 75.0% of the race with an average speed of 7.20 m/s. We can then solve for the average speed $v_{\text{average},x}$ at which she needs to run the remaining 25% of the race.

SOLVE

$$(0.750)\left(7.20\frac{\text{m}}{\text{s}}\right) + (0.250)v_{\text{average},x} = 8.00\ \frac{\text{m}}{\text{s}}$$

$$v_{\text{average},x} = \frac{8.00\frac{\text{m}}{\text{s}} - (7.20)\left(7.20\frac{\text{m}}{\text{s}}\right)}{(0.25)} = \boxed{10.4\frac{\text{m}}{\text{s}}}$$

REFLECT

Kharissia needs to run 2.8 m/s faster, on average, for the last 250 m of the race in order to achieve her goal overall speed.

2.79

SET UP

Steve Prefontaine ("Pre") completed a 10-km race in 27 min, 43.6 s. He ran the first 9 km in 25.0 min, which means he ran the final 1 km in 2 min, 43.6 s (= 163.6 s). During the final 1000 m, he accelerates for 60.0 s and maintains that increased speed for the remainder of the race (that is, 103.6 s). We are told that his speed at the 9-km mark is equal to the average speed over the first 9 km. We can use the constant acceleration equations to write the total distance of the final leg in terms of the acceleration a_x. He accelerates over a distance of Δx_1 for $t_1 = 60.0$ s and then runs at his final constant speed over a distance of Δx_2 for $t_2 = 103.6$ s. These distances must sum to 1000 m.

SOLVE

Average speed for the first 9 km:

$$v_{\text{first 9 km}} = \frac{9.00\text{ km}}{25.0\text{ min}} \times \frac{1000\text{ m}}{1\text{ km}} \times \frac{1\text{ min}}{60\text{ s}} = 6.00\frac{\text{m}}{\text{s}}$$

To calculate the total time it takes to run the race, begin with:

$$27\text{ min} \times \frac{60\text{ s}}{1\text{ min}} = 1620\text{ s}$$

Total time = 1620 s + 43.6 s = 1663.6 s. Time it takes to run the first 9 km :

$$25\text{ min} \times \frac{60\text{ s}}{1\text{ min}} = 1500\text{ s}$$

Time for last 1 km = 1663.6 s − 1500 s = 163.6 s.

Calculating his acceleration:

$$\Delta x_{\text{total}} = 1000\text{ m} = \Delta x_1 + \Delta x_2$$

$$\Delta x_1 = v_{0x}t_1 + \frac{1}{2}a_x t_1^2$$

$$\Delta x_2 = v_{1x}t_2 = (v_{0x} + a_x t_1)t_2$$

$$\Delta x_{\text{total}} = 1000\text{ m} = \left(v_{0x}t_1 + \frac{1}{2}a_x t_1^2\right) + (v_{0x} + a_x t_1)t_2$$

$$= \left(\left(6.00\frac{\text{m}}{\text{s}}\right)(60.0\text{ s}) + \frac{1}{2}a_x(60.0\text{ s})^2\right) + \left(\left(6.00\frac{\text{m}}{\text{s}}\right) + a_x(60.0\text{ s})\right)(103.6\text{ s})$$

$$1000\text{ m} = (981.6\text{ m}) + (8016\text{ s}^2)a_x$$

$$\boxed{a_x = 2.30 \times 10^{-3}\frac{\text{m}}{\text{s}^2}}$$

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REFLECT

During the last portion of the race, Pre travels $\Delta x_1 = \left(6.0\frac{\text{m}}{\text{s}}\right)(60\text{ s}) + \frac{1}{2}\left(0.0023\frac{\text{m}}{\text{s}^2}\right)(60\text{ s})^2 = 364\text{ m}$ while accelerating up to a final speed of $v_1 = \left(6.0\frac{\text{m}}{\text{s}}\right) + \left(0.0023\frac{\text{m}}{\text{s}^2}\right)(60\text{ s}) = 6.138\frac{\text{m}}{\text{s}}$. At this speed he travels a total distance of $\Delta x_2 = \left(6.138\frac{\text{m}}{\text{s}}\right)(103.6\text{ s}) = 636\text{ m}$. These two final distances do indeed add up to 1000 m: $364\text{ m} + 636\text{ m} = 1000\text{ m}$.

2.80

SET UP

A ball (ball A) is thrown straight down at a speed of 1.50 m/s from the top of a tall tower. After 2.00 s a second ball (ball B) is thrown up at a speed of 4.00 m/s from the same starting position. Since both balls are undergoing free fall, we can calculate the distance each ball is relative to the top of the tower as a function of time. Ball A is in flight for 6.00 s, while Ball B is in flight for 4.00 s. In order to calculate the minimum separation between the balls, we first need to calculate the position of Ball A when Ball B is thrown. This will give us insight into what the minimum separation will be.

SOLVE

Distance apart 4 s after Ball B is thrown:

$$\Delta y_A = v_{A0y}t_A + \frac{1}{2}a_y t_A^2 = \left(-1.50\frac{\text{m}}{\text{s}}\right)(6.00\text{ s}) + \frac{1}{2}\left(-9.80\frac{\text{m}}{\text{s}^2}\right)(6.00\text{ s})^2 = -185\text{ m}$$

$$\Delta y_B = v_{B0y}t_B + \frac{1}{2}a_y t_B^2 = \left(4.00\frac{\text{m}}{\text{s}}\right)(4.00\text{ s}) + \frac{1}{2}\left(-9.80\frac{\text{m}}{\text{s}^2}\right)(4.00\text{ s})^2 = -62.4\text{ m}$$

$$\Delta y_B - \Delta y_A = (-62.4\text{ m}) - (-185\text{ m}) = \boxed{123\text{ m}}$$

Location of Ball A when Ball B is thrown:

$$\Delta y_A = v_{A0y}t_A + \frac{1}{2}a_y t_A^2 = \left(-1.50\frac{\text{m}}{\text{s}}\right)(2.00\text{ s}) + \frac{1}{2}\left(-9.80\frac{\text{m}}{\text{s}^2}\right)(2.00\text{ s})^2 = -22.6\text{ m}$$

This is already below the starting position, so the minimum separation between the balls occurs at the $\boxed{\text{instant the second ball is thrown}}$; the minimum separation between the balls is $\boxed{22.6\text{ m}}$.

REFLECT

We did not need to know the exact height of the tower in order to find the relative separation of the balls because they started from a common location.

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2.81

SET UP

A rocket with two stages of rocket fuel is launched straight up into the air from rest. Stage 1 lasts 15.0 s and provides a net upward acceleration of 2.00 m/s^2. Stage 2 lasts 12.0 s and provides a net upward acceleration of 3.00 m/s^2. After Stage 2 finishes, the rocket continues to travel upward under the influence of gravity alone until it reaches its maximum height and then falls back toward Earth. We can split the rocket's flight into four parts: (1) Stage 1, (2) Stage 2, (3) between the end of Stage 2 and reaching the maximum height, and (4) falling from the maximum height back to Earth's surface. The acceleration of the rocket is constant over each of these legs, so we can use the constant acceleration equations to determine the total distance covered in each leg and the duration of each leg. The initial speed for legs #1 and #4 is zero, but we will need to calculate the initial speeds for legs #2 and #3. The maximum altitude is equal to the distance covered in legs #1–#3. The average speed is the total distance covered by the rocket divided by the total time of the flight. Because the rocket starts and ends at the same position, its displacement and, therefore, average velocity are both equal to zero.

SOLVE

Part a)

Distance traveled in Stage 1:

$$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$$

$$\Delta y = 0 + \frac{1}{2}\left(2.00\frac{\text{m}}{\text{s}^2}\right)(15.0\text{ s})^2 = 225\text{ m}$$

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Speed after Stage 1:

$$v_y = v_{0y} + a_y t = 0 + \left(2.00\frac{\text{m}}{\text{s}^2}\right)(15.0\text{ s}) = 30.0\frac{\text{m}}{\text{s}}$$

Distance traveled in Stage 2:

$$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$$

$$\Delta y = \left(30.0\frac{\text{m}}{\text{s}}\right)(12.0\text{ s}) + \frac{1}{2}\left(3.00\frac{\text{m}}{\text{s}^2}\right)(12.0\text{ s})^2 = 576\text{ m}$$

Speed after Stage 2:

$$v_y = v_{0y} + a_y t = \left(30.0\frac{\text{m}}{\text{s}}\right) + \left(3.00\frac{\text{m}}{\text{s}^2}\right)(12.0\text{ s}) = 66.0\frac{\text{m}}{\text{s}}$$

Distance traveled after Stage 2:

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$$

$$\Delta y = \frac{v_y^2 - v_{0y}^2}{2a_y} = \frac{0 - \left(66.0\frac{\text{m}}{\text{s}}\right)^2}{2\left(-9.80\frac{\text{m}}{\text{s}^2}\right)} = 222 \text{ m}$$

Maximum altitude: 225 m + 576 m + 222 m = $\boxed{1023 \text{ m}}$.

Part b)

Time after Stage 2:

$$v_y = v_{0y} + a_y t$$

$$t = \frac{v_y - v_{0y}}{a_y} = \frac{0 - \left(66.0\frac{\text{m}}{\text{s}}\right)}{\left(-9.80\frac{\text{m}}{\text{s}^2}\right)} = 6.73 \text{ s}$$

Time from maximum height to the ground:

$$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$$

$$\Delta y = 0 + \frac{1}{2}(-g)t^2$$

$$t = \sqrt{\frac{2(\Delta y)}{-g}} = \sqrt{\frac{2(-1023 \text{ m})}{-\left(9.80\frac{\text{m}}{\text{s}^2}\right)}} = 14.4 \text{ s}$$

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Total time of flight: 15.0 s + 12.0 s + 6.73 s + 14.4 s = 48.1 s.

i) Average speed:

$$v_{\text{average},y} = \frac{2046 \text{ m}}{48.1 \text{ s}} = \boxed{42.5\frac{\text{m}}{\text{s}}}$$

ii) Average velocity = $\boxed{0}$ because the rocket's displacement is zero.

REFLECT

Although they are used interchangeably in everyday speech, speed and velocity have different meanings in physics. Average speed is the total *distance* traveled per time, while average velocity is the total *displacement* traveled per time.

$$t = \frac{-(-5.00 \text{ m/s}) \pm \sqrt{(-5.00 \text{ m/s})^2 - 4(4.90 \text{ m/s}^2)(2.00 \text{ m})}}{2(4.90 \text{ m/s}^2)}$$

The quantity inside the square root is

$$(-5.00 \text{ m/s})^2 - 4(4.90 \text{ m/s}^2)(2.00 \text{ m}) = 25.0 \text{ m}^2/\text{s}^2 - 39.2 \text{ m}^2/\text{s}^2 = -14.2 \text{ m}^2/\text{s}^2$$

The square root of a negative number is *imaginary:* There is no real number that is equal to $\sqrt{-14.2}$. So this problem has no solution, and we conclude that the ball never reaches a height of 2.00 m.

Questions and Problems

In a few problems, you are given more data than you actually need; in a few other problems, you are required to supply data from your general knowledge, outside sources, or informed estimate.

Interpret as significant all digits in numerical values that have trailing zeros and no decimal points. For all problems, use $g = 9.80 \text{ m/s}^2$ for the free-fall acceleration due to gravity. Neglect friction and air resistance unless instructed to do otherwise.

• Basic, single-concept problem

•• Intermediate-level problem, may require synthesis of concepts and multiple steps

••• Challenging problem

SSM *Solution is in Student Solutions Manual*

Conceptual Questions

1. •What happens to an object's velocity when the object's acceleration is in the opposite direction to the velocity? SSM

2. •Discuss the direction and magnitude of the velocity and acceleration of a ball that is thrown straight up, from the time it leaves your hand until it returns and you catch it.

3. •Explain the difference between average *speed* and average *velocity*.

4. •Under what circumstances will the displacement and the distance traveled be the same? When will they be different?

5. •Compare the concepts of *speed* and *velocity*. Do these two quantities have the same units? When can you interchange these two with no confusion? When would it be problematic? SSM

6. •Which speed gives the largest straight-line displacement in a fixed time: 1 m/s, 1 km/h, or 1 mi/h?

7. •The manufacturer of a high-end sports car plans to present its latest model's acceleration in units of m/s^2 rather than the customary units of miles/hour/second. Discuss the advantages and disadvantages of such an ad campaign in the global marketplace. Would you suggest making any modifications to this plan?

8. •The upper limit of the braking acceleration for most cars is about the same magnitude as the acceleration due to gravity on Earth. Compare the braking motion of a car with a ball thrown straight upward. Both have the same initial speed. Ignore air resistance.

9. •Under what circumstance(s) will the average velocity of a moving object be the same as the instantaneous velocity? SSM

10. •A video is made of a ball being thrown up into the air and then falling. Is there any way to tell whether the video is being played backward? Explain your answer.

11. •The velocity of a ball thrown straight up decreases as it rises. Does its acceleration increase, decrease, or remain the same as the ball rises? Explain your answer.

12. •Under what circumstances is it acceptable to omit the units during a physics calculation? What is the advantage of using SI units in *all* calculations, no matter how trivial?

13. •A device launches a ball straight up from the edge of a cliff so that the ball falls and hits the ground at the base of the cliff. The device is then turned so that a second, identical ball is launched straight down from the same height. Does the second ball hit the ground with a velocity that is higher than, lower than, or the same as the first ball? Explain your answer. SSM

14. •What are the units of the slopes of the following graphs: (a) displacement versus time? (b) velocity versus time? (c) distance fallen by a dropped rock versus time?

15. •Is there any consistent reason why "up" can't be labeled as "negative" or "left" as "positive"? Explain why many physics professors and textbooks recommend choosing *up* and *right* as the positive directions in a description of motion.

Multiple-Choice Questions

16. •Figure 2-23 shows a position versus time graph for a moving object. At which lettered point is the object moving the slowest?

A. A
B. B
C. C
D. D
E. E SSM

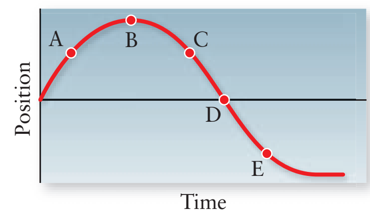

Figure 2-23 Problem 16

17. •Figure 2-24 shows a position versus time graph for a moving object. At which lettered point is the object moving the fastest?

A. A
B. B
C. C
D. D
E. E

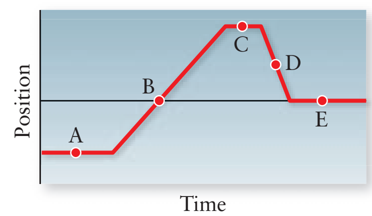

Figure 2-24 Problem 17

18. •A person is driving a car down a straight road. The instantaneous acceleration is constant and in the direction of the car's motion. The speed of the car is
   A. increasing.
   B. decreasing.
   C. constant.
   D. increasing but will eventually decrease.
   E. decreasing but will eventually increase.

19. •A person is driving a car down a straight road. The instantaneous acceleration is constant and directed opposite the direction of the car's motion. The speed of the car is
   A. increasing.
   B. decreasing.
   C. constant.
   D. increasing but will eventually decrease.
   E. decreasing but will eventually increase.

20. •A 1-kg ball and a 10-kg ball are dropped from a height of 10 m at the same time. In the absence of air resistance,
   A. the 1-kg ball hits the ground first.
   B. the 10-kg ball hits the ground first.
   C. the two balls hit the ground at the same time.
   D. the 10-kg ball will take 10 times the amount of time to reach the ground.
   E. there is not enough information to determine which ball hits the ground first.

21. •When throwing a ball straight up, which of the following are correct about the magnitudes of its velocity (v) and its acceleration (a) at the highest point in its path?
   A. both $v = 0$ and $a = 0$
   B. $v \neq 0$, but $a = 0$
   C. $v = 0$, but $a = 9.80 \text{ m/s}^2$
   D. $v \neq 0$, but $a = 9.80 \text{ m/s}^2$
   E. There is not enough information to determine the velocity (v) and acceleration (a).

Estimation/Numerical Analysis

22. •**Medical** Estimate the acceleration, upon hitting the ground, of a painter who loses his balance and falls from a step stool. Compare this to the acceleration he would experience if he bends his knees as he hits the ground.

23. •Estimate the time required for an average car to reach freeway speeds. Estimate the time required for an average car to slow down to zero from freeway speeds.

24. •**Sports** A marathon race is just over 26 mi in length. Estimate the average speed of a runner who completes the marathon in 5 h.

25. ••**Medical** The severity of many sports injuries is related to the magnitude of the acceleration that an athlete's body undergoes as it comes to rest, especially when joints (such as ankles and knees) are not properly aligned during falls. (a) Estimate the acceleration of a woman who falls while running at full speed and comes to rest on a muddy field. Compare the acceleration to that of the same woman who falls while running at full speed and comes to rest on a running track made from a synthetic material. (b) Repeat these estimates for a male athlete. Assume they both are world-class athletes. SSM

26. • Suppose a 1000-km airline trip takes 3 h with about 30 min of that spent taxiing, taking off, and landing. Estimate your average speed while airborne.

27. •**Biology** Estimate the acceleration that a cat undergoes as it jumps from the floor to a countertop.

28. •**Astronomy** Estimate the speed of Earth as it orbits the Sun. Explain any assumptions that you make in your estimation.

29. • Estimate the acceleration of a large cruise ship that is leaving port to head out to sea. SSM

30. • (a) Estimate the displacement of a swimmer during a typical workout. (b) Estimate the distance swam during the same workout.

31. •**Sports** (a) Estimate the acceleration of a thrown baseball. (b) Estimate the acceleration of a kicked soccer ball.

32. • A trainer times his racehorse as it completes a workout on a long, straight track. The position versus time data are given below. Plot an x–t graph and calculate the average speed of the horse between (a) 0 and 10 s, (b) 10 and 30 s, and (c) 0 and 50 s.

x(m)	t(s)	x(m)	t(s)
0	0	500	30
90	5	550	35
180	10	600	40
270	15	650	45
360	20	700	50
450	25		

33. • Write the equations for $x(t)$ for each interval of constant acceleration motion for the object whose position as a function of time is shown in the following table. (*Hint:* Graph the data on a graphing calculator or in a spreadsheet.) SSM

x(m)	t(s)	x(m)	t(s)	x(m)	t(s)
−12	0	18	9	85	18
−6	1	24	10	90	19
0	2	33	11	95	20
6	3	45	12	100	21
12	4	60	13	90	22
15	5	65	14	80	23
15	6	70	15	70	24
15	7	75	16	70	25
15	8	80	17		

34. • A coconut is dropped from a tall tree. Complete the following table. You may wish to program a spreadsheet to calculate these values more quickly.

t(s)	y(m)	v(m/s)	a(m/s^2)
0	0	0	0
1			
2			
3			
4			
5			
10			

Problems

2-3 Solving straight-line motion problems: Constant velocity

35. •Convert the following speeds:
   A. 30.0 m/s = _____ km/h
   B. 14.0 mi/h = _____ km/h
   C. 90.0 km/s = _____ mi/h
   D. 88.0 ft/s = _____ mi/h
   E. 100 mi/h = _____ m/s

36. •A bowling ball moves from $x_1 = 3.50$ cm to $x_2 = -4.70$ cm during the time interval from $t_1 = 3.00$ s to $t_2 = 5.50$ s. What is the ball's average velocity?

37. •What must a jogger's average speed be in order to travel 13.0 km in 3.25 h?

38. •**Sports** The Olympic record for the marathon set in 2008 is 2 h, 6 min, 32 s. The marathon distance is 26.2 mi. What was the average speed of the record-setting runner in km/h?

39. ••**Sports** Kevin completes his morning workout at the pool. He swims 4000 m (80 laps in the 50-m-long pool) in 1.00 h. (a) What is the average velocity of Kevin during his workout? (b) What is his average speed? (c) With a burst of speed, Kevin swims one 25.0-m stretch in 9.27 s. What is Kevin's average speed over those 25 m? SSM

40. ••A student rides her bicycle home from physics class to get her physics book and then heads back to class. It takes her 21.0 min to make the 12.2 km trip home and 13.0 min to get back to class. (a) Calculate the average velocity of the student for the round-trip (from the lecture hall to home and back to the lecture hall). (b) Calculate her average speed for the trip from the lecture hall to her home. (c) Calculate the average speed of the girl for the trip from her home back to the lecture hall. (d) Calculate her average speed for the round-trip.

41. •A school bus takes 0.700 h to reach the school from your house. If the average speed of the bus is 56.0 km/h, how far does the bus have to travel?

42. ••A car traveling 80.0 km/h is 1500 m behind a truck traveling at 70.0 km/h. How long will it take the car to catch up with the truck?

43. •**Medical** Alcohol consumption slows people's reaction times. In a controlled government test, it takes a certain driver 0.320 s to hit the brakes in a crisis when unimpaired and 1.00 s when drunk. When the car is initially traveling at 90.0 km/h, how much farther does the car travel before coming to a stop when the person is drunk compared to sober? SSM

44. ••A jet takes off from SFO (San Francisco, CA) and flies to ORD (Chicago, IL). The distance between the airports is 3000 km. After a 1-h layover, the jet returns to San Francisco. The total time for the round-trip (including the layover) is 9 h, 52 min. If the westbound trip (from ORD to SFO) takes 24 more minutes than the eastbound portion, calculate the time required for each leg of the trip. What is the average speed for the overall trip? What is the average speed *without* the layover?

45. •**Biology** The position versus time graph for a red blood cell leaving the heart is shown in Figure 2-25. Determine the instantaneous speed of the red blood cell when $t = 10$ ms. Recall, 1 ms = 0.001 s, 1 mm = 0.001 m.

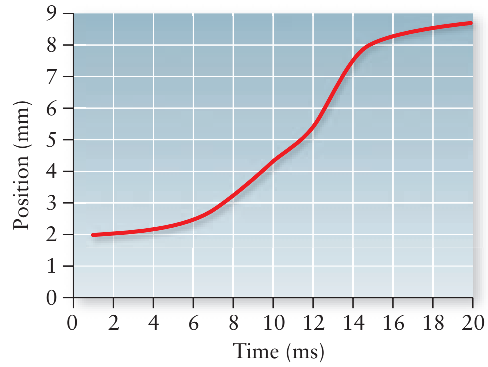

Figure 2-25 Problem 45

2-6 Solving straight-line motion problems: Constant acceleration

46. •Paola can flex her legs from a bent position through a distance of 20.0 cm. Paola leaves the ground when her legs are straight, at a speed of 4.43 m/s. Calculate the magnitude of her acceleration, assuming that it is constant.

47. •A runner starts from rest and achieves a maximum speed of 8.97 m/s. If her acceleration is 9.77 m/s^2, how long does it take her to reach that speed? SSM

48. •A car traveling at 35.0 km/h speeds up to 45.0 km/h in a time of 5.00 s. The same car later speeds up from 65.0 km/h to 75.0 km/h in a time of 5.00 s. (a) Calculate the magnitude of the constant acceleration for each of these intervals. (b) Determine the distance traveled by the car during each of these time intervals.

49. •A car starts from rest and reaches a maximum speed of 34.0 m/s in a time of 12.0 s. Calculate the magnitude of its average acceleration.

50. •The world's fastest cars are rated by the time required for them to accelerate from 0 to 60.0 mi/h. Convert 60.0 mi/h to kilometers per hour and then calculate the acceleration in m/s^2 for each of the cars on the following list:

1.	Bugatti Veyron 16.4	2.4 s
2.	Caparo T1	2.5 s
3.	Ultima GTR	2.6 s
4.	SSC Ultimate Aero TT	2.7 s
5.	Saleen S7 Twin Turbo	2.8 s

51. ••Using the information for the Bugatti Veyron in the previous problem, calculate the distance that the car would travel in the time it takes to reach 90.0 km/h, which is the speed limit on many Canadian roads. Compare your answer to the distance that the Saleen S7 Twin Turbo would travel while accelerating to the same final speed. SSM

52. •A driver is traveling at 30.0 m/s when he sees a moose crossing the road 80.0 m ahead. The moose becomes distracted and stops in the middle of the road. If the driver of the car slams on the brakes, what is the minimum constant acceleration he must undergo to stop short of the moose and avert an accident? (In British Columbia, Canada, alone, there are over 4000 moose–car accidents each year.)

53. •**Biology** A sperm whale can accelerate at about 0.100 m/s^2 when swimming on the surface. How far will a whale travel if it starts at a speed of 1.00 m/s and accelerates to a speed of 2.25 m/s? Assume the whale travels in a straight line. SSM

54. •At the start of a race, a horse accelerates out of the gate at a rate of 3.00 m/s^2. How long does it take the horse to cover the first 25.0 m of the race?

55. ••Derive the equation that relates position to speed and acceleration but in which the time variable does not appear. Start with the basic equation for the definition of acceleration, $a = (v - v_0)/t$, solve for t, and substitute the resulting expression into the position versus time equation, $x = x_0 + v_0 t + \frac{1}{2}at^2$.

2-8 Solving straight-line motion problems: Free fall

56. •A ball is dropped from rest at a height of 25.0 m above the ground. (a) How fast is the ball moving when it is 10.0 m above the ground? (b) How much time is required for it to reach the ground level? Ignore the effects of air resistance.

57. •Alex climbs to the top of a tall tree while his friend Gary waits on the ground below. Alex throws down a ball with an initial speed of 4.00 m/s from 50.0 m above the ground. At what speed must Gary throw a ball up in order for the two balls to cross paths 25.0 m above the ground? The starting height of the ball thrown upward is 1.50 m above the ground. Ignore the effects of air resistance. SSM

58. ••**Biology** A fox locates its prey, usually a mouse, under the snow by slight sounds the rodents make. The fox then leaps straight into the air and burrows its nose into the snow to catch its next meal. If a fox jumps to a height of 85.0 cm, calculate (a) the speed at which the fox leaves the snow and (b) how long the fox is in the air. Ignore the effects of air resistance.

59. •**Medical** More people end up in U.S. emergency rooms because of fall-related injuries than from any other cause. At what speed would someone hit the ground who accidentally steps off the top rung of a 6-ft-tall stepladder? (That step is usually embossed with the phrase "Warning! Do not stand on this step.") Ignore the effects of air resistance. SSM

60. ••Wes stands on the roof of a building, leans over the edge, and drops a rock. Lindsay waits 1.25 s after Wes releases his rock and throws her own rock straight down at 28.0 m/s. Both rocks hit the ground simultaneously. Calculate the common height from which the rocks were released. Ignore the effects of air resistance.

61. ••A ball is thrown straight up at 18.0 m/s. How fast is the ball moving after 1.00 s? After 2.00 s? After 5.00 s? When does the ball reach its maximum height? Ignore the effects of air resistance.

62. ••A tennis ball is hit straight up at 20.0 m/s from the edge of a sheer cliff. Sometime later, the ball passes the original height from which it was hit. (a) How fast is the ball moving at that time? (b) If the cliff is 30.0 m high, how long will it take the ball to reach the ground level? (c) What total distance did the ball travel? Ignore the effects of air resistance.

63. •••Mary spots Bill approaching the dorm at a constant rate of 2.00 m/s on the walkway that passes directly beneath Mary's window, 17.0 m above the ground. When Bill is 120 m away from the point below Mary's window she decides to drop an apple down to him. (See **Figure 2-26**.) (a) How long should Mary wait to drop the apple if Bill is to catch it 1.75 m above the ground, without either speeding up or slowing down? (b) How far from directly below the window should Bill be when Mary releases the apple? (c) What is the angle θ between the vertical and the line of sight between Mary and Bill at the instant Mary should release the apple? Ignore the effects of air resistance. SSM

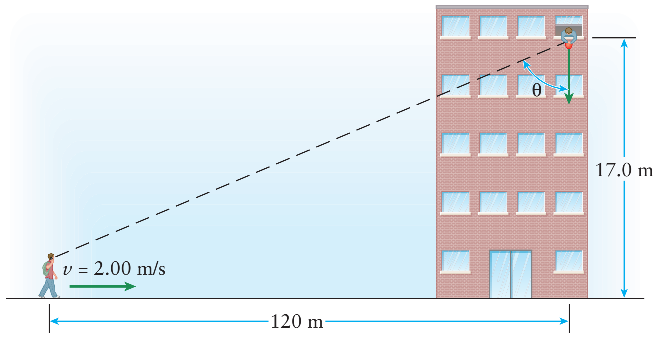

Figure 2-26 Problem 63

General Problems

64. •A car is driving at a speed of 40.0 km/h toward an intersection just as the light changes from green to yellow. If the driver has a reaction time of 0.750 s and the magnitude of the braking acceleration of the car is 5.50 m/s^2, find the minimum distance x_{min} the car travels before coming to a stop after the light changes.

65. ••Two trains, traveling toward one another on a straight track, are 300 m apart when the engineers on both trains become aware of the impending collision and hit their brakes. The eastbound train, initially moving at 98.0 km/h, slows down at 3.50 m/s^2. The westbound train, initially moving at 120 km/h, slows down at 4.20 m/s^2. Will the trains stop before colliding? If so, what is the distance between them once they stop? If not, what initial separation would have been needed to avert a disaster? SSM

66. ••**Biology** The cheetah is considered the fastest running animal in the world. Cheetahs can accelerate to a speed of 20.0 m/s in 2.50 s and can continue to accelerate to reach a top speed of 29.0 m/s. Assume the acceleration is constant until the top speed is reached and is zero thereafter. (a) Express the cheetah's top speed in mi/h. (b) Starting from a crouched position, how long does it take a cheetah to reach its top speed and how far does it travel in that time? (c) If a cheetah sees a rabbit 120 m away, how long will it take to reach the rabbit, assuming the rabbit does not move?

67. •**Medical** Very large accelerations can injure the body, especially if they last for a considerable length of time. One model used to gauge the likelihood of injury is the severity index (SI), defined as $SI = a^{5/2}t$, where a is the acceleration in multiples of g and t is the time the acceleration lasts (in seconds). In one set of studies of rear-end collisions, a person's velocity increases by 15.0 km/h with an acceleration of 35.0 m/s^2. (a) What is the severity index for the collision? (b) How far does the person travel during the collision if the car was initially moving forward at 5.00 km/h?

68. •••A man on a railroad platform attempts to measure the length of a train car by walking the length of the train and keeping the length of his stride a constant 82.0 cm per step. After he has paced off 12 steps from the front of the train car it begins to move, in the direction opposite to his, with an acceleration of 0.400 m/s^2. The end of the train passes him 10.0 s later, after he has walked another 20 steps. Determine the length of the train car.

69. ••Blythe and Geoff compete in a 1.00-km race. Blythe's strategy is to run the first 600 m of the race at a constant speed of 4.00 m/s, and then accelerate to her maximum speed of 7.50 m/s, which takes her 1.00 min, and then finish the race at that speed. Geoff decides to accelerate to his maximum speed of 8.00 m/s at the start of the race and to maintain that speed throughout the rest of the race. It takes Geoff 3.00 min to reach his maximum speed. Assuming all accelerations are constant, who wins the race?

70. ••Figure 2-27 is a graph of the velocity of a moving car. What is its instantaneous acceleration at times $t = 2$ s, $t = 4.5$ s, $t = 6$ s, and $t = 8$ s?

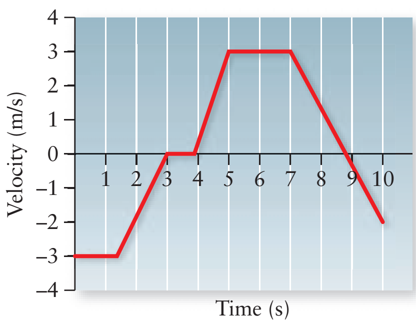

Figure 2-27 Problem 70

71. ••A ball is dropped from an upper floor, some unknown distance above your apartment. As you look out of your window, which is 1.50 m tall, you observe that it takes the ball 0.180 s to traverse the length of the window. Determine how high above the top of your window the ball was dropped. Ignore the effects of air resistance. SSM

72. •••A ball is thrown straight up at 15.0 m/s. (a) How much time does it take for the ball to be 5.00 m above its release point? (b) How fast is the ball moving when it is 7.00 m above its release point? (c) How much time is required for the ball to reach a point that is 7.00 m above its release point? Why are there two answers to part (c)?

73. ••In the book and film *Coraline*, the title character and her new friend Wybie discover a deep well. Coraline drops a rock into the well and hears the sounds of it hitting the bottom 5.50 s later. If the speed of sound is 340 m/s, determine the depth of the well.

74. •••Ten washers are tied to a long string at various locations, as in Figure 2-28. When the string is released some known height above the floor, the washers hit the floor with equal time intervals. Determine the distance between each washer ($y_n = ?$, $n = 1, 2, 3, \ldots, 9, 10$) if the height between the lowest washer (#1) and the floor (before the string is dropped) is 10 cm.

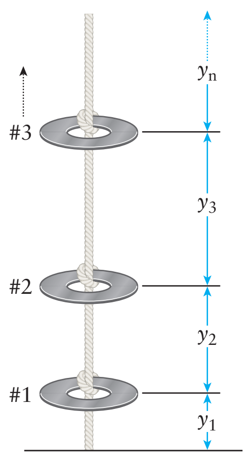

Figure 2-28 Problem 74

75. •••A rocket is fired straight up. It contains two stages (Stage 1 and Stage 2) of solid rocket fuel that are designed to burn for 10.0 and 5.00 s, respectively, with no time interval between them. In Stage 1, the rocket fuel provides an upward acceleration of 15.0 m/s^2. In Stage 2, the acceleration is 12.0 m/s^2. Neglecting air resistance, calculate the maximum altitude above the surface of Earth of the payload and the time required for it to return to the surface. Assume the acceleration due to gravity is constant. SSM

76. •••A lacrosse ball is hurled straight up, leaving the head of the stick at a height of 2.00 m above the ground level. The ball passes by a 1.25-m-high window in a time of 0.400 s as it heads upward. Calculate the initial speed of the ball if it is 13.0 m from the ground to the bottom of the window. Ignore the effects of air resistance.

77. ••**Biology** A black mamba snake has a length of 4.30 m and a top speed of 8.90 m/s! Suppose a mongoose and a black mamba find themselves nose to nose. In an effort to escape, the snake accelerates at 18.0 m/s^2 from rest. (a) How much time does it take for the snake to reach its top speed? (b) How far does the snake travel in that time? (c) How much reaction time does the mongoose have before the tail of the mamba snake passes by?

78. ••**Sports** Kharissia wants to complete a 1000-m race with an average speed of 8.00 m/s. After 750 m, she has averaged 7.20 m/s. What average speed must she maintain for the remainder of the race in order to attain her goal?

79. ••**Sports** In April 1974, Steve Prefontaine completed a 10.0-km race in a time of 27 min, 43.6 s. Suppose "Pre" was at the 9.00-km mark at a time of 25.0 min even. If he accelerates for 60.0 s and maintains the increased speed for the duration of the race, calculate the acceleration that he had. Assume his instantaneous speed at the 9.00-km mark was the same as his overall average speed at that time.

80. ••A ball is thrown straight down at 1.50 m/s from a tall tower. Two seconds (2.00 s) later, a second ball is thrown straight up at 4.00 m/s. How far apart are the two balls 4.00 s after the second ball is thrown? What is the minimum separation between the balls and when does it occur? Ignore the effects of air resistance.

81. ••A two-stage rocket blasts off vertically from rest on a launch pad. During the first stage, which lasts for 15.0 s, the acceleration is a constant 2.00 m/s^2 upward. At the end of the first stage the second stage engine fires, producing an upward acceleration of 3.00 m/s^2 that lasts for 12.0 s. At the end of the second stage, the engines no longer fire and therefore cause no acceleration, so the rocket coasts to its maximum altitude. (a) What is the maximum altitude of the rocket? (b) Over the time interval from blastoff at the launch pad to the instant that the rocket falls back to the launch pad, what are its (i) average speed and (ii) average velocity? Ignore the effects of air resistance.

Chapter 2 Linear Motion

Section 2-2

Problem-Solving Review

Set Up

1. 1.00m

Solve

1. From t=2 s to t = 5 s and again from t = 5s to t = 6 s.
2. 1.00m/s
3. 0.00 m/s
4. 0.500 m/s

Reflect

1. 8.00m
2. 0.00m

Part II

Set Up

Solve

1. 0.00 m/s, 2.00m/s, 1.00m/s

Reflect

1. 9.00m

Section 2-3

Problem-Solving Review

Set Up

2. $v_{average,x} = \frac{\Delta x}{\Delta t}$ $\quad x = x_o + v_x t$
3. $v_{average,x} = \frac{\Delta x}{\Delta t}$

Solve

1. 14.3m/s
2. 17.2s
3. 104m from the finish line

Reflect

1. Instantaneous velocity is an objects velocity measured at a single moment. Average velocity is an object's velocity averaged over a long period of time.

Section 2-4

Problem-Solving Review

Set Up

1. The object is slowing down in both cases
2. Negative
3. Negative
4. The object is not accelerating

Solve

1. -30.6m/s^2
2. -1.00 m/s
3. 0.00m/s

Reflect

1. Before the object has a negative velocity it is decelerating. When the object gets to *v*=0 m/s it starts accelerating in the opposite direction of that with which it started out.
2. The motion is the same.

Section 2-5

Problem-Solving Review

Solve

1. They are both 0.500 m/s.
2. a(t=2) = 0.00, a(t=6) = 1.00
3. Parabola, Parabola

Reflect

1. It is easiest to find the slope of the v-t graph.
2. The object is speeding up, both a and v are positive.

Section 2-6

Problem-Solving Review

Set Up

1. They are at the same position.

2.

Car 1	
Quantity	Know/Don't Know
t	?
x_0	0
x	?
v_{0x}	150 km/hr
v_x	150 km/hr
a_x	0

Car 2	
Quantity	Know/Don't Know
t	?
x_0	0
x	x_{car1}
v_{0x}	120 km/hr
v_x	?
a_x	200 km/hr^2

3.

Car 1						
Equation	Quantity					
	t	x	x_0	v_{0x}	v_x	a_x
$v_x = v_{0x} + a_x t$	?	-	-	150 km/hr	150 km/hr	0
$x = x_0 + v_{0x} t + \frac{1}{2} a_x t^2$	?	?	0	150 km/hr	-	0
$v_x^2 = v_{0x}^2 + 2a_x (x - x_0)$	-	?	0	150 km/hr	150 km/hr	0

Car 2						
Equation	Quantity					
	t	x	x_0	v_{0x}	v_x	a_x
$v_x = v_{0x} + a_x t$	?	-	-	120 km/hr	?	200 km/hr^2
$x = x_0 + v_{0x} t + \frac{1}{2} a_x t^2$	?	x_{car1}	0	120 km/hr	-	200 km/hr^2
$v_x^2 = v_{0x}^2 + 2a_x (x - x_0)$	-	x_{car1}	0	120 km/hr	?	200 km/hr^2

Solve
3. 0.548 hr
4. 95.8km

Reflect
1. No

Section 2-7

Problem-Solving Review
Set Up
1. They will land at the same time

Solve
1. $y = -\frac{1}{2}gt^2 + V_0t + y_0$
2. 0.00m/s y=10.0km
3. 10.1s

Reflect
1. No, $V = at + V_0$

Section 2-8

Problem-Solving Review
Set Up
3. 0.00 m/s

Solve
1.

Equation	Quantity					
	t	Y	y_0	v_{0y}	v_y	a_y
$v_y = v_{0y} + a_y t$	?	-	-	?	0	-g
$y = y_0 + v_{0y} t + \frac{1}{2} a_y t^2$	?	10.5	10	?	-	-g
$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$	-	10.5	10	?	0	-g

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Equation	Quantity					
	t	y	y_0	v_{0y}	v_y	a_y
$v_y = v_{0y} + a_y t$	?	-	-	0	?	-g
$y = y_0 + v_{0y} t + \frac{1}{2} a_y t^2$	?	0	10.5	0	-	-g
$v_y^2 = v_{0y}^2 + 2a_y (y - y_0)$	-	0	10.5	0	?	-g

2. $v^2 = v_0^2 + 2a(y - y_0)$, 3.13 m/s

3. $v_y = v_{0y} + a_y t$, 0.319 s

4. $y = y_0 + v_{0y} t + \frac{1}{2} a_y t^2$ 1.46 s

5. $v_y = v_{0y} + a_y t$ 14.3m/s

Reflect

1. Downwards, Downwards

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